Improving the Surgical Patient Care Pathway Through Use of Activity Monitoring

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Abstract

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We can now monitor the physical activity levels of patients in the perioperative period. This has several potential applications including preoperative monitoring to assess patient fitness, postoperative monitoring to assess patient recovery, and to measure the impact of interventions aiming to improve cardiorespiratory fitness.

The research presented in this thesis set out to explore the relationship between daily physical activity levels and a patient's cardiorespiratory fitness, and how measurement of daily physical activity levels can be used to improve patient fitness. To this aim, I developed two clinical study protocols to explore the use of activity monitoring as part of the surgical patient care pathway. A secondary aim was to improve the usability of activity monitoring for measuring physical activity levels in this population of patients. For this, a physical activity classification method and a system of remote activity monitoring was developed.

I found that there was a relationship between summary measures of daily physical activity levels as measured using a wearable accelerometer and patient fitness levels as measured using cardiopulmonary exercise testing. A feasibility study was commenced and successfully recruited six patients into a randomised controlled study involving daily physical activity monitoring and remotely supervised exercise intervention. Analysis of accelerometer data was shown to be a useful measure of the change in patient physical activity levels over a period of four weeks. Qualitative analysis of patient interview data revealed themes relevant to development of behavioural change techniques to improve adherence to preoperative exercise intervention.

The results from the novel study presented in this thesis showed how activity monitoring could be used in the surgical care pathway. From my studies, I have also identified the benefits and limitations of accelerometer measured daily activity in both the assessment of cardiorespiratory fitness and as a remote supervision and patient behavioural change tool during prehabilitation.

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2. List of abbreviations

AAA	Abdominal aortic aneurysm
ADL	Activities of daily living
ASA	American Society of Anesthesiologists Physical Status Classification System
AEE	Activity related energy expenditure
AT	Anaerobic threshold
AUC	Area under the curve
BCT	Behaviour change technique
BMI	Body mass index
CAD	Coronary artery disease
CCI	Charlson Comorbidity Index
CHD	Coronary heart disease
CI	Cardiac index
COM-B	The capability, opportunity and motivation model of behaviour change
COPD	Chronic obstructive pulmonary disease
CPET	Cardiopulmonary exercise testing
CVD	Cardiovascular disease
DASI	Duke Activity Status Index questionnaire
DLW	Doubly labelled water method
DM	Diabetes mellitus
DO_2	Oxygen delivery
ECG	electrocardiogram
EE	Energy expenditure
EQ-5D	Euroqol quality of life 5-point questionnaire
EPCO	European perioperative clinical outcomes
ERAS	Enhanced recovery after surgery
ESRD	End-stage renal disease
g	Gravitational unit
GAD7	Generalised anxiety disorder assessment
GPS	Global positioning system
HADS	Hospital anxiety and depression scale
HIIT	High intensity interval training
HR	Heart rate
HTN	hypertension
IMT	Inspiratory muscle training
IPAQ	International physical activity questionnaire
ISWT	Intermittent shuttle walk test
ITU	Intensive care unit
MEMS	Microelectromechanical system
MI	Myocardial infarction
MVPA	Moderate-to-vigorous-intensity physical activity
NHS	National Health Service
NICE	National Institute for Clinical Excellence
NCEPOD	National Confidential Enquiry into Patient Outcomes and Death

NHQ9	National Health Questionnaire for depression severity
NPV	Negative predictive value
POSSUM	Physiological and Operative Severity Score for the enUmeration of Mortality and Morbidity
PROM	Patient reported outcome measure
PPC	Postoperative pulmonary complications
PPV	Positive predictive value
RCT	Randomised controlled trial
ROC	Receiver operator curve
SCT	Stair climb test
SF-12 MCS / PCS	SF-12 quality of life questionnaire Mental Component Score and Physical Component Score
TEE	Total energy expenditure
TIA	Transient ischaemic attack
VBA	Very brief advice
VO_2	Oxygen consumption
WHO	World Health Organisation
6MWT	Six-minute walk test

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1 Introduction: The importance of preoperative fitness assessment

1.1 The burden of surgery

Advances in surgical technique and perioperative care have made surgery safer than ever. Even so, the risk of postoperative complications and death for the same operation can vary significantly between patients. Worldwide, perioperative mortality is the third most common cause of death, accounting for 7.7% of all deaths, behind ischaemic heart disease and stroke.[1] Fortunately, postoperative mortality in the UK within the same hospital admission is very low at less than 1% overall, which accounts for approximately 20,000 to 25,000 deaths per year.[2] However, 80% of these in hospital postoperative deaths occur in a small population of patients who are at ‘high risk’ for surgery. They make up 10% of the surgical population but have a much higher mortality rate of 10-15%.2 Identifying these ‘high risk’ patients is a priority in the period before the operation so that perioperative planning can take place. For the other 90% of the surgical population, who are not ‘high risk’, the expectation is that patients will survive the operation. The challenge is, therefore, how to ensure their outcomes from surgery justify having the operation and ultimately benefit the patient’s long-term health.

1-in-10 members of the UK population undergo a surgical procedure every year, with the annual number of surgical procedures increasing year on year.[3] Along with this, the number of operations in the elderly has increased from 1.5 million in those over the age of 75 years between 2006 and 2007, to 2.5 million between 2014 and 2015 in England, of which nearly 30 % of these 2.5 million were over 85 years old.[4]

In terms of overall outcomes from surgery, mortality at 30 days after planned surgery is rare (with a crude mortality rate of 6.7 per 1000 cases)[5] but the rate of postoperative morbidity or complications after major elective surgery can be high, at around 30% for radical cystectomy and 60% for oesophagectomy.[6,7] After the initial postoperative period, it has been shown that patients who have a complication within 30 days after surgery also have an increased risk of death for several years after the operation, even after controlling for patient comorbidities.[8] The risk of these postoperative complications is determined by the premorbid state in addition to the surgical and disease factors. For patients to be able to make an informed decision on whether an operation is the best option for themselves, evaluating and reducing their individual risks before the operation is a key part of the patient surgical care pathway. Traditionally, perioperative pathways have been designed around a particular procedure rather than being patient-based. Redesigning the pathway around the risk to the patient, a 'risk adapted' approach, can improve surgical outcomes and patient benefit.[9]

1.2 Individual risk assessment before surgery

Subjective assessment of patient risk and 'readiness' for surgery both by the patient and clinicians has been shown to unreliable when compared to objective tests in identifying the higher risk group of patients.[10] Evidence shows that more objective and detailed information regarding the patient is required to be able to formulate an risk profile for an individual patient. Objective individual risk assessment includes a combination of patient history and examination, simple and specialist investigations where required, risk stratification using a validated preoperative risk score, and finally, assessment of functional capacity using a questionnaire or exercise testing.

Individual risk assessment is important for shared decision making and planning perioperative care for the patient. The perioperative care of higher risk surgical patients can still be improved. The 2012 European Surgical Outcomes study of 46539 patients undergoing non-cardiac surgery across 28 European countries, showed a higher than expected, in-hospital mortality rate of 4%.[11] The authors found that hospital critical care resources did not seem to be allocated to patients at greatest risk of death.[11] Similarly, the 2011 report, 'Knowing the risk' by the National Confidential Enquiry into Patient Outcome and Death (NCEPOD) (after elective and emergency surgery in the UK), found significantly increased mortality from those patients deemed to be at high risk for surgery.[2] Although the high-risk group made up just 20% of the patient population, more than half of all postoperative co-morbidities, and 79% of all deaths were found in this high-risk patient group. Urgency of surgery was not a significant factor in risk categorisation, as half of all high-risk patients were undergoing elective procedures. The study found there was significant variation and inaccuracy across hospitals as to which patients were classified as high risk, suggesting that there was no reliable preoperative assessment process in place for patient risk stratification.[2] Individual risk assessment is therefore the key starting point to identifying and improving the care of these high risk patients.

1.3 Preoperative optimisation of the surgical patient

A principle recommendation from the NCEPOD report is the need for a UK wide system that allows rapid and easy identification of patients who are at high risk of postoperative mortality and morbidity.[2] This system would allow for identification of known significant risk factors for postoperative morbidity and mortality, and the ability to use this information to place the patient into a lower or higher risk category.[12] Following this individual risk assessment, the second tenant of preoperative care is then the optimisation of the patient before surgery to reduce risk from surgery. This would aid planning of intraoperative and postoperative care such as use of regional or general anaesthesia, need for blood transfusion or cell salvage, need for additional intraoperative monitoring, and need for an intensive care (ITU) bed postoperatively.[13] Less than a third of high risk surgical patients are admitted to critical care after surgery despite the higher mortality rates.[2] Given the limited resource of critical care beds, reliable methods of being able to compare the risk profile between patients is crucial to allocation of critical care resources. Postoperative critical care availability is the biggest cause of last minute cancellation before surgery.[13]

In addition to advance risk stratification for planning which patients require higher level care postoperatively, the preoperative period is a good opportunity to try and optimise patient physiology in preparation for surgery. Preoperative risk factors for surgery include fixed and modifiable risk factors. Fixed factors include innate factors such as age and genetics. Modifiable factors include acquired factors such as anaemia, diabetes and lung disease; as well as behaviour factors related to smoking, alcohol, diet and exercise. Preoperative assessment and optimisation are the processes of performing individual risk assessment, to then focusing on the modifiable risk factors. These risk factors can then be addressed to optimise treatment of existing conditions and to undergo collaborative behaviour change for risk factors related to smoking, diet, alcohol and exercise. The prospect of surgery can be a powerful stimulus to change and the preoperative period provides ‘teachable moments’ for the patient. The patient during this period may be more amenable to collaborative behaviour change to improve their baseline health status. This concept of maximising the opportunity of the preoperative period is illustrated in Figure 1.1 which shows the traditional model of the surgical pathway, and Figure 1.2, which shows the potential improvements that could be made to the pathway. This thesis will focus on the modifiable risk factor of cardiorespiratory fitness and the accompanying preoperative optimisation of exercise intervention. Cardiorespiratory fitness is a key component of preoperative assessment and a potential area to target preoperative optimisation.

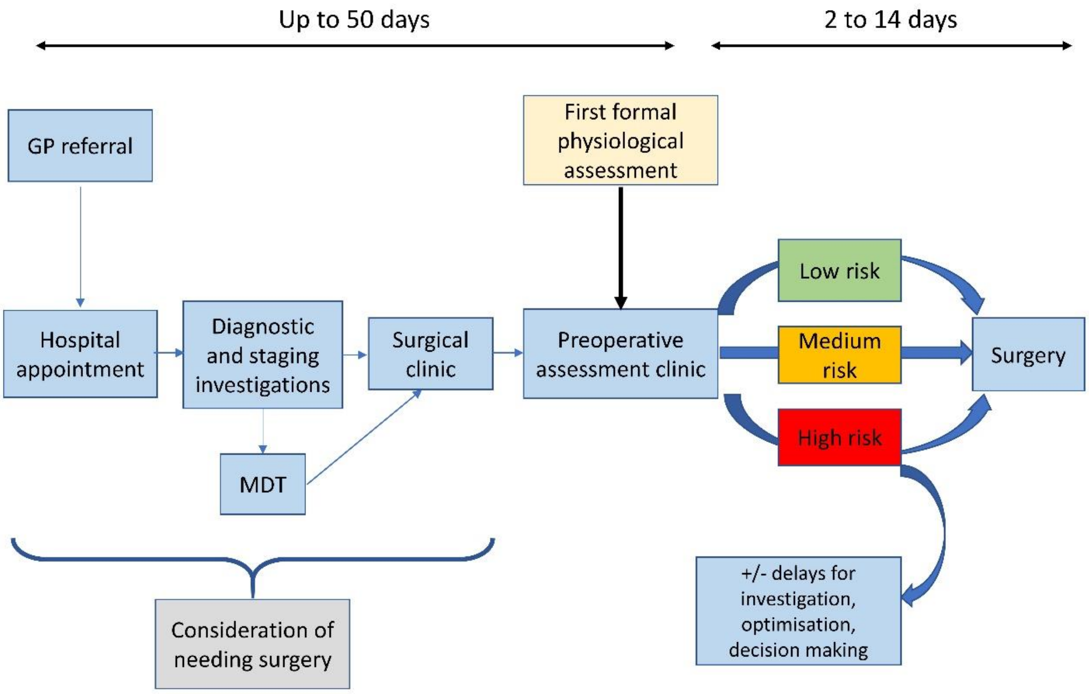


Figure 1.1 Traditional model of the surgical pathway. MDT, multidisciplinary team. Based on a diagram in Grocott et al. Perioperative Medicine (2017).[14]

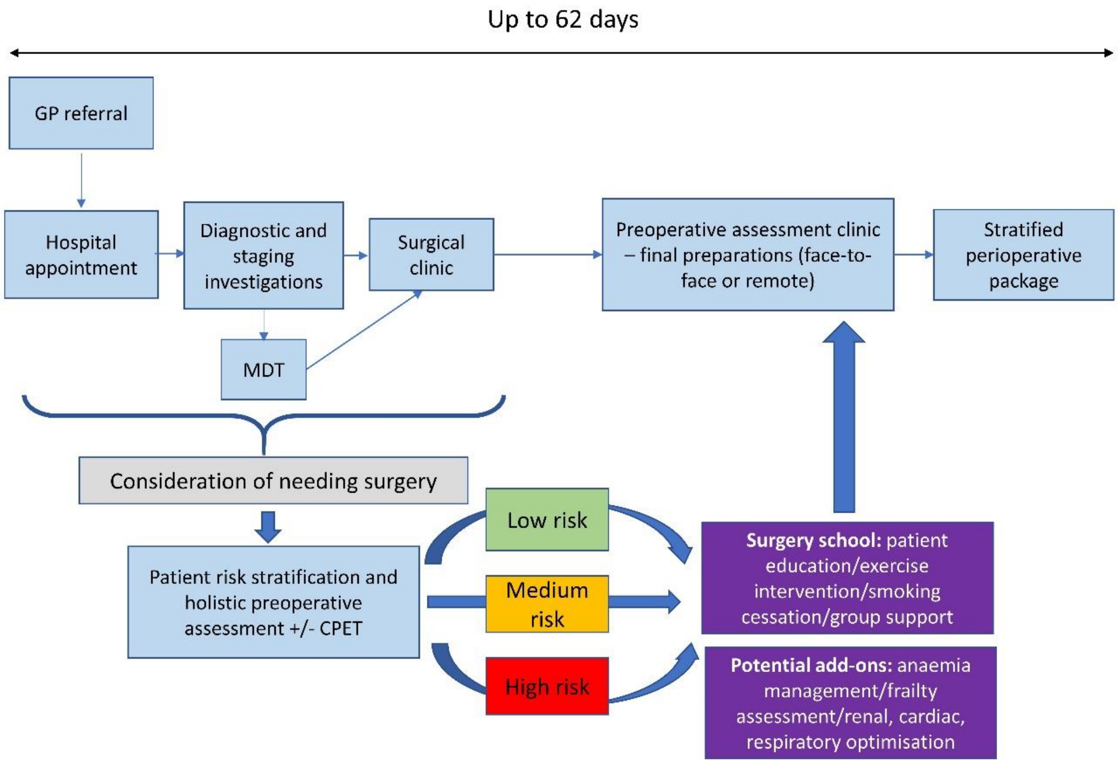


Figure 1.2 The surgical pathway with improvement for preoperative assessment and optimisation. CPET, cardiopulmonary exercise testing; MDT, multi-disciplinary team. Based on a diagram in Grocott et al. Perioperative Medicine (2017).[14]

1.4 The concept of patient fitness for surgery

The process of undergoing an operation is seen as a traumatic stimulus to the body which triggers a stress response and leads to significant physiological disturbance.[15] This has physiological manifestations that can be both beneficial and detrimental. Benefits include increasing oxygen demand through a catabolic process as part of the stress response, but this can also be a contributor to less desirable effects which may lead to postoperative complications.[16] Major surgery provokes a strong inflammatory response which can increase the oxygen requirement of the patient by over 50%, from an average resting oxygen consumption of 110 $ml.min^{-1}.m^{-2}$ (or less in an elderly patient) to an average of 170 $ml.min^{-1}.m^{-2}$ in the postoperative period.[17] The inflammatory response, although triggering an increase in cardiac output and decrease in systemic vascular resistance, is also associated with poor peripheral uptake of oxygen. This may be due to damage to the vascular endothelium with resultant disruption of the microcirculation, as well as inflammatory mediators changing the intracellular mechanisms that regulate oxygen use, including mitochondrial function.[18]

The majority of patients can meet this increased oxygen demand by increasing cardiac output and tissue oxygen extraction, which reduces the risk of the adverse effects of the inflammatory response to surgery.[17] Patients with higher aerobic fitness levels can meet the demands of increasing oxygen delivery, induced by surgery, without exhausting their physiological parameters.[19] Survivors of major surgery and critical illness tend to have higher cardiac index (CI), oxygen delivery (DO_2) and oxygen consumption (VO_2) than non-survivors.[20] However, there will be a significant number of patients who do not have the physiological or ‘functional reserve’ to be able to increase their cardiac output to the required level and will therefore be in a state of oxygen debt postoperatively. This will have adverse consequences on organ function, and a resultant higher risk of morbidity and mortality postoperatively.[21]

Reduced functional reserve as a concept relates to a patient’s decreased ability to meet the increased demands for cardiac output, carbon dioxide excretion, as well as protein synthesis and immune responsiveness during and after surgery.[22] More invasive and extensive operations are more likely to increase the extent and duration of the stress response, which in turn, is associated with a higher risk of developing postoperative complications.[15,16] Even without significant postoperative complications, surgery often results in reduced functional capacity and fitness postoperatively.[16,23] Surgery can also trigger a deterioration in a diagnosed or undiagnosed long term illness, which can also delay recovery.[13]

Specific postoperative complications will have different contributing patient-related factors such as pre-existing lung disease on postoperative pulmonary complications, or factors related to wound healing such as obesity and diabetes on the risk of wound infection. However, a patient's ability to meet the physiological demands of surgery, namely meeting the increased oxygen demand, is thought to be related to baseline cardiorespiratory fitness, which is also referred to as functional capacity in this context. Measurement of baseline cardiorespiratory fitness, or functional capacity, using exercise testing has shown worse postoperative outcomes for those with decreased ability to meet the oxygen demands of the body during exercise.[24] Similarly, exercise interventions to improve functional capacity in patients before surgery have shown to reduce postoperative complications and improve postoperative recovery, supporting the hypothesis that overall patient functional capacity is an important predictor of surgical outcomes.[15] It is thought that a patient who has previously undergone consistent exercise, has been exposed to a state of 'ischaemic preconditioning' whereby the body has undergone adaptive responses, such as improved ability for tissues to extract oxygen, to meet the increased oxygen demand. This exposure to consistent exercise could reduce the impact of the relatively ischaemic conditions of surgery.

Therefore, knowledge of the patient's baseline functional capacity is useful to be able to prognosticate for their individual level of risk for surgery as well as to plan on how to reduce these risks. It can also form part of the preoperative patient education and informed consent process on the likely outcome of their operation in terms of likelihood of death, complications and length of recovery. Aside from the prognostic value of preoperative functional capacity assessment, its real value is likely to be in planning interventions which aim to improve functional capacity, also known as prehabilitation.

1.5 Prehabilitation

Perioperative care aims to reduce patient risk from surgery by reducing the negative effects of the stress response to surgery. Focus to date has mainly been directed to intraoperative technique and anaesthesia, and postoperative ‘enhanced recovery’ protocols. With the growing interest in the preoperative period as a golden time for patient optimisation, the value of preoperative rehabilitation or ‘prehabilitation’ is being recognised as an intervention that can improve surgical outcomes.[15] This concept is illustrated in Figure 1.3, showing the effect of surgery on baseline health postoperatively, and in the long term, and the potential for improved outcomes with prehabilitation.

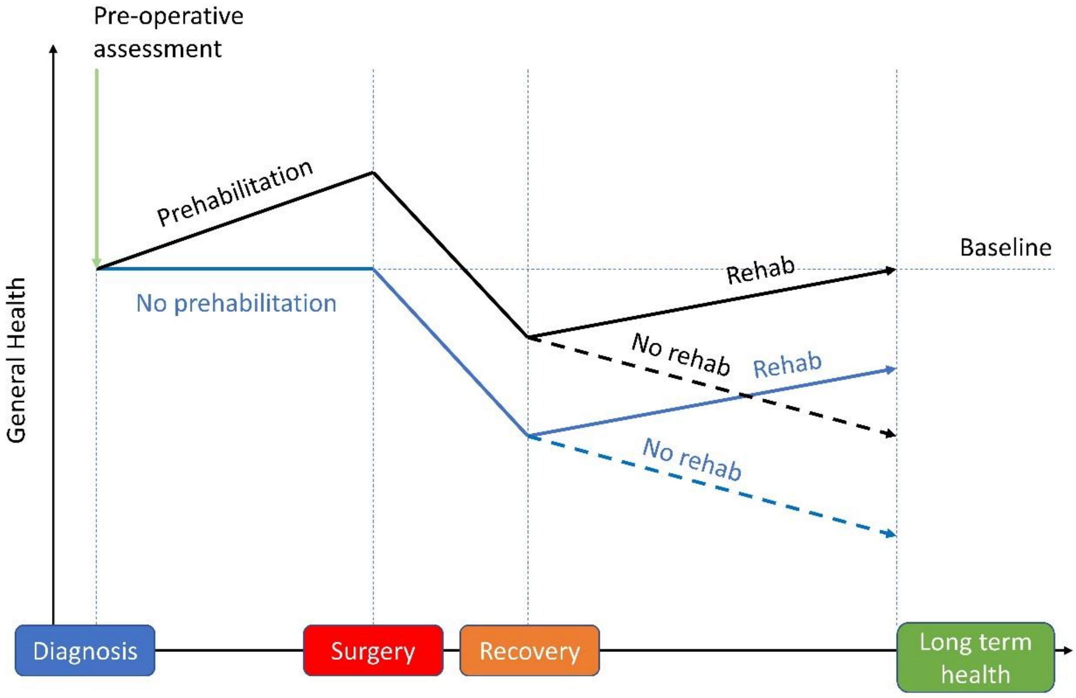


Figure 1.3 Timeline of possible outcomes with prehabilitation before, and rehabilitation after, surgery.

There is wide agreement that prehabilitation needs to be multimodal, with an emphasis on patient education, informed patient choice, and motivating the patient to have more autonomy in their own preoperative pathway.[25] One of these multimodal elements is targeting improvement of functional capacity using exercise intervention. The theory behind preoperative exercise intervention is that better physical fitness preoperatively improves a patient's ability to meet the increased oxygen demand during and after surgery.[15] Preoperative exercise intervention has been shown to improve a patient's intra- and postoperative ability to extract oxygen and tolerate the ischaemic conditions of surgery, which lessens the impact of deficits in oxygen delivery to the end organs.[21] Patients with lower baseline functional capacity before surgery are likely to benefit from preoperative exercise intervention to improve exercise tolerance. This, in theory, could improve postoperative outcomes in terms of reducing complication rate and length of stay, as well as improving general physical and mental wellbeing.[26] Therefore, being able to reliably assess functional capacity, as well the effects of exercise intervention on an individual's functional capacity is key to be able to implement prehabilitation. This is an increasingly important risk factor for surgery given the increasing levels of physical inactivity. Globally, 1 in 3 adults are not active enough, with inactivity levels rising year on year. The UK has the highest level of physical inactivity in the European Union.[27,28] A summary of the evidence for the efficacy of preoperative exercise intervention is discussed further in Chapter 5.

In practice, implementation of prehabilitation has several challenges. These include how to measure baseline fitness and physical activity level; how to ensure compliance to exercise intervention; what quantity and intensity of exercise needs to be prescribed for a particular patient; and how to assess whether the exercise has actually improved fitness. These challenges rely on solving the problem of how best to assess cardiorespiratory fitness and functional capacity as part of preoperative individual risk assessment. Given the link between physical activity and physical fitness, this could be exploited to improve preoperative functional capacity assessment and implementation of preoperative exercise intervention.

This thesis will evaluate the current tools available for preoperative fitness assessment and why newly available technology in the form of wearable accelerometers may be a useful adjunct to the surgical pathway. Wearable accelerometers monitor the wearer's physical activity which can provide a surrogate measure of physical fitness. They have the benefit over existing tools as they allow remote and longitudinal patient assessment rather than a snapshot assessment in the hospital. This can aid risk stratification of patients before surgery and be a useful tool in exercise interventions which aim to improve patient preoperative fitness. However, wearable accelerometers have not been widely used in the preoperative assessment context and little is known about how data from these devices can be used in this patient setting.

1.6 Aims of the thesis

The aims of this thesis were:

- To evaluate current methods of assessing cardiorespiratory fitness in preoperative patients and how this can be improved
- To consider how daily physical activity may be a useful measure of physical fitness in the context of preoperative assessment and optimisation
- To investigate whether daily physical activity as measured by a wearable accelerometer represents physical fitness as measured using exercise testing in the preoperative patient and the relationship between preoperative physical activity and postoperative outcomes
- To evaluate current methods of delivering prehabilitation and how this may be improved with objective measurement of physical activity using a wearable accelerometer
- To investigate the utility of physical activity monitoring to improve adherence to and reduce the resource burden of delivering a preoperative exercise intervention.

This chapter has discussed the importance of patient fitness for surgery and the next chapter will discuss the current methods of preoperative assessment and intervention. Chapter 3 will discuss accelerometers and how they can be used to measure patient activity and fitness, and why they may be useful in the surgical pathway. Chapters 4 and 5 will contain the two clinical studies undertaken in this thesis to investigate the utility of wearable accelerometers in the assessment and optimisation of patient fitness for surgery. The first study investigates the usefulness of activity monitoring to assess for functional capacity as compared to cardiopulmonary exercise testing. The second study investigates the usefulness of activity monitoring as a tool to improve delivery of preoperative exercise intervention as part of prehabilitation.

2 Introduction: Preoperative functional capacity assessment

2.1 Quantifying functional capacity

Cardiorespiratory fitness for surgery is often described in terms of functional capacity. This term is synonymous with other terms such as exercise capacity and exercise tolerance. Fitness for surgery is measured by an individual's ability to perform sustained aerobic activity and can most reliably be assessed by maximal exercise testing to find that individual's maximal exercise capacity or functional capacity. In practical terms it is often measured by the intensity of exercise a person can achieve which is scaled by metabolic equivalents or METs. Metabolic equivalents are calculated from the work rate achieved during an exercise test. One metabolic equivalent is equivalent to the energy expenditure of a healthy, 70 kg, 40-year-old man at rest, defined by convention as an oxygen uptake of 3.5 $mlO_2.kg^{-1}.min^{-1}$, or an energy expenditure of 1 $kcal.kg^{-1}.hour^{-1}$. A MET of 1, which describes rest, is then used as a baseline from which a scale of METs can be created to express energy expenditure during work, as a ratio of the energy expended during rest. METs are useful as a scale to compare intensities of activities. An activity with a MET value of 2, for example slow walking, would require twice the amount of energy expenditure of being at rest (MET = 1).[29] Actual MET values for any given activity will vary across individuals based on their individual oxygen uptake required for that activity, but the MET scale provides a useful estimate of likely functional capacity.

For the purposes of preoperative assessment, functional capacity based on METs is often classified as poor (< 4 metabolic equivalents), moderate (4–10 metabolic equivalents) or good (> 10 metabolic equivalents). Cardiopulmonary exercise testing and other submaximal exercise tests give a more accurate measure of functional capacity and hence their increasing uptake in as part of preoperative assessment. The different methods of estimating and measuring functional capacity are discussed below.

2.2 Methods of assessing preoperative functional capacity

Methods for preoperative assessment of patient fitness or functional capacity range from: expert opinion of the surgeon or anaesthetist based on patient history and examination; questionnaires which aim to estimate patient functional capacity; to different forms of exercise testing.

2.2.1 Subjective assessments of functional capacity

Subjective assessment of functional capacity relies on the clinical experience and judgement of the surgeon and anaesthetist. This judgement will be formed based on history and examination, with the ASA grade most commonly used by anaesthetists to summarise their judgement of patient risk for surgery.

2.2.1.1 Clinician assessment using ASA grade

For the anaesthetic preoperative assessment, the most commonly used subjective risk classification is the American Society of Anesthesiologists (ASA) physical status classification system, or ASA grade (Table 2.1).[30] Although examples are given in this table, this is not a comprehensive list, and the ASA does not endorse any further elaboration of these definitions within the classification system. However, anaesthetists in the UK often interpret these grades as relating to functional capacity – that is, comorbidity that does not (ASA II) or that does (ASA III) limit a person's activity.[31] Since it was derived in 1963, the ASA grade has been shown to correlate with other perioperative variables such as intraoperative blood loss, duration of ventilation and ITU stay,[32] as well as having a unique contribution to statistical modelling of multiple variables for predicting postoperative morbidity and mortality.[33] This suggests that, this mostly subjective classification of patient preoperative risk, based on patient history and general examination, has validity for risk prediction. NICE guidelines for elective surgery recommend using a combination of the ASA grade and a classification of surgical complexity (minor, intermediate, major or complex) to decide on which routine preoperative tests should be performed.[31] Anaesthetists also use the ASA grade to plan for more specialised tests and postoperative level of care. For example, in the Oxford University Hospitals NHS Foundation trust, a decision for level of postoperative care required is based on the complexity of surgery, the ASA grade, and the anaerobic threshold obtained during CPET, or patient reported maximum metabolic equivalent (METs) activity. This is shown in the Figure 2.1 decision table.

ASA Grade	Definition	Examples including, but not limited to:
I	A normal healthy patient, (that is, without any clinically important comorbidity and without a clinically significant past/present medical history.	Healthy, non-smoking, no or minimal alcohol use
II	A patient with mild systemic disease	Mild diseases only without substantive functional limitations. E.g. current smoker, social alcohol drinker, pregnancy, obesity (30 < BMI <40), well-controlled DM/HTN, mild lung disease
III	A patient with severe systemic disease	Substantive functional limitations; One or more moderate to severe diseases. E.g. poorly controlled DM or HTN, COPD, morbid obesity (BMI ≥40), active hepatitis, alcohol dependence or abuse, implanted pacemaker, moderate reduction of ejection fraction, ESRD undergoing regularly scheduled dialysis, history (>3 months) of MI, CVA, TIA, or CAD/stents.
IV	A patient with severe systemic disease that is a constant threat to life	Recent (< 3 months) MI, CVA, TIA, or CAD/stents, ongoing cardiac ischaemia or severe valve dysfunction, severe reduction of ejection fraction, sepsis, DIC, AKI or ESRD not undergoing regularly scheduled dialysis.
V	A moribund patient who is not expected to survive without the operation	Ruptured abdominal/thoracic aneurysm, massive trauma, intracranial bleed with mass effect, ischemic bowel in the face of significant cardiac pathology or multiple organ/system dysfunction
VI	A declared brain-dead patient whose organs are being removed for donor purposes	

Table 2.1 American Society of Anesthesiologists physical classification system. AKI, acute kidney injury; BMI, body mass index; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident; DIC, disseminated intravascular coagulation; DM, diabetes mellitus; HTN, hypertension; ESRD, end-stage renal disease; MI, myocardial infarction; PCA, TIA, transient ischaemic attack.

Decision Algorithm for postoperative care facility		
Operations		
Grid A	Grid B	Grid C
SPK	Whipples	Major Bowel Surgery
Major head & neck (tracheostomy)	Hepatic Segmentectomy	Major Urology Surgery
	Right or Left Hepatectomy	Laparotomy other than above
Extended Hepatectomy	Oesphagectomy	Living related donor
	Major Gynae Surgery	Major Endocrine
	Major head & neck (no tracheostomy)	
	GIST resection	
	Abdominal wall restruction	

Grid A				
Comorbid Status	*AT* / **METS**	*<10* / **<4**	*10.1-12* / **4-8**	*<12* / **>8**
	ASA 1/2	ICU (Level 2)	ICU (Level 2)	ICU (Level 2)
	ASA 3	ICU (Level 3)	ICU (Level 2)	ICU (Level 2)
	ASA >3	ICU (Level 3)	ICU (Level 3)	ICU (Level 2)

Grid B				
Comorbid Status	*AT* / **METS**	*<10* / **<4**	*10.1-12* / **4-8**	*>12* / **>8**
	ASA 1/2	ICU (Level 2)	CORU	CORU
	ASA 3	ICU (Level 2)	ICU (Level 2)	CORU
	ASA >3	ICU (Level 3)	ICU (Level 2)	CORU

Grid C				
Comorbid Status	*AT* / **METS**	*<10* / **<4**	*10.1-12* / **4-8**	*>12* / **>8**
	ASA 1/2	CORU	WARD	WARD
	ASA 3	CORU	CORU	WARD
	ASA >3	ICU (Level 2)	CORU	WARD

AT = Anaerobic Threshold
METS = Metabolic Equivalent Activity

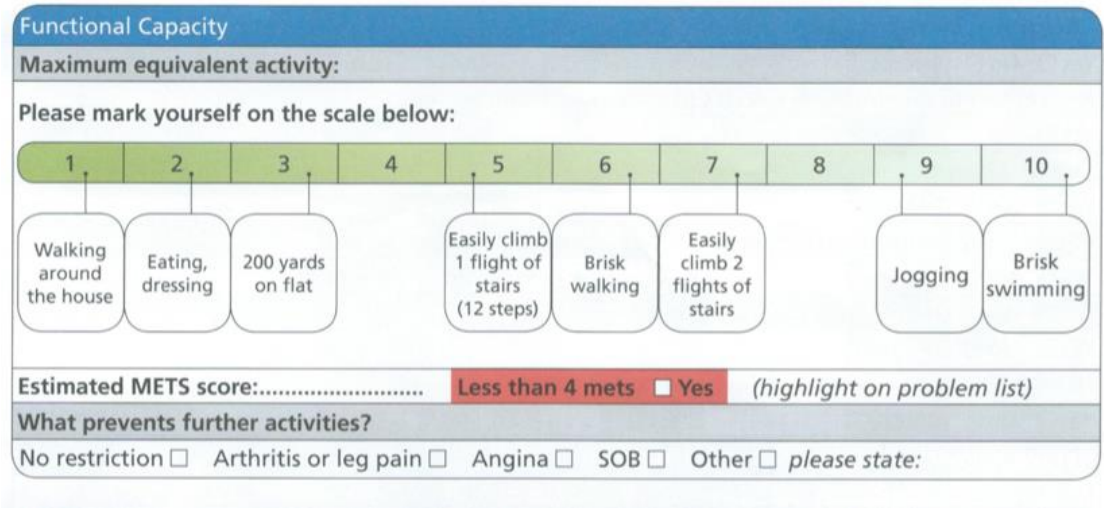
Figure 2.1 Decision table used by the Oxford University NHS Foundation Trust preoperative assessment clinic (accurate as of 2014-17). Level 2 care denotes need for single organ failure support. Level 3 care denotes need for respiratory, or multiple organ failure support. CORU, Churchill overnight recovery unit; ICU, intensive care unit; SPK, simultaneous pancreas kidney transplant; GIST, gastrointestinal stromal tumour.

However, regarding subjective assignment of ASA grade, it has also been found that inter-observer consistency between anaesthetists to classify the same patient is only moderately reliable, with percentage of agreement between 31% and 85%.[34] Another study showed that subjective assessment of functional capacity by anaesthetists using usual preoperative history was inaccurate compared to results obtained from cardiopulmonary exercise testing (CPET) and had poor predictive ability for postoperative cardiac complications.10 Subjective classification of the patient into poor (< 4 metabolic equivalents), moderate (4–10 metabolic equivalents) or good (> 10 metabolic equivalents) by anaesthetists did not correlate to classification into the same categories using peak oxygen uptake results from CPET, and subjective assessment only identified 16% of patients with poor function (less than four metabolic equivalents achieved on CPET).[10]

Patient history and examination is an important part of the preoperative assessment process and is the initial step to guide operative and anaesthetic planning, including decisions on which further preoperative assessment tests are needed. However, judging functional capacity on preoperative history alone is not accurate for identifying patients with poor fitness who may be at increased risk of postoperative morbidity and mortality.[10] As a quick and easy measure, with a large evidence base, ASA continues to be used in routine preoperative assessment. When considering a new preoperative assessment tool, this should be borne in mind that quick and easy measures such as ASA are widely adopted as it is easy to use and understand, and easy to compare between patients.

2.2.1.2 Patient assessment by estimating METs

A simple method of estimating functional capacity is asking the patient to judge their own exercise tolerance based on their ability to do certain activities ranging from walking to sports. The Oxford University Hospitals preoperative assessment proforma uses the visual analogue scale shown in Figure 2.2. Patients are asked to mark themselves on a scale of METs with descriptions of the activity level corresponding to the estimated number of METs. Patients who mark 1 to 3 on this scale are highlighted as being high risk and this is accounted for in the decision algorithm for level of postoperative care required as shown in Figure 2.1.


Functional Capacity
Maximum equivalent activity:
Please mark yourself on the scale below:

1	2	3	4	5	6	7	8	9	10
Walking around the house	Eating, dressing	200 yards on flat		Easily climb 1 flight of stairs (12 steps)	Brisk walking	Easily climb 2 flights of stairs		Jogging	Brisk swimming

Estimated METS score:.......................... Less than 4 mets ☐ Yes (highlight on problem list)
What prevents further activities?
No restriction ☐ Arthritis or leg pain ☐ Angina ☐ SOB ☐ Other ☐ please state:

Figure 2.2 Patient self-assessment of functional capacity using a visual analogue scale on the Oxford University Hospitals preoperative assessment proforma.

An alternative to the MET score is the more detailed Duke Activity Status Index (DASI) questionnaire shown in Figure 2.3.[35] This comprises of 12 yes or no questions on the ability to do different activities. Each activity mentioned has a MET value and the sum of all achievable activities gives a DASI score that has been shown to be able predict for peak oxygen uptake as measured on formal exercise testing with a correlation coefficient of 0.8.35 The DASI questionnaire is recommended in the 2014 American College of Cardiology guidelines on preoperative cardiovascular assessment as form of functional capacity assessment. However, a recent study comparing DASI estimation of peak oxygen uptake to measured values using cardiopulmonary exercise testing in elective major cancer surgery patients found a significant degree of disagreement between these two measures.[36] The DASI score on average overestimated peak oxygen uptake by 8 $ml.kg^{-1}.min^{-1}$ and was not useful in being able to risk stratify patients into low or high risk categories.36 On the other hand, another recent study of 1546 patients at elevated cardiac risk found that a DASI score of less than 34 increased the odds of 30 day mortality or myocardial infarction and moderate to severe complications after non-cardiac surgery.[37]

Item	Activity	Yes	No
1	Can you take care of yourself (eating, dressing, bathing or using the toilet)?	☐	☐
2	Can you walk indoors such as around your house?	☐	☐
3	Can you walk a block or two on level ground?	☐	☐
4	Can you climb a flight of stairs or up a hill?	☐	☐
5	Can you run a short distance?	☐	☐
6	Can you do light work around the house such as dusting or washing dishes?	☐	☐
7	Can you do moderate work around the house such as hoovering, sweeping floors or carrying in groceries?	☐	☐
8	Can you do heavy work around the house such as scrubbing floors or lifting and moving heavy furniture?	☐	☐
9	Can you do gardening like raking leaves, weeding or pushing a lawnmower?	☐	☐
10	Can you have sexual relations?	☐	☐
11	Can you participate in moderate recreational activities like golf, bowling, doubles tennis, cricket or dancing?	☐	☐
12	Can you participate in strenuous sports like swimming, singles tennis, squash, football or skiing?	☐	☐

Figure 2.3 Duke Activity Status Index questionnaire[35]

Asking patients to estimate their functional capacity by describing the type of activities they are capable is a quick and well understood by patients and clinicians. However, it has been recognised that this is unreliable and the increased ease of being able to perform exercise testing has provided a useful new tool to objectively measure functional capacity.

2.2.2 Preoperative exercise testing

Assessing functional reserve requires an objective measurement of the response of the cardiovascular and respiratory systems to an increase in oxygen demand, or ‘cardiopulmonary fitness'. Cardiopulmonary fitness can be objectively assessed using tests of exercise capacity, of which cardiopulmonary exercise testing provides the most information on both the fitness level and reasons behind a reduced functional capacity. Other exercise tests include walking tests and submaximal exercise tests. These preoperative exercise tests measure cardiopulmonary fitness, as well as the broader definition of patient 'physical fitness' which includes aerobic capacity, muscular strength and endurance, body composition, and flexibility.[38] CPET is described in detail below as it is considered the gold standard preoperative exercise test and will form the basis of the first clinical study of this thesis. Other exercise tests are also described in this section as they are commonly used to measure functional capacity in studies of exercise intervention and are an important consideration for the second clinical study of prehabilitation in this thesis.

2.2.2.1 Cardiopulmonary exercise testing (CPET)

Preoperative CPET has been used for many years to quantify the exercise capacity of the patient.[39] A surgical patient's exercise capacity tested during CPET reflects their ability to increase their cardiac output, and therefore oxygen delivery, to sufficiently meet the increased metabolic need of the postoperative phase. CPET has been shown, to some extent, to be able to identify those patients with a reduced capacity to cope with this increased oxygen demand and therefore identify the high-risk patient group for intraoperative and postoperative complications and delayed recovery from surgery.[24]

The largest preoperative CPET evidence base is currently in cardiothoracic surgery, but there is a growing interest for its utility in patients undergoing intra-abdominal surgery.[40–44] A 2017 survey of CPET use in the UK showed that, of the 73% of all anaesthetic departments who responded, 68% had an established CPET service, with an estimated 30,000 tests performed a year.[45] This has increased from a previous estimate in 2010, of 40% of UK hospitals using CPET as part of preoperative assessment of patients undergoing major surgery.[2]

CPET is an exercise test according to a defined, ramped protocol, with concomitant expired gas analysis. Expired tidal volumes, oxygen and carbon dioxide concentrations, heart rate and respiratory rate are measured. During CPET the patient is asked to exercise to their maximal effort on a treadmill or against increasing resistance on a static exercise bike. In the UK, it is estimated 93% of CPET is performed using cycle ergometry.[45] This is often preferred as it is easier for the patient to undertake, and is not as influenced by general mobility issues as a treadmill test. The test is performed with continuous ECG, blood pressure, oxygen saturation and inspiratory and expiratory ventilatory gas monitoring. The exercise component of the test takes up to 15 minutes, and combined with a full anaesthetic consultation, a CPET clinic routinely lasts up to one hour.[42]

2.2.2.2 CPET parameters

CPET generates several variables that characterise the patient's cardiorespiratory reserve and some of these parameters have been shown to prognosticate for postoperative mortality and morbidity across a range of operations. Table 2.2 lists the definitions of the key response variables commonly reported from CPET.[42,46,47] The two main CPET parameters with prognostic value are the peak oxygen uptake ($\dot{V}O_2$peak), and the anaerobic threshold (AT).[47] The $\dot{V}O_2$peak is the maximum level of oxygen consumption the patient can achieve at maximal effort; the AT is the threshold of oxygen consumption at which aerobic respiration is supplemented by anaerobic respiration in order to eliminate excess carbon dioxide. Both parameters are expressed in $ml.kg^{-1}.min^{-1}$.

Variable name	Denotation	Units	Description
Exercise capacity variables			
Anaerobic threshold	AT	ml O_2.kg^{-1}.min^{-1} ml O_2.min^{-1}	AT is a metabolic rate at a $\dot{V}O_2$ above which arterial lactate first begins to increase systematically during incremental exercise reflecting increased glycolysis
Peak oxygen uptake	$\dot{V}O_2$peak	ml.min^{-1} ml.kg^{-1}.min^{-1}	$\dot{V}O_2$peak is a metabolic rate defined as the highest $\dot{V}O_2$ attained on a rapid incremental test at end-exercise
Peak work rate	WRpeak	Watts (W)	The highest work rate in watts achieved during CPET. Patient usually start the test with no load, and then an incrementally increasing load of 10 to 20 watts per minute is applied until $\dot{V}O_2$max is reached or the patient cannot continue the test.
Cardiorespiratory variables			
$\dot{V}O_2$-work rate slope	$\Delta\dot{V}O_2/\Delta WR$	ml.min^{-1}.watt^{-1}	The relationship between the oxygen consumed ($\dot{V}O_2$) and the work (W) achieved. The slope of this relationship reflects the ability of the muscle to extract oxygen for aerobic respiration. This is usually linear and can be reduced in conditions affecting oxygen transport.
Heart rate	HR	Beats.min^{-1}	At resting and peak exercise
Oxygen pulse		ml.beat^{-1}	Calculated from peak $\dot{V}O_2$ divided by heart rate at peak exercise. It approximates the stroke volume
Arterial blood pressure	BP	mm Hg	At resting and peak exercise.
Arterial oxygen saturation	SpO_2	%	At resting and peak exercise
Tidal volume	V_T	ml or litres	At resting and peak exercise. Volume of gas inspired (or expired) during each breathing cycle.
Respiratory rate	RR	Breaths per minute (bpm)	At resting and peak exercise
Ventilation	$\dot{V}E$	litres.min^{-1}	Expired volume of gas per minute.
Breathing reserve	BR	litres.min-1 and % of $\dot{V}E$ at peak exercise	BR is a measure of how closely VE approaches maximum voluntary ventilation (MVV), calculated as BR = MVV-$\dot{V}E_{PEAK}$. This represents the potential for further increase ventilation during peak exercise.
Ventilatory equivalent for oxygen	$\dot{V}E$ / $\dot{V}O_2$		At AT or minimum value This is the ratio of the volume of gas expired per minute to the volume of **oxygen** consumed per minute

Variable name	Denotation	Units	Description
Ventilatory equivalent for carbon dioxide	$\dot{V}E / \dot{V}CO_2$		At AT or minimum value. This a measure of ventilatory efficiency (i.e. minute ventilation ($\dot{V}E$) relative to CO_2 exhalation). A $\dot{V}E / \dot{V}CO_2$relationship of < 30 is considered normal without adjustment for age or sex. Can be elevated in heart failure, pulmonary hypertension and chronic obstructive airways disease.
Respiratory exchange ratio	RER		Respiratory Exchange Ratio is the ratio of exhaled CO_2 (VCO_2) to inhaled oxygen (VO_2). Used as a measure of subject effort rather than using maximum heart rate. At higher exercise intensities, VCO_2 will increase at a faster rate than VO_2, as lactic acid buffering contributes to VCO_2 output. A peak RER > 1.10 is considered excellent effort, RER > 1.0 is good effort

Table 2.2 Table of descriptions of commonly reported CPET variables [42,46,47]

2.2.2.3 Value of CPET

There have been several reviews of the potential utility of CPET in identifying high-risk patients before intra-abdominal surgery, of which the most recent was published in 2016 by Moran et al .[24] In this review, heterogeneity of the data (of the included 37 observational, prognostic studies) precluded a meta-analysis. Quantitative analysis of the 37 studies led the reviewers to recommend that CPET should be included in the preoperative assessment of liver, pancreatic, and intra-abdominal surgery and abdominal aortic aneurysm (AAA) repair.

Four of these ten studies reported an AT of < 11 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$ to be a significant predictor of postoperative mortality. However, one study showed AT was not a significant predictor of mortality, and of the two studies of CPET before radical cystectomy, one had an insufficient number of postoperative deaths and no statistical analysis for mortality,[48] and the other had an insufficient sample size.[49]

In terms of predicting postoperative morbidity, 5 studies of intra-abdominal surgery, including the 2 studies of radical cystectomy patients only, showed AT was again the strongest predictor. Therefore, the authors of this systematic review have recommended that, for intra-abdominal surgery, an AT threshold of 10.9 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ to predict for significantly lower risk of postoperative mortality and an AT < 10.1 ml $O_2{\cdot}kg^{-1}{\cdot}min^{-1}$ to predict for higher risk of postoperative morbidity. In this group, patients with an AT of 10.1–12 ml $O_2{\cdot}kg^{-1}{\cdot}min^{-1}$ should also be treated with caution.[24] The authors also suggest, that the use of a single cut-off threshold may not be informative, and that patients may be need to stratified for risk from surgery into subgroups based on patient fitness.[24]

This lack of standardization of reporting of CPET variables and outcomes may be part of the reason why the evidence base for CPET may still be considered not strong enough to change the practice of perioperative risk stratification. CPET has not been widely adopted in other countries such as the United States and does not feature as recommendation in European or American consensus statements on perioperative risk stratification – although these guidelines are for postoperative cardiovascular outcomes only.[50–52]

2.2.3 Other tests of exercise capacity

Although CPET is considered the gold standard method of preoperative exercise capacity testing, there are other tests of exercise capacity, known as ‘field tests’ that can provide an objective measure of exercise capacity and physical fitness. These include the six minute walk test (6MWT), the intermittent shuttle walk test (ISWT) and the stair climbing test (SCT). However, these tests will not have the ability to provide physiological information on why exercise capacity may be limited as there is no concomitant gas exchange and cardiovascular assessment. CPET is used for clinical preoperative assessment for certain groups of patients, and in research studies of preoperative assessment and fitness, but has limitations for widespread use. Other tests of exercise capacity that may require less space, specialist equipment and expertise have been investigated for their potential utility as an objective measure of preoperative fitness and therefore risk for surgery, as well as a method of determining outcomes in preoperative exercise intervention studies. These tests can be loosely classified as testing maximal or submaximal exercise capacity, with an incremental or continuous workload, and using a treadmill or a cycle ergometer or are walking based.

2.2.4 Value of field tests of exercise capacity for preoperative assessment in non-cardiac intra-abdominal surgery

In a recent systematic review of the ability of ‘field tests’ to predict for postoperative outcomes after non-cardiac intrabdominal surgery conducted by Moran and colleagues, only six studies – all observational and using validated field tests - were included. Of these six studies, four studies included the 6MWT, two studies included the ISWT, and only one study included the SCT.[19] The 6MWT has been shown to be predictive of medical, but not surgical complications after colorectal surgery in one study,[53] but another study of colorectal resection found no predictive ability of the 6MWT for postoperative complications.[54] Two studies of upper abdominal surgery showed no statistical difference in 6MWT distance for patients who developed cardiopulmonary complications postoperatively.[19,55,56] For the ISWT, one study suggested there was a shorter length of stay of 8 days, compared with 14 days, for patients undergoing colorectal surgery who had an ISWT distance of > 250 m. The same study showed that patients who had no complications postoperatively achieved a significantly higher mean ISWT distance of 382.7 m, compared to patients who did develop complications who had a mean ISWT distance of 256.8 m.[19,57]

This systematic review of field tests of exercise capacity concluded that there was insufficient evidence to know whether these field tests could predict postoperative outcomes due to the low rate of mortality in the included studies and lack of statistical analysis to justify their predictive utility.[19] It appears that the ISWT and SCT have some utility for predicting postoperative complications in thoracic surgery, likely due to their high correlation to $\dot{V}O_2$peak in this group of patients (whereas it seems AT is more predictive of postoperative complications for intra-abdominal surgery).[19,24] The authors note that CPET is a specialised test and may not be available in some centres, but there is currently little evidence to justify the use of these other field based tests of exercise capacity for preoperative assessment of intra-abdominal surgery patients.[19]

2.2.5 Summary of methods of assessing preoperative functional capacity

Assessment of functional capacity is one of the many elements of preoperative assessment but one that is challenging to undertake. Other preoperative assessments for renal and cardiac disease have well-known parameters that can be measured with routine investigations such as blood tests and imaging. Objective and accurate measurement of functional capacity can be achieved with CPET. However, this test requires significant resources in the form of a dedicated clinic with a consultant anaesthetist and nurse, specialist equipment, and in our hospital, CPET is currently only indicated for patient undergoing specific major operations. Patients who are not able to walk on a treadmill or cycle on the machine are precluded from CPET assessment, and patient motivation to be able to achieve maximal exercise can be variable.

A study which aimed to recruit patient preoperatively to undergo CPET only managed to recruit 23% of eligible participants. Patient reluctance to undergo CPET was a major reason for low screening to recruitment ratio.[10] Furthermore, CPET only provides a snapshot picture of the patient in the hospital setting. Although serial measurements with CPET can be undertaken, to see if, for example, there is change in status after neoadjuvant chemotherapy, the format of this test is not well designed to monitor the patient longitudinally over time. Other subjective measures such as the ASA score, visual analogue scale of METs and the

DASI questionnaire are much less burdensome to do, but again, are more useful as a one-time estimate of functional capacity and suffer from subjective bias from both the patient and clinician.

Field tests of submaximal exercise capacity such as the 6 Minute Walk test, the ISWT and stair climb test do correlate with CPET results but are not validated nor widely used in the preoperative setting. They are not necessarily more practical to perform than a CPET test as more space and time is required and are prone to a greater degree of bias depending on the delivery of the test by the assessor and patient motivation.

Using METs to estimate functional capacity makes use of the link between physical activity and physical fitness. The more vigorous physical activity or exercise a patient can undertake, the greater the functional capacity of the patient is likely to be. Given that the aim of preoperative assessment and optimisation of functional capacity is closely related to measuring and increasing physical activity, an objective measure of physical activity in patients may be a useful tool in the preoperative period. This can give a surrogate measure of patient functional capacity to enable risk stratification, as well as measuring changes in physical activity level as part of preoperative exercise intervention. Physical activity encompasses all physical movement performed by a person, but not all this information is useful for understanding physical fitness. The nature of the relationship between physical fitness and physical activity is discussed below, concluding with why being able to measure activity intensity is crucial to be able to relate physical activity to physical fitness.

2.3 Relationship between activity levels and physical fitness

2.3.1 Definitions of physical activity, exercise and physical fitness

Physical activity refers to any bodily movement produced by skeletal muscles that results in energy expenditure. The term exercise is often used interchangeably with physical activity, but exercise is a subcomponent of physical activity. Total daily physical activity is therefore the sum of the non-exercise and the exercise-related energy expenditure.

Exercise, in addition to skeletal muscle movement, is a planned, structured, repetitive, purposeful activity that is performed with the aim of maintaining or improving physical fitness. Activities such as household tasks are usually performed with the aim of conserving energy and not improving physical fitness. But, if walking as part of shopping was done with the aim of expending more energy to improve fitness, then this would be considered an activity of daily living that was also exercise.

2.3.2 Relationship between physical activity, physical fitness and premature death

2.3.2.1 Physical activity and physical fitness

Physical activity can lead to lasting physiological effects which can change physical fitness. Physical activity in the form of exercise has been proven to offer strong cardio-protection, and this may start to occur even after a single episode of exercise, through a process of cardiovascular preconditioning. After several days of exercise, physiological and functional adaptations can occur with improved coronary artery vascular function and sympathetic nervous system function. After weeks to months of consistent exercise, structural adaptations can occur including changes to coronary artery vascular structure, formation of collateral vessels and cardiac remodelling. Exercise training increases maximum ventilatory oxygen uptake by increasing both maximum cardiac output and the ability of skeletal muscle to extract oxygen. After a period of years, exercise training can lead to reduction in cardiovascular risk factors such as lowered blood pressure and cholesterol, reduction in body fat and body mass index and reduction in insulin resistance.[58]

2.3.2.2 Physical activity and health outcomes

This association between physical activity and physical fitness is supported by studies which have shown that physical activity influences general health and mortality.[59–63] In addition, studies of interventions to improve activity in sedentary adults have shown benefits in physical activity, cardiorespiratory fitness and blood pressure.[64] Exercise interventions will be discussed further in Chapter 5.

The original links between physical activity levels and mortality from coronary heart disease (CHD) were made from the British Social Class data through observations that those in skilled and less active jobs had higher mortality than those in unskilled work.[59] Weekly energy expenditure from assessment of adult activity levels may be a better predictor of all-cause mortality than established risk factors such as smoking, diabetes, hypertension and obesity.[65] There is still debate on whether physical activity is a predictor of mortality risk, independent of physical fitness. In a 2004 study, 842 men underwent exercise testing for suspected CHD, and estimation of energy expended in weekly physical activity using a self-administered activity questionnaire.[62] Myers and colleagues found that a 1000 kcal a week increase in estimated energy expenditure from physical activity was approximately similar to an increase in physical fitness of one metabolic equivalent (which is considered equivalent to an oxygen consumption of 3.5 $ml.kg^{-1}.min^{-1}$), and both increase in physical activity and physical fitness conferred a mortality benefit of 20%. However, physical activity was poorly correlated to physical fitness on exercise test performance, and physical fitness was a stronger predictor of mortality than physical activity levels.[62]

Overall, based on over five decades of epidemiological studies, the value of physical activity and physical fitness to better health outcomes is beyond dispute.[66] Although physical fitness does appear to be the stronger predictor of mortality risk, the evidence also shows that physical activity can explain mortality risk above and beyond traditional risk factors, suggesting physical activity is capturing additional useful information about mortality risk. The question of whether physical activity is an independent predictor of mortality risk may be moot as physical activity is co-correlated with physical fitness, and physical activity is the primary determinant of change in physical fitness.[61]

2.3.3 Relationship between physical fitness and activity intensity

Current thinking is that aerobic physical activity, whether occupational, transport or leisure related, needs to reach a certain level of intensity and duration to induce long-lasting physiological changes that confer a health benefit. This is based on evidence from epidemiological studies and exercise intervention studies. Epidemiological studies have tended to show a graded relationship between the physical activity and reduction in mortality risk. Recommendations for how much physical activity is protective, have previously ranged from needing to do thirty minutes of vigorous intensity exercise a day, to just twenty minutes of walking a day, to needing to expend between 500 and 2000 kcal a week in additional exercise to confer benefit.[59] The current UK national recommendations for physical activity in adults follows the World Health Organisation (WHO) recommendations. Adults aged 18 to 64 should do at least 150 minutes of moderate-intensity aerobic physical activity throughout the week, or vigorous-intensity aerobic activity of 75 minutes per week, or a combination of moderate- and vigorous-intensity activity that is equivalent.[27,67]

Therefore, the intensity level of activity is an important component of activity classification that has implications for understanding the 'effectiveness' of the physical activity performed. Moderate-intensity level aerobic activity is required to sufficiently stimulate the cardiorespiratory, musculoskeletal and metabolic systems to adapt to achieve increased physical fitness.

2.3.3.1 Activity intensity level

Activity intensity level, generally classified as sedentary, light, moderate or vigorous can be measured as relative or absolute intensity, using subjective or objective criteria. The moderate to vigorous intensity physical activity category is often denoted as MVPA.

Absolute vs. relative intensity level

The absolute intensity is the energy expended doing the activity and is determined by the external work performed. This is often measured in METs - an index of the absolute metabolic costs of the activity, with different MET ranges corresponding to different categories of activity intensity level (see Table 2.3). The relative intensity is the absolute intensity in relation to a person's individual level of cardiorespiratory fitness. If a fit and an unfit person do the same activity, the absolute intensity of the activity will be the same for both, but the relative intensity will be greater for the less fit person. For example, walking at 3 mph would have a MET value of 3 by absolute measures. If person A has a $\dot{V}O_2max$ of 17.5 ml $O_2.kg^{-1}.min^{-1}$ (5 METs), and person B has a $\dot{V}O_2max$ of 42ml $O_2.kg^{-1}.min^{-1}$ (12 METs), walking at 3 mph would be the same absolute level of physical activity at 3 METs. However, using relative intensity level, person A would be performing at a hard-intensity level, as they are walking at 60% of their $\dot{V}O_2max$, whereas person B would only be performing light-intensity activity, at 25% of their $\dot{V}O_2max$.[68]

Table 2.3 shows the equivalent values for different intensity levels of physical activity based on relative and absolute measures (taken from the American Heart Association scientific statement on assessment of physical activity).[68,69] The question of whether the key protective element of physical activity is the absolute intensity or the relative intensity remains unresolved.[70,71] Most studies have used absolute intensity, based on calorimetric methods or tools validated with calorimetry, to categorize activity intensity. But an inverse relationship between the relative intensity and risk of coronary heart disease has also been shown, such that, men who did not even achieve above sedentary absolute intensity level activity (less than three METs) could confer benefit. This suggests that, in unfit people, activities with intensities lower than three METs may still have important beneficial effects.

	Relative Intensity			**Absolute Intensity**	
Intensity	$\dot{V}O_2max$ (%)	Maximal Heart Rate, %	RPE	Intensity	METs
Very light	<25	<30	<9	Sedentary	1–1.5
Light	25–44	30–49	9-10	Light	1.6–2.9
Moderate	44–59	50–69	11–12	Moderate	3.0–5.9
Hard	60–84	70–89	13–16	Vigorous	≥6.0
Very hard	≥85	≥90	>16		
Maximal	100	100	20		

Table 2.3 Classification of physical activity intensity based on absolute and relative measures. Table based on 'Guide to the Assessment of Physical Activity: Clinical and Research Applications. A scientific statement from the American Heart Association (2013).[68,69] METs, metabolic equivalents; RPE, rate of perceived exertion, $\dot{V}O_2max$, maximal aerobic capacity.

Subjective vs. objective assessment of activity intensity level

Subjective criteria to assess activity intensity level is based on the Borg exertion scale which standardises activity recommendations based perceived symptoms by the patient on a scale of 6 to 20 (see Table 2.4).[72] Although subjective, there has been shown to be a high correlation between a person's perceived exertion rating and their heart rate. The scale has been designed such that the Borg rating times ten will approximate the heart rate. A Borg exertion level of 6 is equivalent to no exertion at all, and an exertion level between 12 and 15 is generally considered to be of moderate-intensity and would be equivalent to a heart rate of above 110 beats.min^{-1}. In this range, the patient should experience an increase in breathing rate, an increase in heart rate to the level where the pulse can be felt, a feeling of increased warmth, and should be sustainable for many minutes without causing exhaustion or extreme fatigue. For patients with more unpredictable heart rate-to-work done relationships, the Borg scale may be a more useful measure of intensity level achieved than heart rate monitoring. This subjective scale of relative activity intensity can be used to prescribe equivalent amounts of exercise, based on effort level needed to reach moderate intensity, for individuals with varying levels of fitness. Therefore, for an activity such as walking, to achieve moderate-intensity threshold for an individual, the focus should be on their perception of effort rather than the speed of walking.

Borg Scale	Level of Exertion	Description
6	No exertion at all	
7		
7.5	Extremely light	
8		
9	Very light	9 corresponds to "very light" exercise. For a healthy person, it is like walking slowly at his or her own pace for some minutes
10		
11	Light	
12		
13	Somewhat hard	13 on the scale is "somewhat hard" exercise, but it still feels OK to continue.
14		
15	Hard (heavy)	
16		
17	Very hard	"very hard" is very strenuous. A healthy person can still go on, but they really have to push themselves. It feels very heavy, and the person is very tired.
18		
19	Extremely hard	19 on the scale is an extremely strenuous exercise level. For most people this is the most strenuous exercise they have ever experienced.
20	Maximal exertion	

Table 2.4 Borg scale of perceived exertion. Taken from the Centers for Disease Control and Protection website. (https://www.cdc.gov/physicalactivity/basics/measuring/exertion.htm)[72,73]

Objective measures of activity intensity level can be based on heart rate, or calculation of the MET value of the type of activity. Moderate-intensity activity can be defined as activity which increases heart rate to a range between 50% and 70% of an individual's maximum estimate heart rate for age. For example, a 50-year-old would have a maximum age-related heart rate of 200 - 50 = 170 beats per minute. The 50% to 70% range would be a target heart rate range of between 85 and 119 to qualify as moderate-intensity activity. Vigorous-intensity activity is defined as a target range of between 70% to 85% of maximum age-related heart rate.[74]

Methods which measure or estimate the energy expenditure of activities, can be converted to MET values, which are an objective, absolute measure of activity intensity. A sedentary-intensity activity is generally considered to have a MET value of less than 1.5. The light activity range is 1.5 to 3 METs, moderate intensity is a MET value of between 3–6, and vigorous is a MET value of above 6.[75]

The relationship between physical fitness and intensity of activity being performed is an important factor to consider when attempting to measure physical activity levels and prescribing preoperative exercise intervention. As previously discussed, measurement of physical fitness or functional capacity can be achieved with a variety of exercise tests. However, there is currently no pragmatic, real-time, accurate and reliable method of measuring day-to-day physical activity. This is discussed in the next section.

2.4 Assessing physical activity

Physical activity assessment can cover a wide range of the different domains of physical activity depending on the purpose of the assessment. These domains include physical activity duration, frequency, volume, intensity and energy expenditure, the type of physical activity, and timing and location of the bouts of activity. Preoperative assessment of functional capacity using a tool that measures physical activity must be able to identify and quantify the important aspects of physical movement that can provide information on physical fitness. The ability of physical movement to reflect physical fitness hinges on the ability to estimate energy expenditure for the physical movement undertaken. A useful tool for measuring physical activity must be able to quantify the activity according to energy expenditure and be validated against known energy expenditure amounts for that activity. The measurement of energy expenditure and why this is important for physical activity monitoring is discussed below.

Different methods of measuring physical activity are discussed including the emerging role of accelerometers in this field.

2.4.1 Energy expenditure

In order to be able to quantify the amount of physical activity or 'work' done, the amount of energy expended during this activity must be measured or estimated. As previously discussed, the use of METs presumes a certain amount of energy expended for different types of activities and can act as a crude scale to estimate a patient's functional capacity, but individuals will expend different amounts of activity when performing the same types of activity. However, measuring energy expenditure directly or even indirectly during physical activity is problematic as discussed in this section.

The amount of energy expended by physical activity can be measured in kilojoules (kJ) or kilocalories (kcal).[76] Energy expenditure (EE) can be measured using indirect or direct calorimetry, or can be estimated using non-calorimetric techniques by extrapolation from physiological measurements and observations. These non-calorimetric methods include using doubly labelled water, heart rate monitoring, integrated electromyography, thermal imaging, activity logs and measurement of human movement using pedometers and accelerometers. The calorimetric methods can measure total energy expenditure (TEE). This is the sum of the basal metabolic rate, also known as the resting energy expenditure (REE), the thermic effect of feeding (TEF) and the energy expenditure of activity (AEE) - which can further be divided into exercise (ExEE) and non-exercise activity thermogenesis (NEAT). Figure 2.4 (based on a diagram from Hills, 2014, p2), summarises these components of TEE and how they may be assessed.[77]

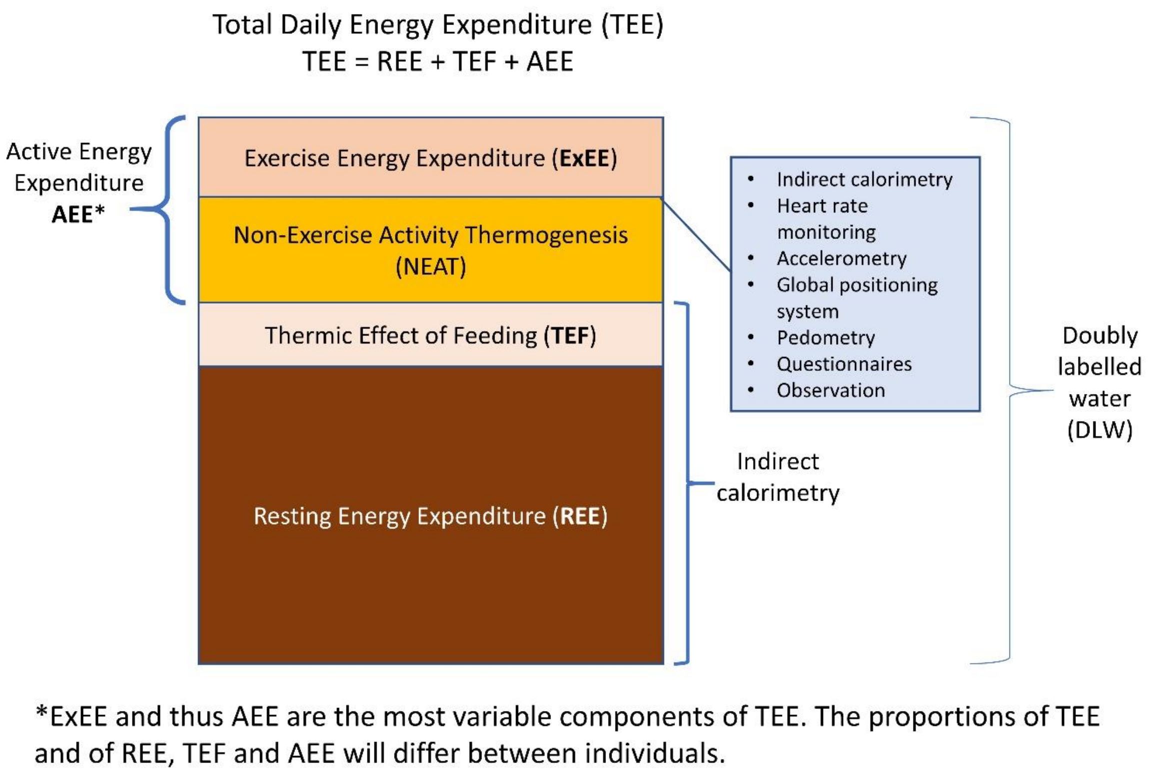


Figure 2.4 Components of total energy expenditure and available assessment methods. Figure based on diagram from Hills, 2014, p.2.[77]

2.4.2 Validity of physical activity monitoring tools for estimating energy expenditure

Direct and indirect calorimetry are the laboratory standard techniques for measuring energy expenditure during physical activity. However, in real-living situations, surrogate measures of physical activity level are often used. These include using patient questionnaires, heart rate monitors, pedometers and more recently accelerometers. The validity of these tools has been tested against calorimetric methods and are discussed below.

2.4.2.1 Self-reported tools of quantifying physical activity and METs

Self-reported activity tools may be in the form of questionnaires asking for patient recall of activities over the past few days, one week or even a year; or activity diaries which list activities over a period. The estimate energy expenditure of each activity can be calculated for the individual using indirect calorimetry methods, or a reference value can be looked up in a table of metabolic equivalent (METs) values of many different types of activity. An example table taken from the Department of Health activity recommendations report is shown in Table 2.5.[70,78] Tables of metabolic equivalent values for different types of activities vary across different sources, based on the population used to validate the METs values against indirect calorimetry measurements. Reference METs values for the absolute energy expenditure in kcal per minute of a specific activity are most applicable to men aged 30 to 50 years and women aged 20 to 40 years. Therefore, for older individuals, and those with chronic illness or disability, the classification of activity intensity may be higher.[78]

Activity	Intensity	Intensity (METS)	Energy Expenditure (Kcal equivalent for a person of 60kg doing the activity for 30 minutes
Ironing	Light	2.3	69
Cleaning and dusting	Light	2.3	75
Walking, 2mph	Light	2.5	75
Painting/decorating	Moderate	3.0	90
Walking, 3pm	Moderate	3.3	99
Hoovering	Moderate	3.5	105
Golf, walking, pulling clubs	Moderate	4.3	129
Badminton, social	Moderate	4.5	135
Tennis, doubles	Moderate	5.0	150
Walking, brisk, 4mph	Moderate	5.0	150
Mowing lawn	Moderate	5.5	165
Cycling, 10-12mph	Moderate	6.0	180
Aerobic dancing	Vigorous	6.5	195
Cycling, 12-14mph	Vigorous	8.0	240
Swimming, slow crawl, 50 years per minute	Vigorous	8.0	240
Tennis, singles	Vigorous	8.0	240
Running, 6mph	Vigorous	10.0	300
Running, 7mph	Vigorous	11.5	345
Running, 8mph	Vigorous	13.5	405

Table 2.5 Reference metabolic equivalent values, intensity category and calorific expenditure for common daily activities.[70,78] *MET, metabolic equivalents.*

This estimate of energy expended in patient recorded activities can then be combined with measured or estimated basal metabolic rate to give an estimate of total energy expenditure.

Therefore, there are two potential sources of error in this method. Firstly, the ability and accuracy of the person to record their activities. Previous attempts to reconcile self-reported measures with accelerometer measured activity have shown that the subjective error in recording activities is not systemic, but random, which would make adaptation of self-reported tools to compensate for recall bias difficult.[79] Secondly, the estimation of the energy expenditure of each type of activity the person may list is often derived from reference tables based on indirect calorimetry studies and may therefore not be applicable to a specific individual. Baseline measurement of the energy expenditure expected for a specific individual doing different activities, using indirect calorimetry methods, would be preferred to give the reference value, but is only practical for small group studies.[80]

2.4.2.2 Heart rate monitoring

Energy expenditure can be estimated from heart rate, which can be monitored with a variety of devices in the non-laboratory, free-living context. However, heart rate and energy expenditure are not linearly related because stroke volume will not be constant with each heartbeat. The linear relationship breaks down both at resting heart rate, and at very high work levels near maximal exercise capacity. Large inter-individual variance also exists for the heart rate–energy expenditure relationship. Heart rate monitoring may be combined with accelerometer measured physical activity to give more information on the intensity of physical activity and therefore more closely relates the physical movement measured to the energy expended. However, heart rate is not just dependent on physical activity.[81] Other sensory stimuli and use of cardiac medication can also alter heart rate. This is used in the second clinical study of this thesis and is discussed in Chapter 5.

2.4.2.3 *Kinematic measurements using pedometers and accelerometers*

This is measurement of bodily movement, most commonly using pedometers measuring step count, or accelerometers which measure body displacement. Other possible methods, suitable for confined environments are radar tracking or visual imaging. Pedometers measure the person's displacement with each stride and can only measure walking activity. However, other vertical movements, such as getting up from a chair may also be recorded as a step count. Also, when using pedometers, the stride length, distance walked, and other bodily movements are not known which make pedometers poor predicters of physical activity energy expenditure. However, pedometers have been extensively in medical studies of cardiac rehabilitation and weight loss programmes. Pedometers are inexpensive, easy to use and the data easily interpretable in contrast to accelerometers which offers more sensitive body movement recording.

Pedometers have been shown to be accurate for step estimation where the speed of walking is more than 80 metres per minute, but less accurate at slower walking speeds of less than 54 metres per minute.[82] Most studies have also found that pedometers tend to overestimate energy expenditure.[68] More recent attention has focused on using pedometers to measure step-rate per minute, and to use this metric to estimate the intensity of activity. One study has suggested using a step-rate count of more than 100 steps a minute to equate to moderate-intensity activity.[83] Use of step-rate recording by pedometers can assess physical activity levels in more detail and may be able to further motivate patients in exercise programs.[68] A systematic review of pedometers in exercise intervention has shown they are effective in increasing physical activity level, reduce body mass index and blood pressure.[84]

Recent interest has grown in the ability of accelerometers to use human movement to objectively measure physical activity. This can potentially assess physical activity across a range of domains including timing, duration, frequency, volume and intensity. Validation studies have also shown some forms of activity measured using accelerometers can be used to estimate energy expenditure and even predict the type of physical activity. Adjuncts to accelerometers such as GPS and heart rate monitoring may also provide further information on volume, intensity and location of activity. This makes it a particularly attractive tool for use in clinical medicine and is a natural progression from traditional methods of using patient questionnaires, heart rate monitors and pedometers. In the preoperative assessment context, accelerometers can contribute information on physical activity and physical fitness that is not currently assessed using existing tools such as the ASA score, METs questionnaire or exercise testing. The next chapter discusses accelerometers in detail and how they may be applied in the preoperative assessment of functional capacity.

3 Introduction: Measuring physical activity using accelerometers

Wearable accelerometers have been popular commercially for personal health monitoring and are now starting to be investigated for medical applications. Accelerometers in medicine have mainly be used in the context of studying population and age-related activity levels, movement disorders and weight loss interventions, but there is growing interest for the use of wearable accelerometers for preoperative assessment and exercise intervention.[85,86] It is clear that accelerometers has the potential to offer an objective and low-burden method of measuring physical activity levels, and estimating physical fitness levels, with several advantages over existing tools.

The lack of adoption for patients may be because information derived from accelerometers is not easily relatable to real-life concepts of physical activity or physical fitness. Although the resolution of the data is high, with the ability to measure movement in three planes, at a sampling rate of up to 100 times per second, research questions remain on how to best process this large quantity of data, into meaningful metrics, that are useful for answering clinical questions.

The understanding of how accelerometer data should be interpreted for different settings is still developing, and most investigations have been performed in healthy volunteers in controlled laboratory conditions. The uses of accelerometers in medicine is discussed below followed by a discussion how accelerometers work and how movement data may be interpreted.

3.1 Use of accelerometers in medicine

The use of accelerometers to measure and classify physical activity has been mainly in epidemiological public health studies of population activity. Wrist worn accelerometers can provide insight into how activity levels compare between different countries, between men and women, and different age groups.[87] Within medicine, accelerometers have been used for their ability to provide information about gait and posture in studies of neurological and musculoskeletal diseases.[88–90] Focusing on the physical activity and fitness assessment aspect of perioperative care in this thesis, accelerometers have been investigated for their utility to measure physical activity intensity and duration in disease states where exercise intervention has been shown to be effective for improving patient symptoms or reducing complications. This has traditionally been cardiac and pulmonary rehabilitation, and interventions for obesity, but also emerging for studies of cancer surgery patients and prehabilitation studies of exercise intervention before surgery.

3.2 What is an accelerometer?

Accelerometers are electromechanical devices which measure accelerations of an object in either one plane (uniaxial), two planes (biaxial), or three planes (triaxial), and can provide a value of these accelerations at a given rate over time, for example 25 to 100 data points per second. For use on humans, the accelerometer device is enclosed in a case and then attached to the body typically by a strap, in one or more locations, typically the wrist, chest, ankle, hip or waist when measuring general physical activity levels.[68] Table 3.1 provides an overview of the properties of 4 commercially available accelerometers that have been used in physical activity monitoring research.

	Axivity AX3	**Actigraph wGT3X-BT**	**RT3**	**SenseWear armband**	**GENEActiv original**
Manufacturer	Axivity, Newcastle, UK	Pensacola, FL	StayHealthy Inc., Monrovia, CA	Bodymedia, Pittsburgh, PA	Activinsights, Kimbolten, UK
Mechanism	MEMS	MEMS	Piezoelectric with integrated chip	MEMS	MEMS
Size, mm	23 x 32.5 x 7.6	46 x 33 x 15	71 x 56 x 28	62 x 55 x 13	43 x 40 x 13
Weight, g	11	19	65	45.4	16
Battery type	Lithium	Coin cell	AAA	AAA	Lithium polymer
Battery life, days	30 days @ 12.5Hz; 14 days @ 100Hz	25	—	5-7	45 days @ 10Hz, 7 days @ 100Hz
Waterproof?	Yes	Yes	No	Yes	Yes
Memory	512 MB Flash	4 GB	—	—	500 MB
Data storage, days		180	3 hours to 21 days	28	30
No. of axes	3	1	3	2	3
Sampling rate, Hz	12.5–3200 configurable	30–100 Hz	0.017–1 Hz	—	10–100 Hz
Acceleration range, *g*	± 2/4/8/16 configurable	± 8	—	± 1.0	± 16
Resolution, bit	Up to 13	—	—	—	12
Sensors	Skin temperature Light sensor	Light sensor Wear time sensor	Accelerometer only	Temperature Galvanic skin response to sweat Heat loss from skin	Light sensor Temperature sensor
Bluetooth?	No	Yes	No	No	No
Location	Any	Wrist, waist, ankle, thigh	waist	Upper arm	wrist
Output	Raw signals	Raw signals Counts.min^{-1}	Counts.min^{-1}	Raw signals	Raw signals
Software	Open Movement, open source software from Newcastle university	Actigraph software ($349) Will also provide outputs of METs, EE, bouts of sedentary activity, sleep time	RT3 software	SenseWear research software with proprietary algorithm	Open data format

	Axivity AX3	Actigraph wGT3X-BT	RT3	SenseWear armband	GENEActiv original
Cost (as of July, 2018)	£99	$335	—	No longer sold	£220
Validated outcome measures	Energy expenditure, step count, gait analysis, ADLs, posture	Regression equations for predicting energy expenditure using counts	EE, METs	EE, moderate-to-vigorous intensity time, steps, METs	EE, METs
References	91,95	96–101	102–105	68,89,98	106–108

Table 3.1 Comparison of commonly used accelerometer devices in medical studies.

3.2.1 Acceleration

Acceleration is measured in metres per second squared, with the gravity unit *g* used informally to represent units of acceleration. One *g* is 9.806 metres per second per second ($m.s^{-2}$) as acceleration is the change in speed ($m.s^{-1}$) over time. One *g* represents the average acceleration produced by gravity alone at the earth's surface. An acceleration of zero means the body is not changing in speed, but may still be in motion, at a constant speed.[105] Acceleration, rather than speed of bodily movement, is the preferred measure of physical activity, as acceleration is proportional to the net external force involved and therefore more directly reflective of energy expenditure than speed. Measuring acceleration also generates an information rich signal that can be post-processed into speed and distance signals using integration with respect to time. This conserves signal integrity that would be lost if post-processing was performed by differentiation with respect to time.[106]

3.2.2 Piezoelectric and MEMS sensors

Accelerometers may be based on a piezoelectric element or a microelectromechanical system (MEMs). Acceleration is captured mechanically by an accelerometer which is converted into an electrical signal which is either a voltage, a resistance or a capacitance.[107] Accelerometers using piezoelectricity will contain a piezoelectric element and a seismic mass housed together

(Figure 3.1). The piezoelectric element is a material (usually quartz crystal) that can generate an internal electric charge in response to, and proportional to, the applied mechanical stress. The seismic mass is used as a proof mass in the accelerometer. The proof mass is a known quantity of mass used to measure something of unknown quantity. When the sensor undergoes acceleration, the seismic mass deforms the piezoelectric element by either bending the element (in beam sensors) or compressing the element directly in newer integrated chip sensors. [105] This deformation of the piezoelectric element causes a displaced charge to build up on one side of the sensor which can generate a variable output voltage signal that is proportional to amplitude and frequency of the applied acceleration to the proof mass.

MEMS accelerometers work by measuring a change in capacitance which is converted into a digital signal of acceleration. The proof mass is mounted on a cantilever, which when accelerated, moves and causes a change in capacitance. This change is picked up by the integrated silicon chip, which turns the capacitance into a voltage. MEMs accelerometers, unlike those using piezoelectric elements, can measure static acceleration such as the earth's gravitational field but are not as good as piezoelectric accelerometers at high frequencies and large amplitudes of acceleration.

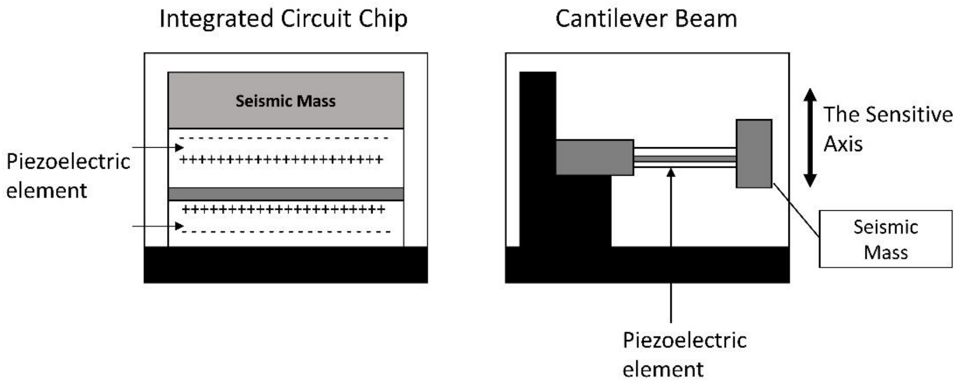


Figure 3.1 Schematic diagram of two common piezoelectric sensor configurations, the integrated chip and the beam sensor. Based on diagram from Chen and Bassett Jr, 2005.[105]

3.3 Raw accelerometer data

Raw accelerometer data is presented as the average acceleration values per ‘window’ or time interval. These acceleration values in *g* are then sometimes transformed to other units such as a ‘count’, which can be expressed as counts per second, or minute, or summed as total counts per day. These counts are then used in validation studies of accelerometers against measurements of actual energy expenditure using portable metabolic systems. Count ranges can then be linked to an absolute measure of intensity in form of METs. How these ‘counts’ are derived are dependent on the individual accelerometer, and the nature of the programming of the software provided for that accelerometer that computes the counts.[68] Although counts are widely used in physical activity research, it is hard to compare counts across monitors due to the technical differences, and lack of a standardized unit of measurement.[100]

Some accelerometers allow collection of raw accelerometry data, which, if not using the provided software, can be analysed through a series of steps to make the data understandable. This will involve a series of steps starting with deciding the sampling rate, which is usually dictated by the device, but can be changed to be between 25Hz and 100Hz. The device is then calibrated to local gravity, which is of more importance where one might expect gravitational acceleration to be different to the average for the earth’s surface of 9.8 $m.s^{-2}$ depending on local altitude and topography. The raw accelerometry data can then be used to calculate the vector magnitude, that is direction and quantity of each movement. The data is further analysed in defined ‘windows’ or ‘epochs’, for example, between five-second to one-minute epochs. Deciding how long an ‘epoch’ should be may depend on the type of activity measured. Shorter epochs may have higher resolution of data but may not relate to human cycles of activity. Longer epochs may average out high and low intensity periods and therefore underestimate time spent in higher intensity activity. Usually, a 60 second epoch is considered reasonable.[106] Non-wear detection is applied to disregard data that appears to be collected when the device is not being worn. This is usually defined as a period between 20 to 60 minutes with no 'counts', with or without allowance for 2-minute interruptions.[108] Finally summary metrics of activity volume and intensity are calculated.[87]

3.3.1 Feature generation from raw accelerometry data

Activity recognition using accelerometer readings depends on how features of the accelerometry signal are generated and then, how these features are inputted into classification algorithms for estimating energy expenditure or classifying a type of activity. There are two main methods of feature generation of the raw accelerometry data that have used in previous studies of human physical activity. These are features derived from the magnitude of acceleration in the time domain and features derived from analysing the data in the frequency domain.[109]

3.3.1.1 Features derived from the magnitude of acceleration in the time domain

Physical activity recognition can be classified by using features derived from quantification of the amplitude of the accelerations. That is the value of the acceleration in *g* in a particular axis, or averaged across several axes, over a time segment. Figure 3.2 shows an example of a plot of the magnitude of acceleration measured by the AX3 triaxial accelerometer over time.

The 'vector magnitude' or 'average vector magnitude' is the term used to describe the magnitude of acceleration averaged over the three axes when using a triaxial accelerometer. The VM is a vector consisting of the Euclidean norm, i.e. positive vector magnitude of the acceleration in the x, y and z axis. The average magnitude of acceleration is the square root of the sum of the squares of each component.

$$VM = \sqrt{(x^2 + y^2 + z^2)}$$

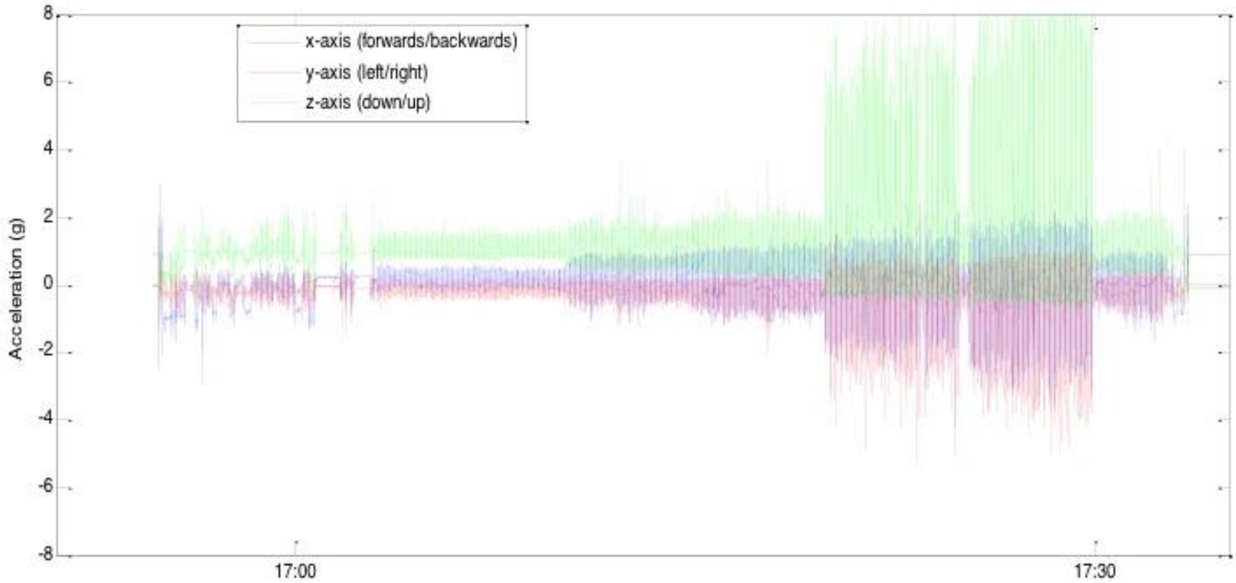


Figure 3.2 Example of raw accelerometry data plotted as magnitude of acceleration in gravity units against time. Each axis is represented in a different colour.

Another feature derived from the magnitude of acceleration (in the time domain) is the signal magnitude area (SMA) which is the area under the acceleration curve. This is thought to be more representative of the intensity of activity and is usually the feature used to calculate the 'counts' offered by some accelerometer software.[110] However, the SMA may give a false representation of the intensity of activity performed. As Figure 3.3 shows, three scenarios of different types of activity profile are shown but will all have the same SMA.

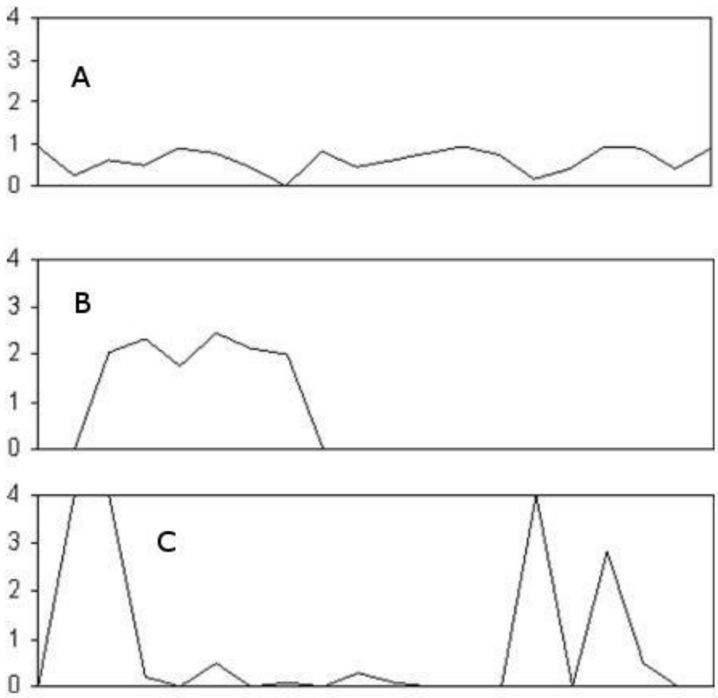


Figure 3.3 Three scenarios with arbitrary accelerometry data points over the same time window of: A) consistent but low intensity level of activity, B) a moderate intensity over a short period, and C) sporadic short bursts of high intensity activity. The integrated outputs for these three signals for this time window are identical although the standard deviations will be different. Modified from Chen and colleagues, 2005. [106]

Statistical measures using the magnitude of acceleration in the time-domain can also be used as features for activity classification. These include calculating of the mean, median, variance, skewness and kurtosis of vector magnitude or signal magnitude area.[110]

3.3.1.2 Features derived from analysis of the magnitude of acceleration in the frequency domain

The magnitude of acceleration expressed in the frequency domain can be calculated using a Fourier transformation. This will show how the acceleration wave signal distributes over the frequency domain, rather than over time, and therefore represents the intensity of the acceleration signal in the frequency domain. This may also have the advantage that human movement is usually periodical and oscillatory and therefore analysis in the frequency domain may be more representative of real-life activity. The SI units of the frequency of the acceleration are $m^2.s^{-4}.Hz^{-1}$. The information obtained from the Fourier transformation is the relative magnitudes of the various sinusoidal signals that compose the overall accelerometer raw data time series.[111] These relative magnitudes are expressed as basis coefficients which represent the amplitudes of the different frequency components of the signal. Figure 3.4 shows how the transformation breaks down an overall, complicated signal, comprised of multiple frequencies, into the predominate contributing frequencies and can therefore reveal further information about the constituent components of the signal.[112] Plotting the amplitude of each sinusoidal term versus its frequency creates a power spectrum as shown in right hand side plots of Figure 3.4. The power spectrum shows the portion of the signal's power falling within given frequency bins. From this power spectrum, features based on the magnitude of acceleration in frequency domain can be expressed as a median frequency, as the integral of the power spectrum (or the area under the curve of the power spectrum), or as a subset of different coefficients combined to give a single feature.

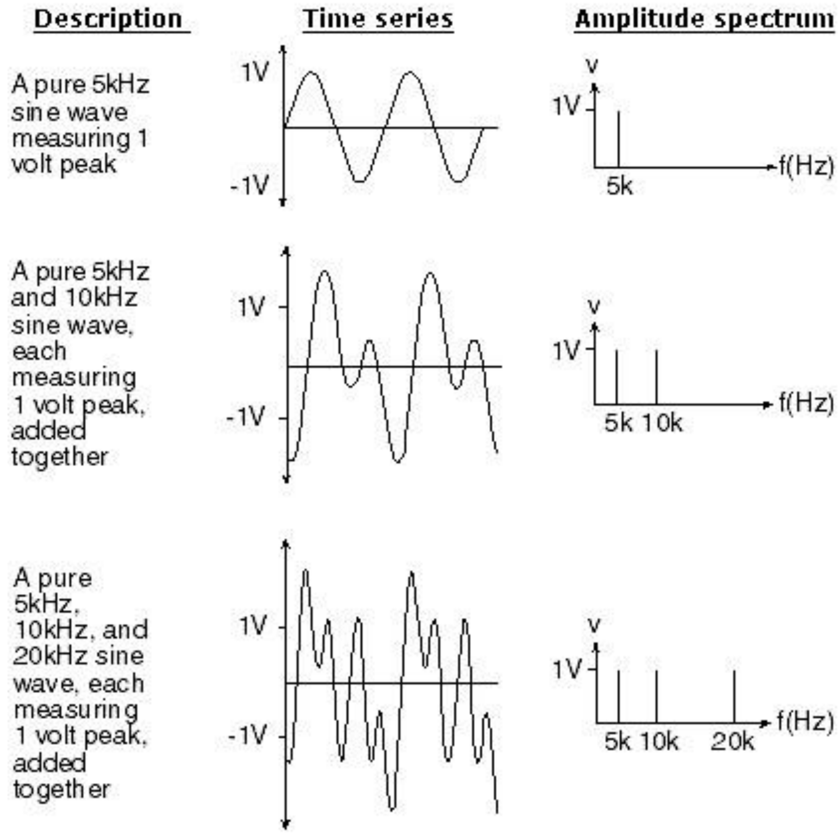


Figure 3.4 Illustrative example of the Fourier Transformation. Modified from https://www.dataq.com/data-acquisition/general-education-tutorials/fft-fast-fourier-transform-waveform-analysis.html.[112]

3.3.2 Classification schemes using accelerometry features

Activity classification using a wearable accelerometer usually involves a multi-step process of first, breaking down the sensor signal into time segments or 'windows', and then within each window, deriving features that characterise the signal. These features are then fed into a classification algorithm which associates each window with an activity type or level.[110] Features derived from the raw accelerometry data can be inputted into classification schemes, usually to try and classify a specific type of activity such as sitting or walking, or a change in posture or limb movement, or to classify a category of activity intensity. The decision for which features comprise the 'feature set' to input into the classification scheme will usually involve a feature selection method. This can range from simple visual and statistical analysis (of the differences in distribution of features for the different activities the classification scheme is trying to discriminate for), to use of a statistical method such as principle component analysis (PCA) to identify the most discriminating set of features that explain the variance in activity classification.

Several studies have been published which report the accuracy of different classification systems, but these are usually ‘bespoke’ classification schemes, created from, and relevant only to the conditions of that particular study, in terms of the type and number of activities, and the location, type and number of accelerometers worn on the body. Therefore, it is hard to find an optimal classification scheme, or feature set, to use for an activity monitoring purpose. Some of the classification schemes may have been reported to be marginally more accurate compared to another scheme, but researchers must also take into account the ease of development, and how time- and labour-intensive a particular classification scheme may be to implement.[110]

3.4 Using accelerometer data to measure movement and physical activity

Accelerometers have been studied for their ability to measure the type, frequency, duration and intensity of physical activity, in the laboratory setting and the free-living setting, using accelerometers in different body locations and multiple accelerometers. However, several key methodological considerations must be considered which will affect the collection and interpretation of the accelerometry data. These will include device placement, number of devices used, the sampling frequency, any bandwidth filters applied to exclude possible non-human movement, definition of non-wear time, what constitutes a representative period of time of monitoring, how sedentary activity and sleep are classified, and how activity intensity is classified.[108]

3.4.1 Validation using energy expenditure

The ability of accelerometers to measure physical activity intensity can be tested with validation against energy expenditure measured using direct calorimetry in a room calorimeter, indirect calorimetry in the form of a portable metabolic measurement system, or using the doubly labelled water method for the free-living environment.[113]

3.4.1.1 Validation using indirect calorimetry in laboratory conditions

Validation studies in laboratory settings have found moderate to strong positive linear correlation (r values between 0.58 to 0.92) between readings from a single accelerometer (usually on the waist, hip or thigh), and actual energy expenditure as measured by indirect calorimetry for various activities performed in a controlled manner. Level walking has the highest correlation with waist-worn triaxial accelerometers, with the Pearson r value as high as 0.99. For non-laboratory settings, use of a room calorimeter for 24-hour periods can provide validation of estimated EE for free-living activities using an accelerometer. This has shown a correlation of r = 0.54 between triaxial accelerometer (worn on the hip) calculated vector magnitude on a sedentary day, and a correlation of r = 0.74 on a day with light activity included.[114] It is known that accelerometer readings of the same activity can vary greatly between individuals, and within an individual, accelerometers can underestimate or overestimate certain activities depending on the characteristics of body movement of that individual in doing a certain activity.[105]

3.4.1.2 Validation using doubly labelled water technique in free-living conditions

There is currently no method to be able to accurately measure both the energy expenditure and patterns of activity in free-living conditions. DLW can measure TEE but not the patterns of activity. A combination of indirect calorimetry or DLW technique could be used with movement monitoring such as accelerometers or direct observation. All these methods, except for accelerometry, are impractical to perform physical activity measurements in daily life over long periods of time. The validity of accelerometers to estimate free-living activity related energy expenditure (AEE) can only be tested using DLW as the gold standard technique to measure free-living energy expenditure.[108] In a review of eight different accelerometers by Plasqui and colleagues, the most extensively studied commercially available accelerometer was the Actigraph, a uniaxial accelerometer worn on the lower back or hip of healthy individuals.[113] The Actigraph had a correlation with activity related energy expenditure (AEE) derived from the TEE using DLW over 7–14 days, ranging from r = 0.30 to r = 0.96. In another seven-day study of comparing AEE measured using DLW, and waist-worn accelerometry; regression equations using accelerometer counts underestimated energy expenditure by between 35% and 59% depending on the accelerometer used.[115]

Free-living validation studies using DLW will apply to the population studied, and may have poor external validity for other populations of generally lower or higher activity level.[113] Few validation studies have been done using older people or those with illness. A study of 13 people with COPD using an Actireg accelerometer on the chest and thigh showed a correlation of r = 0.82 to DLW measured AEE using both accelerometer counts and the individual’s REE as independent variables.[116] The contribution of the accelerometer readings to the overall correlation was actually r = 0.4.124.[116] Another study of 28 older people wearing a Tracmore triaxial accelerometer on the lower back for 14 days showed a correlation of r = 0.78 between accelerometer counts and AEE measured using DLW.[117] Although correlations are moderately strong, the evidence base appears to show a general trend for accelerometers to underestimate energy expenditure in free-living monitoring, which can be an underestimation of as much as 60%.[115,118,119]

3.4.1.3 Limitations of accelerometers to estimate energy expenditure of physical activity

Using a single point of acceleration cannot distinguish between certain activities, which may produce the same activity counts, but involve very different levels of effort, or associated MET values for the individual, even before the variation due to relative intensity is factored in. Waist-worn accelerometers underestimate energy expenditure for a number of reasons, including: insensitivity for upper body movements, sustained standing posture (which appears as static acceleration or no movement, but does expend more energy than being sedentary or sitting), vertical work such as stair climbing, pushing or pulling objects (where large movements are not produced centrally), carrying weighted objects, non-weight bearing exercise such as cycling, and physical activity in water (if the device is usable in water). In free-living accelerometry, without GPS information on the distance travelled and speed, it can be hard to quantify a period of activity in terms of intensity and energy expenditure.

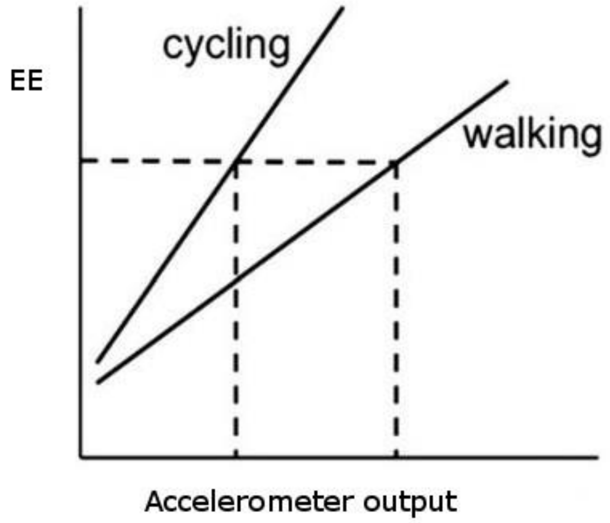


Figure 3.5 Relationship between accelerometer output i.e. counts and energy expenditure (EE) for cycling versus walking for an accelerometer located at the lower back or chest. Accelerometer output will increase at a greater rate related to increased intensity or energy expenditure related to walking activities compared to cycling. Modified from Plasqui and colleagues, 2017.[120]

Accelerometers have been shown to underestimate energy expended from running activity, even on a treadmill, at higher running speeds. Linear regression models may therefore be appropriate for certain activities, but many activities will display a non-linear relationship between accelerometer readings and energy expended as illustrated in Figure 3.5.[105] Activities of daily living (ADL) , such as housework, gardening, ironing often will show a non-linear relationship between accelerometer counts and measured energy expenditure. More work is needed on determining which features of the raw accelerometer signal are useful for estimating energy expenditure related to activity, or for classifying specific types of activities.[105]

3.4.2 Sensor positioning

In addition to the possible benefit of using triaxial over uniaxial accelerometers, some investigators have experimented with using different body positions, or multiple body positions for sensor positioning. Most of the studies using first generation accelerometers were positioned on the waist or hip.[105] Information from both upper and lower body movements can be combined if an accelerometer is placed both at the hip and the wrist. One study showed this produced a small, but significant, improvement in estimation of energy expenditure compared to using a hip sensor alone, but accelerometer readings could still only explain 34% of the value of energy expended during activities (r^2= 0.34) in a bivariate regression model.[121,122] There is also the potential for soft-tissue motion at the waist location to create significant errors for belt-worn accelerometers.[123]

There is no optimal single sensor placement for all activities of daily living and using more than one sensor is likely to be cumbersome for the participant. In general. walking and hand movements can be accurately classified approximately 60% of the time with a dominant wrist single accelerometer, although the hip location is better for detecting running (98%) and lying down (87%) and sitting (66%).[124] The wrist location stays fairly fixed during running and change of posture from lying to sitting to standing. The chest location is best for classifying activities that involve leg motion or change or posture such as squatting (76%) and standing (78%).The chest location may provide the best overall activity recognition accuracy (62%), and the addition of a second accelerometer on the hip or wrist can improve classification accuracy by approximately 20%.[124] Therefore, sensor location may best be decided by the activity level of the population studied. For healthy participants with a likely high activity level, sensors on the arm, ear and leg would be best for classifying higher intensity activities. For a low level activity population, such as the major surgery population, accelerometers worn on the chest, waist and wrist appear to be better for classifying low level activities.[109]

3.4.3 Combining accelerometry with heart rate monitoring

Some studies have shown improved predictive accuracy by using a combination of accelerometry measured movement and heart rate monitoring to using either alone. However, the evidence base for the added value of heart rate monitoring to increase predictive accuracy for the intensity of activity or energy expenditure is weak. A study of five triaxial accelerometers worn in different body locations on 21 people, during a set of laboratory-controlled activities of walking, cycling and rowing, showed that the addition of heart rate data, including accounting for change from resting heart rate only improved subject dependent recognition of activity type by 1.2% and subject-independent training by 2.1%.[125] This inaccuracy was largely due to the lag in heart rate from when the physical activity started. Using heart rate for physical activity assessment may require fitting individual curves for EE prediction and controlling for various factors, including fatigue, hydrational state, body temperature, emotional state and current medications; as well as taking into account that heart rate is not a good predictor of EE at low levels of activity.[106]

3.5 Summary of thesis introduction

Introduction: Measuring physical activity using accelerometers

These first two introductory chapters have met the following two aims of the thesis:

- To evaluate current methods of assessing cardiorespiratory fitness in preoperative patients and how this can be improved
- To consider how daily physical activity may be a useful measure of physical fitness in the context of preoperative assessment and optimisation.

The following points summarise the background and gaps in the literature discussed in this introduction that forms the basis of this thesis:

- Preoperative assessment tools to measure baseline functional capacity and patient fitness are limited and are mainly designed to provide information for clinicians.
- Physical fitness is closely related to physical activity, and increasing physical activity is a key component of exercise intervention in prehabilitation to reduce risk from surgery for high-risk, unfit patients.
- The relationship between daily physical activity and physical fitness in this population is not known.
- Tools to assess physical activity have evolved from calorimetry and activity questionnaires to the current availability of wearable accelerometers and heart rate monitoring.
- The utility of wearable accelerometers in the preoperative setting has not previously been investigated and is not known whether daily physical activity measured by an accelerometer bears any relation to patient fitness.
- The understanding of how the raw data collected from wearable accelerometers can be used to represent physical activity is also not well understood in the free-living, patient setting.

- This can be investigated by comparison to CPET measurements in preoperative patients which forms the basis of the first clinical study of this thesis.
- If there is a relationship between physical activity as measured using an accelerometer and physical fitness, then the use of activity monitoring as part of prehabilitation may provide a useful tool to improve patient adherence and measure outcomes of exercise intervention. This forms the basis of the second clinical study of this thesis.
- Previous prehabilitation studies have highlighted problems with being able to monitor and prescribe a certain ‘dose’ of exercise. Activity monitoring using wearable accelerometers could help solve this problem.

4 Clinical study of physical activity levels before and after surgery

4.1 Rationale

The clinical need behind the research in this thesis is the identification and optimization of high-risk patients for major elective non-cardiac operations to improve the outcomes of these patients at high risk of peri-operative morbidity and mortality. These patients often have reduced functional reserve and a reduced ability to increase oxygen flux to meet postoperative demand.[21] Pre-operative assessment of the patient's functional reserve for surgery aids individual risk stratification and provides the basis on which pre- and peri-operative interventions can be implemented to improve postoperative outcome.

If interventions to improve patient cardiorespiratory fitness before surgery are to be targeted effectively, measures of both patient physical activity and physical fitness are needed to assess the need for intervention, the capacity for improvement, and the resultant change in patient functional reserve.[43] Although daily physical activity levels do not directly measure cardiorespiratory reserve, there is increasing evidence of the graded relationship between physical activity levels to cardiorespiratory fitness, chronic disease and risk of premature death. Trial evidence has shown that improving activity levels, as measured by self-reported physical activity, results in improved cardiorespiratory levels as measured by peak oxygen consumption during CPET.[64]

Wearable accelerometers are a relatively cheap method for objectively measuring patient activity and can assess the efficacy of exercise programs.[85,99,126,127] Tri-axial accelerometry provides accurate and sensitive data on the duration, frequency and intensity of activity that is more detailed than pedometers and questionnaires.[128] Given the ability to provide rapid and detailed feedback on activity levels, as has been demonstrated in commercial wrist worn devices, wearable accelerometers also have the potential to change behaviour in patients such as increasing exercise. In controlled environments accelerometers have been shown to be discriminative of different activity types and intensities, with good correlation to measured energy expenditure.[129] However, accelerometers have not previously been used to assess fitness before major surgery. This study aimed to increase the understanding of how to interpret accelerometry features of daily physical activity in the preoperative period, in terms of what level of physical activity can be expected from this kind of population, and whether this correlates to an objective assessment of exercise capacity in the form of preoperative CPET.

The other main research area of this study was to find if postoperative surgical outcomes, as measured by Patient Reported Outcome Measures (PROMs) correlated with postoperative physical activity. This study used activity monitoring in the post-operative period in conjunction with existing validated PROMs questionnaires to give an objective measure of change in activity levels after the operation. Activity parameters can then be correlated to patient reported outcomes and perception of quality of life and thus ascertain to what degree the questionnaires accurately reflect actual activity. This can provide information on the possible utility of using activity monitoring using an accelerometer in the postoperative period, in addition to collecting data on clinical outcomes and patient-reported outcomes.

4.2 Study objectives and outcome measures

Objectives	**Outcome Measures**	**Measurement method and timepoint**
Preoperative period		
The acceptability and feasibility using a wearable accelerometer in the preoperative period to determine the preoperative physical activity level of patients.	How many days the accelerometer was worn. Study dropout rate. Patient questionnaire on the acceptability of wearing the accelerometer. Any adverse events or patient complains regarding the use of the accelerometer.	Accelerometer data and time stamps to determine wear time. Patient paper questionnaire completed at the end of the three-day preoperative home activity monitoring period.
To explore the associations between accelerometer variables measured at home with results from cardiopulmonary exercise testing (CPET) and patient self-reported activity levels.	Pearson r correlation value between CPET parameters and accelerometry features and the DASI and SF-12 PCS questionnaires.	Results reported by an anaesthetist performing a CPET test as part of the patient's standard preoperative care. Physical activity measured using a chest mounted AX3 triaxial accelerometer worn for three days in the preoperative period after CPET clinic attendance. Accelerometry features will be used as extracted from raw accelerometer data averaged for each day and over three days.
To investigate the ability of accelerometry features to discriminate for higher-risk patients	Difference in means testing of the distribution of accelerometry features between patients who would be considered high-risk for surgery based on CPET thresholds for $\dot{V}O_2$peak < 15 $ml \cdot kg^{-1} \cdot min^{-1}$ or AT < 11 $ml\ O_2 \cdot kg^{-1} \cdot min^{-1}$.	
To identify which accelerometry features are useful as summary measures of daily physical activity in the preoperative fitness testing context.	Based on strength of the Pearson r correlation value between CPET parameters and accelerometry features. Multiple regression analysis of the contribution of accelerometry features to predict for higher-risk patients based on CPET thresholds of $\dot{V}O_2$peak < 15 $ml \cdot kg^{-1} \cdot min^{-1}$ or AT < 11 $ml\ O_2 \cdot kg^{-1} \cdot min^{-1}$.	

Objectives	Outcome Measures	Measurement method and timepoint
Postoperative Period		
To explore if there was a relationship between patient self-reported function and quality of life measures and physical activity levels as measured using an accelerometer before and after surgery.	Pearson r correlation value between patient questionnaire scores, activity monitoring variables and CPET variables.	Patient completed questionnaires (DASI, SF-12 and EQ-5D) before and after surgery. Physical activity measured using a chest mounted AX3 triaxial accelerometer worn for three days at approximately 3 months postoperatively compared to the activity variables measured preoperatively.

4.3 Ethics

Ethical approval was obtained from the East of England Regional Ethics Committee prior to study commencement (14/EE/1192).

4.4 Study design

This was an observational study conducted as a collaboration between the Nuffield Department of Surgical Sciences (NDS) at the University of Oxford, and McLaren Applied Technologies (MAT). The NDS team designed the study, recruited the patients, and performed all patient related study procedures. The accelerometers were provided by MAT and post-processing of raw accelerometry data and feature generation was performed by MAT. Study results were analysed by me and engineers at MAT.

4.4.1 Selection of the patient population

The patient population of interest were those scheduled for major elective non-cardiac surgery. Due to the major nature of the surgery, these patients are already at higher risk from surgery, and therefore require more intensive preoperative assessment and investigation. Recruiting patients from those who have been referred to the CPET clinic aimed to capture those scheduled for major surgery and or deemed to be a higher risk of surgery. At the time of the study, all patients requiring abdominal aortic aneurysm (AAA) repair were referred for CPET as part of the decision-making process for open or endovascular repair of AAA. Most patients being considered for Whipples, oesophagectomy and major abdominal wall repair surgery were also being referred for CPET. However, this was at the surgeon's discretion. Eligible study participants were patients scheduled for elective surgery and referred for CPET at the John Radcliffe or Churchill Hospital, Oxford.

4.4.1.1 Inclusion criteria

- Participant was willing and had capacity to give informed consent for participation in the study.
- Male or Female, aged 18 years or above.
- Was on the waiting list for an elective operation that requires preoperative CPET. Elective operations could include abdominal, vascular or head and neck surgery.

4.4.1.2 Exclusion criteria

The participant was excluded from the study if ANY of the following applied:

- Patients who are not able to mobilise independently before the operation. This will be patients who can only mobilise with a wheelchair or who are bedbound as activity monitoring will not reflect their physical activity.
- Patients without capacity to give informed consent for participation in the study.
- Patients who were in prison.

4.4.2 Study procedures

The overall study design was a feasibility and observational study into use of an activity monitor for perioperative assessment.

The duration of participation was four months. There was no change to routine clinical care for the patient and no extra visits to the hospital were required. Patients were recruited at the time of their CPET appointment and provided with the Patient Information Leaflet (see Appendix A.i). After providing informed consent to participate in the study, they completed three preoperative questionnaires to self-report their physical activity, daily function and quality of life. After their CPET clinic, the patients wore the activity monitor home and were asked to continue to wear it for three days. The patient was then followed up using medical records to determine if they went on to have their operation and the postoperative course including length of stay, complication event rate and severity. At approximately three months after the operation, the participants were contacted and posted a set of postoperative questionnaires to complete, as well as the accelerometer to wear for 3 days continuously at home. On completion of the postoperative questionnaires and monitoring, the patient posted this back to the researcher and their involvement in the study ended.

4.4.2.1 CPET

As part of their standard preoperative assessment each patient underwent CPET at one of two hospitals conducted by one of four consultant anaesthetists according to a standardised protocol. Tests were conducted on a cycle ergometer (Ergoline 200P) connected to a 12-lead electrocardiogram, oxygen saturation monitor and continuous non-invasive blood pressure cuff. Results were compiled by Breeze (Medgraphics, UK) software and presented in standard 9-panel format. Anaerobic Threshold (AT) was determined after each test using the V-plot technique and confirmed by ventilatory equivalents. $\dot{V}O_2$peak was measured as the highest $\dot{V}O_2$ attained over a 10-second period at peak exercise. As recommended by previous studies covering a similar range of operations, a $\dot{V}O_2$peak cut-off value of < 15 $ml.kg^{-1}.min^{-1}$ and an AT cut-off value of < 11 ml $O_2.kg^{-1}.min^{-1}$ were used to assign patients to the higher risk category.[12,49,130]

This study used the terminology for the group of patients at higher risk for surgery the 'unfit' group, whereas those who are relatively fitter, with values of $\dot{V}O_2$peak ≥15/ $ml.kg^{-1}.min^{-1}$ or AT ≥11 ml $O_2.kg^{-1}.min^{-1}$, were termed the 'fit' group of patients. Therefore, within each category of VO_2peak or AT, there were a group of 'unfit' patients and a group of 'fit patients'. Other parameters collected from CPET were: peak power; the ventilatory equivalent for carbon dioxide (determined as a ratio at the anaerobic threshold); oxygen consumption normalised to body size ($kg^{-0.83}$); and the predicted values for peak oxygen consumption and ventilatory equivalents for oxygen and carbon dioxide (normalised to patient sex, age, height and weight).[131]

4.4.2.2 Activity monitoring

Choice of accelerometer

The choice of accelerometer for this considered patient usability, requirement for a battery life of at least several days, wearability and durability. The device chosen for this study, the AX3 (Figure 4.1), had the advantage of being small, with a battery life that can continuously record for 21 days, and waterproof so it can be worn continuously without the need to remove it. The device is easy to affix to the chest with an adhesive plaster and requires no switching on or charging by the user. This aimed to make data capture as reliable as possible whilst the device is being used by the patient with no need for input from the researcher. The AX3 is smaller and lighter than the RT3 and the Actigraph and can be worn in several different body locations. The AX3 device (Version 1.3 released in July 2014, made by Axivity, Newcastle, UK) is a Micro-Electromechanical System (MEMS) based accelerometer that measures the specific force in three axes (X, Y and Z). Table 3.1 provides the summary specifications of the AX3 device. For this study, the configurations were set to a sampling rate of 100 data points per second (100Hz), and the acceleration range was ± 8*g* for each axis. These settings were applied based on McLaren Applied Technologies (MAT) experience of capturing human movement without recording too much noise or non-human movement. The raw accelerometer data is downloaded as a CWA (Castelware Inventory Hardware / Software Audit File, Castelware GmbH) file which MAT then ran data analysis using the mathematical software MATLAB.

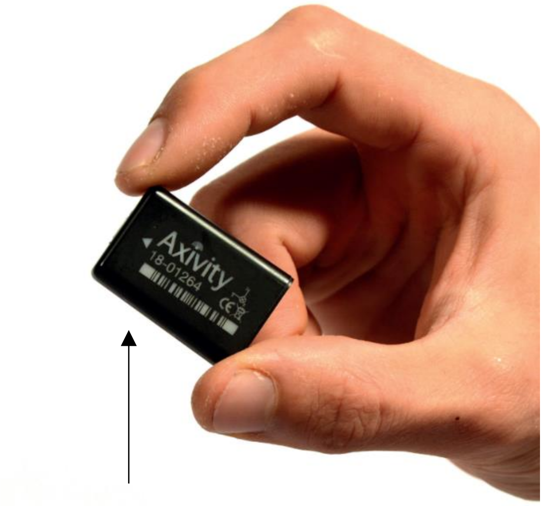


Figure 4.1 Photograph of the Axivity AX3 accelerometer, modified from the Axivity website (https://axivity.com/product/ax3).[91]

The angle of the body relative to the horizontal plane can be inferred from the acceleration in the three axes measured by the AX3. This depends on accurate orientation of the accelerometer worn on the body. Orientation of the device was inferred from the 'USB' sensor axis, i.e. the location of the USB on the device, which, should be approximately vertical, if the accelerometer is attached to the chest with the USB pointing to the floor. The acceleration on the USB sensor axis should be close to 1*g* when the wearer is standing or active. All sensor orientations were checked by comparing data in the axis to expected data when the subject is awake versus asleep. Any sensors which appeared to have changed orientation during the monitoring period, because the patient may have removed it and reattached it, were corrected by transforming the data.

Analysis of raw accelerometry data and generation of accelerometry features by MAT

The raw accelerometry data was analysed both as continuous data (of 100 data points per second) for the purposes of calculating the *Mean Magnitude of Acceleration*, the direction of acceleration and *Mean Tilt Angle*; and as data packaged into windows of ten seconds to produce summary measures of the *Activity Score* and classification into *Activ*e, *Lying* or *Stationary* for each window.

For the activity variables generated from the analysis of the data as a continuous stream of data points, the summary values for the variables were averaged over the total accelerometer wear time. This was defined as the total period of time of whole 24-hour periods (or highest number of integer days) the accelerometer was worn for continuously. This includes days with more than 23 hours of accelerometer wear. We did not analyse data from days when the accelerometer was worn for less than 23 h, to avoid misrepresentation of daytime and night-time activity.

The *Magnitude of Acceleration* was calculated as the average of the magnitude of the accelerometer vector in the x, y and z plane in milli-gravity units. The *Mean Magnitude of Acceleration* was the mean value across the total accelerometer wear time. The direction of acceleration was calculated from the *Mean Magnitude of Acceleration*, represented in the x-y-plane, or approximately the forwards and backwards plane, and also the z-plane, which is the vertical or up and down plane, when the person is standing up. These variables give the direction of acceleration denoted as *Acceleration in the Lateral Plane* and *Acceleration in the Vertical Plane.* The *Mean Tilt Angle* has also been calculated from the accelerometry data as another representation of the direction of acceleration. This is the tilt angle of acceleration relative to the horizontal plane, measured in radians, averaged over all angles measured over the total accelerometer wear time. This angle is measured relative to the horizontal plane.

For analysis using windowed data, each 10-second window was used to calculate an *Activity Score* by MAT. The *Activity Score* is derived from the calculation of the power spectrum of the magnitude of acceleration in the frequency domain. The *Activity Score*, measured in $g^2.Hz^{-1}$ was calculated from the integral between 1Hz and 10Hz of the power spectrum derived from the Fourier Transform of the *Magnitude of Acceleration*, averaged across all windows in the total accelerometer wear time. Therefore, the activity score attempts to represent the intensity of movement, as a summation of the frequency domain representation of the accelerometer magnitude. The activity score summarises the distibution of the frequency peaks of the acceleration signal rather than just the magnitude of acceleration averaged over the 3 axes. The range limit of 1 Hz to 10Hz was used for the signal frequency to ensure human movement was captured.

Furthermore, for each 10-second window of raw accelerometry data, the window was given a categorical classification of *Lying*, *Stationary* or *Active*. *Lying* was defined by the data showing a mean tilt of above 0.90 radians. The tilt angle of acceleration is measured relative to the horizontal plane of zero radians. If the person wearing the accelerometer was upright the tilt angle would be closer to the vertical plane of 1.6 radians.

Active was defined by the *Activity Score* being above 254 $g^2.Hz^{-1}$ for that window. All other windows not classified as *Lying* or *Active* were classified as *Stationary*. These thresholds were based on a random forest classifier that was previously trained on a wide population of healthy individuals by MAT.

Analysis of raw accelerometry data by the Open Movement GUI application (OmGUI)

Further analysis of the raw accelerometry data in the preoperative period was performed using the open source software available for the AX3 Axivity accelerometer, the Open Movement GUI Application (OmGUI, version 1.0.0.43, Open Movement, Newcastle University, UK).[132] This is an application with a graphical user interface which allows visualisation of the accelerometer data graphically (see Figure 4.2) and has embedded algorithms developed by academic groups to generate summary measures of activity from the activity data. This acted as a comparator the analysis performed by MAT to test whether traditional methods of activity analysis based on the initial AX3 validation datasets were similar to results produced by the MAT analysis method.

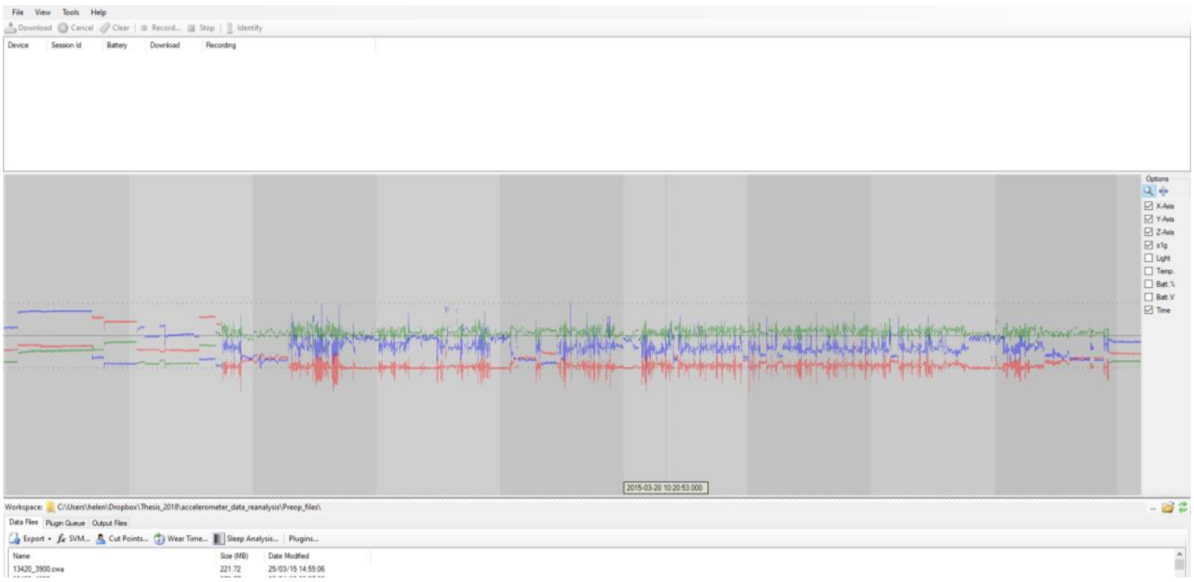


Figure 4.2 Example screenshot of the OmGUI software showing acceleration in the three axes over time.

Non-wear periods were identified using a combination of the wear time validation tool provided in OmGUI and the patient diary of when the accelerometer was worn. The OmGUI wear time validation algorithm is estimated from the standard deviation and range of each accelerometer axis calculated over 30-minute periods. Each 30-minute period is classified as non-wear time if the standard deviation was less than 3.0 m*g* for at least two out of the three axes, or if the value range, was less than 50 m*g*.[133]

The raw accelerometry data was processed as a .cwa file by the OmGUI software to generate the average vector magnitude (or SVM for signal vector magnitude as named by OmGUI) calculation for each epoch of 60 seconds.[103] This signal vector magnitude calculation takes the accelerometer vector length from the Euclidean distance of the three accelerometer axes and subtracts 1 *g* expected from gravity while stationary.

$$\mathrm{SVM} - 1 = \sqrt{(x^2 + y^2 + z^2)} - 1$$

A fourth-order Butterworth band-pass filter between 0.5Hz and 20Hz to improve the signal to be filtered for only frequencies of human movement. The SVM and the standard deviation of the SVM was summarised as the average SVM in m*g* units over 72 hours of wear time. Where patients have worn the accelerometer for more than 72 hours, the initial 72 hours is used. If the total wear time was under 72 hours, the missing hours are supplemented using data from the previous days' activity.

A further function of the OmGUI software was utilised to produce a summary measure of amount of time spent in different activity intensities. The OmGUI cut-point analysis for activity intensity classification is based on previous validation studies using the AX3 and are available for different wear locations. Although the chest location is not one of these, the waist location is one of the algorithms available and this was used to give an estimate of time spent in different activity intensities. This is based on a validation study of a similar GENEA accelerometer worn on the waist using a belt in the mid clavicular line over the right hip in a sample of 60 male and female volunteers aged 40-65 years.[103] A portable gas analysis system was used to estimate energy expenditure whilst the participants performed 10-12 structured activities in both the laboratory and free-living environment. The OmGUI cut-point analysis compares the signal vector magnitude over 60 seconds against cut-points found in this validation study for the AX3 in the waist location to classify each epoch of data as sedentary, light, moderate or vigorous intensity activity level. The average number of hours per day for each activity intensity category over a 72-hour wear period was produced for each patient from their preoperative monitoring data.

Summary measures of activity based on accelerometry features analysed by MAT

In addition to the average activity amount recorded per day, other summary measures of activity were also computed from the activity score for each 10 second window and the total activity summarised for a 24 hour period and then averaged for the whole monitoring period either as a weighted mean, minimum or maximum (summarised in Table 4.1). These measures included the *Maximum Activity Score* recorded, and the *Maximum Time Active* (the maximum time recorded of consecutive windows of data being classified as *Active*). Means were weighted by the hours of wearing and data was excluded if the device was worn for less than 8 hours in a 24-hour period as we deemed that it would not be representative of a patient’s daily activity.

Activity parameter	**Description**	**Method of summarising the activity parameter across the entire monitoring period**
Mean Activity Score (AS)	Total activity measured weighted for the number of hours worn each day.	Weighted mean
Standard deviation of the Activity Score (SDAS)	Standard deviation of the Activity Score weighted for the number of hours worn each day. A measure of the variability of the level of activity for each participant during each day.	Weighted Mean
Maximum Activity Score	Maximum Activity Score recorded at any point during monitoring period.	Maximum
%Active %Stationary %Lying	The proportion of windows in which the accelerometer data was classified as Active, Stationary or Lying.	Weighted mean
Maximum Time Active (mins)	The maximum number of minutes of continuous activity, as defined by windows classified as Active, recorded over the whole period of monitoring.	Maximum
%ASO>500 %ASO>1000	The percentage of time the participant achieved an Activity Score of over 500 or 1000.	Weighted mean
MCTAS>500 (mins) MCTAS>1000 (mins)	The maximum continuous time in minutes, over the whole period of monitoring, of data windows with an Activity Score of over 500 or 1000.	Maximum

Table 4.1 Description of the summary measures of activity derived from the accelerometry data

Categorizing the activity score based on activity score thresholds was problematic as we had not validated the activity score against objectively measured METs for each participant. Based on preliminary work of wearing the accelerometer myself (Table 4.2), for a series of controlled activities each lasting five minutes, we could establish approximate thresholds for the *Activity Score* in differentiating between sedentary to walking type activities. Although the classification of *Active* for each window is based on an activity score of above 254, established on healthy volunteer data by MAT, this is using a low threshold for activity for the purpose of distinguishing *Active* from completely *Stationary*. Based on the Activity Score ranges in Table 4.2, the Activity Score was also summarised as the proportion of time (%ASO>500 and %ASO>1000), and maximum continuous time spent in an Activity Score of above 500 or 1000 (MCTAS>500 and MCTAS>1000). Although no relation to specific activities or activity intensities can be inferred using these *Activity Score* thresholds of 500 and 1000, the time spent above these thresholds can give an idea of the time spent in activity that is unlikely to be sedentary in intensity.

Activity description	**Activity Score ranges measured ($g^2.Hz^{-1}$)**
Sitting (still/eating/at desk)	<300
Hoovering	<750 (short peaks above 1000 for 1min)
Laundry	<2000
Washing Up	<2000
Gardening	<1300
Walking (2mph)	<900
Walking (3mph)	<4700
Walking (4mph)	6000 - 8000
Jogging (5+ mph)	>10,000

Table 4.2 Activity Score Thresholds based on wearing the AX3 accelerometer in the chest location for a series of 5-minute activities.

4.4.2.3 Patient questionnaires

At the time of recruitment, the patient was asked to complete the following preoperative assessment questionnaires: Dukes Activity Status Index (DASI), the EQ-5D with the EQ-VAS and the SF-12 questionnaires (see Appendix A). These questionnaires were chosen to represent the activity, function and quality of life domains of patient reported outcomes from surgery. Patients also completed a questionnaire on the acceptability of using the accelerometer at the end of the study (Appendix A.ii)

The Duke Activity Status Index (see Figure 2.3) asks the patient a series of yes / no questions on whether they can perform activities of varying MET levels, with a maximum score of 58.2.

The DASI has designed as a questionnaire to assess exercise capacity, by trying to estimate the maximum number of METs a patient can achieve and thereby predict their maximum oxygen consumption.[35]

The EQ-5D (Appendix A.iii) is a widely used functional questionnaire to assess generic health status across five domains remains to function in daily life. It is an often-used standardized instrument as part of patient reported outcome measures (PROMs) for operations, as well as having proven validity and reliability over a range of health conditions. The EQ-VAS is a visual analogue scale which asks the patient to rate their own health on a scale of 0 to 100, and is a quantitative way of the patient assessing their own health status or outcome.[134]

The SF-12 (Appendix A.iv) is another generic health survey that comprises of 12 questions covering eight health domains which contribute to a summary Mental Component Score (MCS) and Physical Component Score (PCS) of the SF-12. The total score can range from 0 to 100. The score of the MCS and PCS is norm based, so that 50 is the average score for that age, and therefore scores can be compared to the expected 'mean' value for the population at the same age, as well comparing repeated scores for the same patient.[135]

4.4.2.4 Patient clinical information

Patient baseline clinical information including age, sex, height, weight, medications, comorbidities, smoking history, any mobility problems were collected from the medical notes. Additional information collected from the patient medical records included: the nature of the operation scheduled, the operation date, and postoperative outcomes including length of stay, number and nature of any in-patient complications and mortality. In-patient complications were classified according to the Clavien-Dindo classification system of adverse events following surgery. This system is widely adopted by surgical specialties to grade postoperative complications due to its high interobserver agreement, and strong correlation with patients', nurses' and doctors' perception of the severity of the complication. Table 4.3 describes the different Clavien-Dindo complication grades, and is based on the table from Dindo, Demartines and Clavien, 2004.[136]

Clavien-Dindo Grade	Definition
Grade I	Any deviation from the normal postoperative course without the need for pharmacological treatment, or surgical, radiological or operative intervention.
Grade II	Requiring for pharmacological treatment with drugs other than such allowed for Grade I complications.
Grade III	Requiring surgical, endoscopic or radiological intervention.
Grade IV	Life threatening complication requiring intensive care management.
Grade V	Death of a patient.

Table 4.3 Classification of surgical complications using the Clavien-Dindo system. Based on information from Dindo, Demartines and Clavien, 2004.[136]

4.4.3 Sample size

No formal sample size calculation was required as this was a feasibility study. However, given that the main outcome was the correlation between two variables, of activity monitoring and CPET, a sample size could be approximated from the requirement of a clinically meaningly expected Pearson's correlation coefficient $\geq$ 0.4. Using a power of 0.8 (beta = 0.2) and alpha = 0.05, this would produce a required sample size of 47 cases. Similar previous studies have also used 50 patients as the sample size to compare different assessment methods of exercise capacity.[137,138]

4.4.4 Statistical analysis

Pairwise relationships were analysed between questionnaire, activity monitoring and CPET results using Pearson's correlation coefficient. Comparison of ranks between groups of 'fit' or 'unfit' categorizations based on CPET results of $\dot{V}O_2$peak and AT, was performed using either t-test for parametric data or the Mann Whitney U test non-parametric data. Binary logistic regression analysis (using the 'Enter' method) was used for identifying the contributing activity monitoring variables to predicting for categories of 'fit' or 'unfit' patients based on CPET measured $\dot{V}O_2$peak cut-off value of < 15 $ml.kg^{-1}.min^{-1}$ or an AT cut-off value of < 11 ml $O_2.kg^{-1}.min^{-1}$. Variables which were most predictive on single variable binary logistic regression testing were chosen to be included in the model. Regression diagnostics were used to check that assumptions of linearity, multicollinearity, independence of errors, homoscedasticity and normally distributed errors were not violated. Post-operative results were analysed using the Kruskal-Wallis test for independent non-parametric data with more than 2 groups, for example comparing across grades of complication severity. The Wilcoxon signed rank test was used to test for differences in results within the same patient from the pre- to the post-operative period. Analysis was performed using SPSS (version 22.0, SPSS for Windows, Chicago, USA), Matlab (MATLAB and Statistics Toolbox Release 2013b, The MathWorks Inc, Natick, Massachusetts, USA) and R-3.2.4 (R Foundation for Statistical Computing, Vienna, Austria).

4.5 Results

4.5.1 Feasibility results

Over the period November 2014 to May 2015, patients were screened from a total of 21 CPET clinics. Of the 53 patients eligible for the study after screening, 3 declined to participate for reasons related to the burden of being part of the study. In the follow-up period, 36 patients underwent their operation, of which 31 patients completed follow-up questionnaires and activity monitoring. Of the six patients which did not complete postoperative follow-up assessments, one patient completed the questionnaires, but the accelerometer posted back had no activity monitoring data and five patients were not able to be contacted after their operation. All 50 patients completed the questionnaire of acceptability of wearing the accelerometer. All but one patient expressed that they had ‘No problems with wearing the device' and that they would find it acceptable to wear the device again in the future. One patient expressed that they had 'Slight discomfort or inconvenience' with wearing the device and that they would not find it acceptable to wear the device again. When probed about this, it was related to the feeling of wearing the device and needing to reattach with an adhesive plaster which was sometimes painful on removing the plaster. However, this same patient did agree to participate in the post-operative monitoring.

Each day of activity monitoring was counted as the 24 hours from the time the accelerometer was attached during the CPET clinic. The final day of wearing the accelerometer is only counted if at least 8 hours of monitoring has occurred. In the preoperative period, the accelerometer was worn for a mean of 3.17 days (SD = 0.38) with all patients wearing the monitor for at least 48 hours. 36 participants wore the monitor for at least 3 days (Table 4.4). Postoperatively, the accelerometer was worn for a mean 3.13 days (SD = 0.49), with just one patient wearing it for less than 48 hours. 25 out of 31 patients wore the accelerometer for at least 3 days.

Preoperative monitoring period (days)	Mean monitoring period (Standard deviation)	No. of patients
Less than 3	2 days 19 hrs (4.8 hrs)	14
3	3 days 1hr (1.6 hrs)	20
More than 3	3 days 16 hrs (5 hrs)	16

Table 4.4 Compliance with wearing the accelerometer in the preoperative period.

4.5.2 Study patients and baseline assessments

48 out of 50 patients completed the full CPET protocol and all 50 patients wore an accelerometer at home. The 2 patients who did not complete CPET were unable to use the bike due to mobility restrictions. Given the evidence for the inability to complete CPET having similar prognostic value to those deemed as 'unfit' with AT < 11 ml $O_2.kg^{-1}.min^{-1}$, these two patients were thus classified as higher risk or 'unfit' patients (into the same category as those who achieved CPET results of $\dot{V}O_2$peak < 15 $ml.kg^{-1}.min^{-1}$ and AT < 11 ml $O_2.kg^{-}$

$^{1}.min^{-1}$).146 All patients successfully completed the preoperative DASI and EQ-5D questionnaire. One patient did not complete the preoperative EQ-VAS and two patients had incomplete preoperative SF-12 questionnaires. Table 4.5 summarises the preoperative baseline patient characteristics, CPET and questionnaire results.

Age showed moderate correlation with both AT and $\dot{V}O2$peak. Spearman's rank correlation coefficient for the relationship of patient Charlson Comorbidity Index (CCI) with CPET showed a weak correlation between CCI and $\dot{V}O_2$peak ($r = 0.30$, $p = 0.037$) and no statistically significant relationship with AT ($r = 0.17$, $p=0.25$). On independent samples T-Test, there was no significant difference in AT and $\dot{V}O_2$peak values between males (n=41) and females (n=7).

	Mean (SD)	Range
Patient characteristics		
Age (years)	70.9 (9.9)	46–90
Sex Male: Female (%) *	42 (84): 8 (16)	
BMI (kg/m^2)	27.8 (7.14)	17–48
Charlson Comorbidity Index	4	1–9
Smoking status positive (%) *	46 (92)	
ASA*		
I	5 (10)	
II	26 (52)	
III	19 (38)	
CPET results		
$\dot{V}O_2$peak ($ml.kg^{-1}.min^{-1}$)	16.70 (4.63)	8.1–28
$\dot{V}O_2$peak adjusted for body mass ($ml.kg^{-0.83}.min^{-1}$)	34.9 (9.5)	16.8–58.4
AT ($ml\ O_2.kg^{-1}.min^{-1}$)	11.50 (2.72)	7.5–18.3
Peak power (Watts)	102.2 (34.5)	52–201
Ventilatory equivalent of O_2		
Observed	31.9 (6.7)	21–51
Predicted	30.0 (1.4)	27–33
Ventilatory equivalent of CO_2		
Observed	31.1 (5.3)	22–52
Predicted	30.0 (1.4)	27–33
Questionnaire results		
Duke Activity Status Index (DASI) score (0 to 58.2)	37.64 (14.8)	1.75–58.20
EQ-5D index score	0.752 (0.237)	−0.021–1.0
EQ-VAS (0-100)	68.2 (16.5)	35–98
SF-12 Physical Component Score (PCS) 0 to 100	44.4 (9.14)	21.9–58.4
Operation scheduled	Number of patients:	

	Mean (SD)	Range
Colorectal	9	
Major Hernia/Abdominal wall	3	
Upper GI (cholecystectomy, Whipple procedure, oesophagectomy)	17	
Urology (cystoprostatectomy, nephrectomy)	5	
Abdominal Aortic Aneurysm repair	10	
Head and Neck	6	

*Table 4.5 Summary of patient characteristics and results of CPET (VO_2peak and AT) and questionnaires (DASI, EQ-5D, EQ-VAS and SF-12). *Values presented as number of patients with percentages in parentheses. Smoking status assessed as positive if a current or ex-smoker.*

4.5.3 Preoperative accelerometer data results

The preoperative accelerometer data results are summarized for the whole cohort in Table 4.6. The mean *Activity Score* of the total cohort was 60.2 mg^2.Hz^{-1} (SD = 27.4). This represents the mean of the activity scores for each 10 second window of monitoring, weighted for the total amount of time the monitor was worn across the days of monitoring (except for days with less than 8 hours of data). With regards to variability of activity recorded for each participant across the different days in the monitoring period, weighted *Mean Activity Score* varied by a mean of 20.5% (SD = 42.5%) between days of monitoring.

Using tests of collinearity, accelerometry features which were very strongly co-correlated and therefore measuring much the same dimension, were found between the *Mean Activity Score*, the *Maximum Activity Score* and the *Standard Deviation of the Activity Score*. To a lesser extent, other collinear activity parameters were: *Mean Activity Score* and *%Active*; the *Mean Activity Score* and *%ASO>500*; *%Active* and *%ASO>500*; *MCTAS>500 or 1000* and *%ASO>500 or 1000*; *Maximum Activity Score* and *%ASO>500*. Activity parameters which were not collinear were *Mean Activity Score* and the: *%Lying*, *Maximum Time Active* and

MCTAS>500 or *MCTAS>1000*; *%Active* and *%Lying; %Active* and *Maximum Activity Score*; *%Lying* and *Maximum Activity Score*; and *%Lying* and *%ASO>500*.

Overall, the activity levels of the participants appear to be low, with only a mean of 4.69% of their monitoring period being classified as Active, using the low threshold of an *Activity Score* of above 254 mg^2.Hz^{-1} for a data window to be classified as Active. Using a slightly higher threshold of Activity Score of 500 mg^2.Hz^{-1}, which may represent non-sedentary time, the median proportion of the monitoring time with windows classified as *%ASO>500* was only 0.47%, or equivalent to a median 6.7 minutes per 24-hour period being classified as *%ASO>500*. Most of the windows were classified as Stationary (53%) or Lying (42.6%).

Using the OmGUI software, the median SVM over 72 continuous hours of wear time was 13.4 m*g*. Out of 50 cases, 11 required supplementation of hours using the previous day's accelerometer data to complete 72 hours of wear time. The median number of hours required to be supplemented in these 11 cases was 4 hours (IQR = 2.3–8.0). The median number of hours classified as sedentary per 24-hour period was 18.4 hours (IQR = 17.4–19.7). Only two patients had any 60-second epochs which reached the threshold to be classified as vigorous intensity activity in the 72-hours. They achieved 0.12 and 0.22 hours of vigorous intensity activity per day on average. In terms of co-correlated summaries of activity generated from the OmGUI SVM analysis, the mean SVM and the standard deviation of the SVM were strongly correlated ($r = 0.917$, $p < 0.001$); as were the mean SVM and number of sedentary hours per day ($r = 0.85$, $p<0.001$); and the mean SVM and number of moderate intensity hours per day ($r = 0.94$, $p<0.001$). The relationship between the mean SVM and number of light intensity hours per day was weak ($r = 0.38$, $p = 0.008$).

Accelerometry feature	Result
Magnitude of Acceleration (m*g*)	
Median	1014 (1000–1034 [931–1059])
Standard deviation	47 (39–61 [28–103])
in the Lateral plane, mean	678 (616–753 [534–888])
in the Vertical plane, mean	583 (489–641 [307–737])
Mean Tilt Angle (radians)	0.87 (0.14)
Activity Score ($mg^2.Hz^{-1}$)	
Mean	60.2 (27.4)
Standard deviation	72.0 (38.7–52.5[1.75–58.2])
Maximum	1296(780–2177 [249–17690]
Time spent in activity score above a threshold of 500 or 1000	
%ASO>500	0.470% (0.10–1.54 [0.00–7.61])
%ASO>1000	0.097% (0.0–0.54 [0.0–3.09])
MCTAS>500 (mins)	5.0 (1.75–11.25 [0.0–32.0])
MCTAS>1000 (mins)	2.0 (0.0–6.0 [0.0–28])
Categorised activity	
%Active	4.7% (3.1%)
%Stationary	53.0% (11.9%)
%Lying	42.6% (12.6%)
Maximum Time Active (mins)	6.9 (3.0–11.4 [1.2–29.8])
OmGUI analysis of signal vector magnitude (SVM) (m*g*)	
Median SVM over 72 hours	13.4 (10.6-17.2 [7.5–30.9]
Standard deviation of the SVM over 72 hours	20.0 (14.2–27.7 [9.8–58.7])
OmGUI analysis of cut-points using SVM (average no. of hours spent in each activity intensity category per 24-hour period)	
Sedentary	18.4 (17.4–19.7 [14.6–21.7])
Light activity	4.0 (3.2–4.7 [1.8–6.5])
Moderate intensity activity	1.3 (0.7– 2.3 [0.3–5.0])
Vigorous intensity activity	0.0 (0.0– 0.0 [0.0–0.22])

Table 4.6 Activity recorded at home for 50 participants in the preoperative period by an accelerometer worn for a mean (SD) of 3.17 (0.38) days. Values are mean (SD) or median (IQR [range]). Measures of the magnitude of acceleration are expressed in milli-gravity (mg) units. The units for Activity Score are expressed as the square of the acceleration per frequency ($mg^2.Hz^{-1}$*).*

4.5.3.1 Relationship between McLaren Applied Technology (MAT) and OmGUI analysis of summary measures of activity

The raw accelerometry data was analysed based on the signal vector magnitude (SVM), using the OmGUI custom software for the AX3 accelerometer; and based on the frequency of acceleration using a proprietary algorithm developed by McLaren Applied Technologies. In general, these two methods showed a strong positive linear correlation and suggests that summarising activity using the average vector magnitude and the frequency of acceleration provided\ similar estimates of the quantity of movement that has happened. The SVM was strongly correlated to the *Mean Activity Score* ($r = 0.94$, $p < 0.001$) (Figure 4.3) and *%Active* ($r=0.92$, $p < 0.001$) (Figure 4.4). The mean number of hours per day classified as moderate intensity activity based on SVM cut-point analysis was strongly correlated to the Mean Activity Score ($r = 0.84$, $p < 0.001$) and %Active ($r = 0.96$, $p < 0.96$) (Figure 4.5).

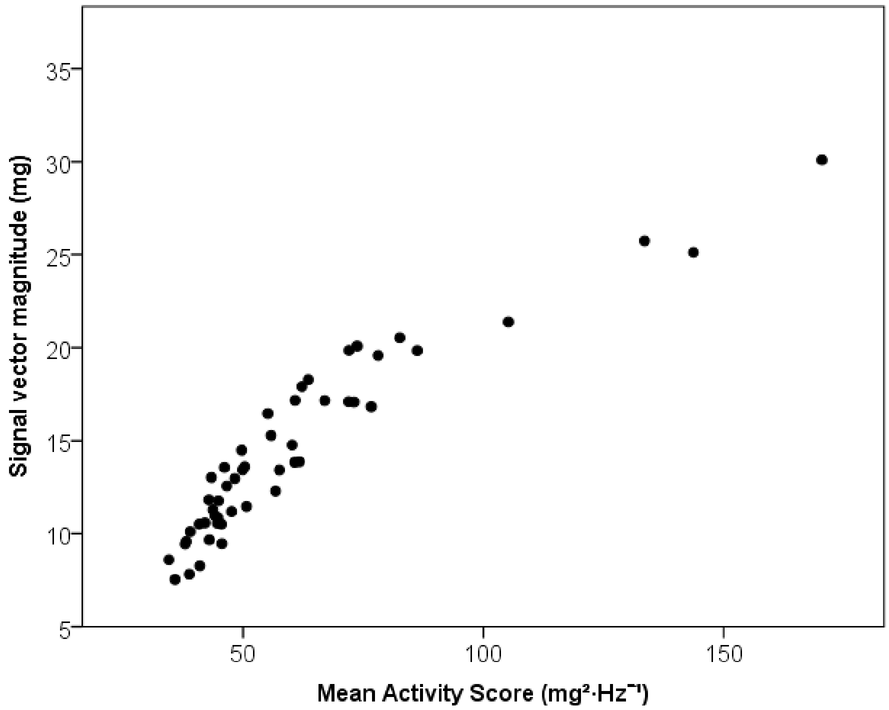


Figure 4.3 Relationship between mean Signal Vector Magnitude (using OmGUI analysis) and Activity Score (based on frequency of acceleration).

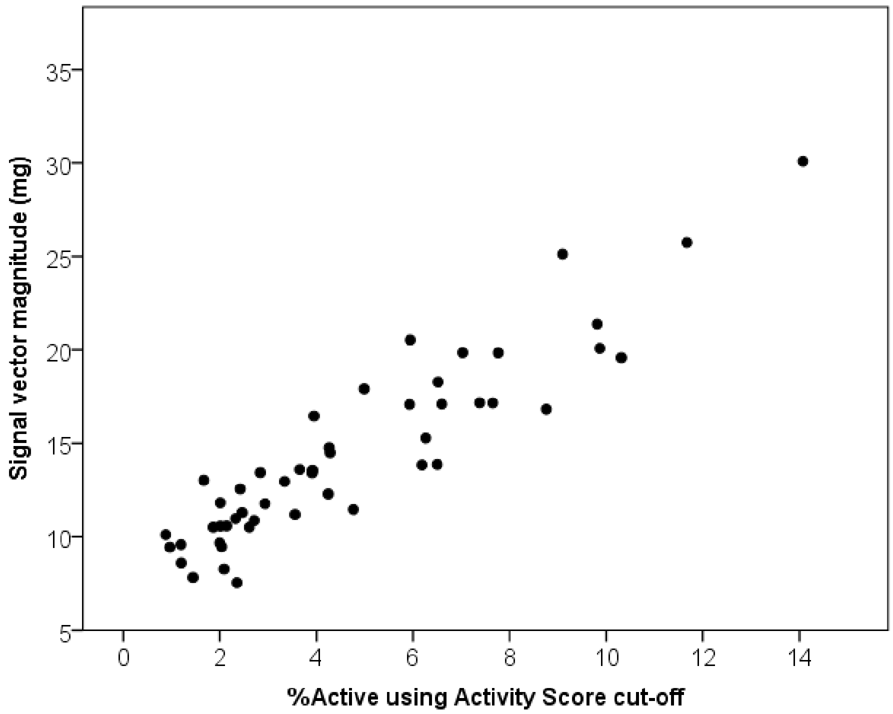


Figure 4.4 Relationship between Signal Vector Magnitude (using OmGUI analysis) and %Active (percentage of the day classified as active based on Activity Score).

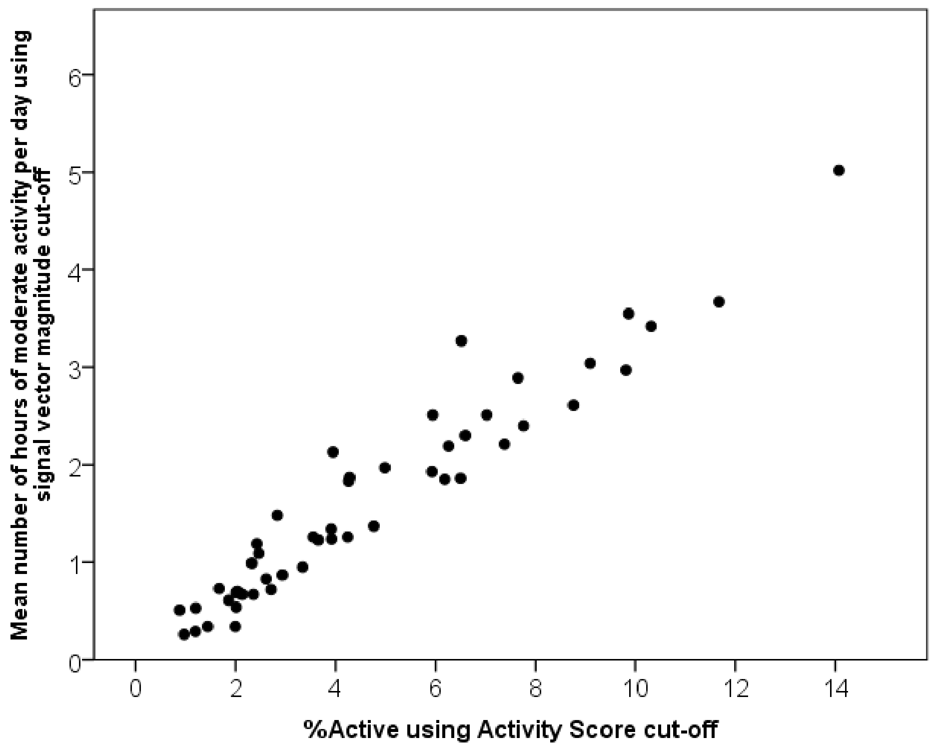


Figure 4.5 Relationship between mean time spent in moderate intensity activity per day in hours (based on signal vector magnitude cut-off using OmGUI analysis) and %Active (percentage of time classified as Active based on the Activity Score).

4.5.4 Correlation with CPET: Accelerometry features

Several measures of activity obtained from the accelerometry data correlated linearly with peak power, peak oxygen consumption and anaerobic threshold, r = 0.5 to 0.7 (Table 4.7, Figure 4.6 and Figure 4.7). *MCTAS>500* and *MCTAS>1000* are not shown in Table 4.7 due to these parameters representing the same dimension of activity as *%ASO>500* and *%ASO>1000*. Accelerometry features also correlated with ventilatory equivalents for oxygen and carbon dioxide, but less strongly so ($r < 0.5$). There was no significant correlation between the accelerometry features and the predicted values for peak oxygen consumption (not shown in Table 4.7). Accelerometry features that did not correlate with cardiopulmonary exercise variables were *Acceleration in the Lateral Plane*, *Acceleration in the Vertical Plane*, *Mean Tilt Angle*, the proportion of time classified as *Stationary* or *Lying*, and the number of hours in light activity as defined by SVM cut-off point.

4.5.5 Predictive of CPET: Accelerometry features

On multivariable linear regression analysis, the accelerometry features that were most predictive for the outcome of peak oxygen consumption were the: the *Maximum Activity Score*, the *Standard Deviation of the Magnitude of Acceleration*, the proportion of time categorised as active (*%Active)*, the roportion of time categorised as having an *Activity Score* above 500 (*%ASO>500*), the mean SVM, the standard deviation of the SVM, and the number of hours of moderate intensity activity as defined by SVM cut-point, which all had peason r squared values of around $r^2 = 0.40$, $p < 0.0001$. Similarly, the strongest predictor variables for the outcome of anaerobic threshold were the proportion of time categorised as active (*%Active*) and the *%ASO>500*, $r^2 = 0.41$, $p < 0.001$; and using the OmGUI analysis, the mean SVM, the standard deviation of the SVM and the number of hours of moderate intensity activity ($r^2 = 0.31$, $p < 0.001$). In comparison, the DASI score explained a similar degree of variance in the $\dot{V}O_2$peak ($r^2 = 0.47$, $p < 0.001$) and the AT ($r^2 = 0.38$, $p < 0.001$).

4.5.6 Correlation with questionnaire results

The DASI, EQ-VAS and SF-12 PCS questionnaire results showed moderately strong positive correlation ($r > 0.5$) to CPET results of $\dot{V}O_2$peak and AT (Table 4.7). The EQ-5D index score and SF-12 MCS showed no significant correlation to CPET results. The *Mean Activity Score* and other co-correlated activity parameters correlated moderately strongly with the DASI score ($r = 0.51$, $p < 0.0001$), and less so with the EQ-5D, EQ-VAS and SF-12 PCS ($r = 0.29$–0.38). There was no significant correlation of activity parameters with the SF-12 MCS.

4.5.7 Correlation with CPET: Patient Factors

Age also showed moderate correlation with both AT and $\dot{V}O_2$peak. Spearman's rank correlation coefficient for the relationship of patient Charlson Comorbidity Index (CCI) with CPET showed a weak correlation between CCI and $\dot{V}O_2$peak ($r = 0.30$, $p = 0.037$) and no statistically significant relationship with AT ($r = 0.17$, $p = 0.25$). On independent samples t-Test, there was no significant difference in AT and $\dot{V}O_2$peak values between males ($n = 41$) and females ($n = 7$).

Cardiopulmonary exercise variables	**$\dot{V}O_2$peak (ml.kg^{-1}.min^{-1})**		**Anaerobic threshold (ml O_2.kg^{-1}.min^{-1})**		**Peak power (Watts)**		**Ventilatory equivalent O_2**		**Ventilatory equivalent CO_2**	
	r	p value	r	p value	r	p value	r	p value	r	p value
Magnitude of Acceleration (m*g*)										
Mean	−0.16 (-0.45–0.13)	0.28	−0.01 (−0.31–0.29)	0.95	−0.36 (−0.64−−0.08)	0.01	0.03 (−0.27–0.33)	0.84	0.03 (−0.26–0.33)	0.83
SD	0.65 (0.42–0.86)	< 0.001	0.55 (0.29–0.78)	< 0.001	0.54 (0.28–0.78)	< 0.001	−0.35 (−0.61−−0.07)	0.02	−0.35 (−0.61− −0.07)	0.02
in the Lateral plane, mean	−0.15 (−0.45–0.15)	0.31	−0.04 (−0.34–0.26)	0.80	0.04 (−0.26–0.34)	0.78	−0.21 (−0.50–0.08)	0.16	−0.07 (−0.37–0.23)	0.66
in the Vertical plane, mean	0.25 (−0.04–0.55)	0.09	0.22 (−0.07–0.53)	0.13	-0.02 (−0.33–0.29)	0.88	0.09 (−0.22–0.40)	0.56	−0.02 (−0.33–0.29)	0.90
Mean Tilt Angle	-0.20 (−0.47–0.09)	0.18	−0.11 (−0.40–0.18)	0.45	0.09 (−0.22–0.39)	0.56	−0.20 (−0.49–0.09)	0.18	−0.04 (−0.34–0.26)	0.77
Activity Score (m*g*^{2}.Hz^{-1})										
Mean	0.60 (0.36–0.83)	< 0.001	0.59 (0.34–0.82)	< 0.001	0.50 (0.23–0.75)	< 0.001	−0.43 (−0.69−−0.16)	0.002	−0.39 (−0.66−−0.12)	0.006
SD	0.58 (0.33–0.81)	< 0.001	0.52 (0.26–0.76)	< 0.001	0.44 (0.17–0.70)	0.002	−0.40 (−0.66−−0.13)	0.005	−0.31 (−0.58−−0.03)	0.03
Maximum	0.52 (0.26–0.76)	< 0.001	0.45 (0.18–0.71)	0.001	0.28 (0.00–0.56)	0.053	−0.32 (−0.60−−0.04)	0.03	−0.20 (−0.49–0.09)	0.17
Proportion of time spent in Activity Score above a threshold of 500 or 1000										
%ASO>500	0.56 (0.32–0.80)	< 0.001	0.62 (0.38–0.84)	< 0.001	0.62 (0.38–0.84)	< 0.001	-0.36 (−0.63−−0.09)	0.01	−0.44 (−0.70−−0.17)	0.002
%ASO>1000	0.64 (0.41–0.86)	<0.001	0.66 (0.43–0.87)	<0.001	0.65 (0.41–0.86)	<0.001	-0.37 (-0.64−−0.10)	0.009	−0.43 (−0.69−−0.16)	0.002
Categorised activity based on Activity Score										
%Active	0.61 (0.38–0.85)	< 0.001	0.60 (0.36–0.84)	< 0.001	0.48 (0.22–0.75)	0.001	−0.43 (−0.70−−0.16)	0.002	−0.45 (−0.72−−0.19)	0.001

Cardiopulmonary exercise variables	$\dot{V}O_2$peak ($ml.kg^{-1}.min^{-1}$)		Anaerobic threshold (ml $O_2.kg^{-1}.min^{-1}$)		Peak power (Watts)		Ventilatory equivalent O_2		Ventilatory equivalent CO_2	
%Stationary	0.08 (−0.22–0.38)	0.59	0.09 (−0.21–0.39)	0.54	−0.14 (−0.43–0.16)	0.35	0.20 (−0.09–0.49)	0.18	0.15 (−0.14–0.44)	0.31
%Lying	-0.24 (−0.53–0.05)	0.11	−0.25 (−0.54–0.04)	0.09	0.02 (−0.28–0.31)	0.92	-0.08 (−0.38–0.22)	0.59	−0.03 (−0.32–0.27)	0.87
Maximum Time Active	0.45 (0.18–0.71)	0.001	0.35 (0.06–0.62)	0.017	0.37 (0.09–0.64)	0.011	−0.34 (−0.62–−0.06)	0.017	−0.30 (−0.58–−0.02)	0.038
OmGUI analysis of signal vector magnitude (SVM) (m*g*)										
Median SVM over 72 hours	0.61 (0.41–0.77)	<0.001	0.56 (0.29–0.74)	<0.001	0.50 (0.19–0.74)	<0.001	−0.29 (0.14–−0.55)	0.49	−0.39 (−0.59–−0.15)	0.06
Standard deviation of the SVM over 72 hours	0.64 (0.47–0.79)	<0.001	0.56 (0.31–0.75)	<0.001	0.56 (0.32–0.77)	<0.001	−0.42 (−0.61–−0.19)	0.003	−0.40 (−0.60–−0.17)	0.005
OmGUI analysis of cut-points using SVM (average no. of hours spent in each activity intensity category per 24-hour period)*										
Sedentary	−0.44 (−0.63–−0.17)	0.002	−0.362 (−0.59–−0.09)	0.12	−0.22 (−0.48–0.06)	0.14	0.17 (−0.67–0.42)	0.23	0.24 (−0.08–0.42)	0.11
Light activity	0.08 (−0.21–0.36)	0.59	0.01 (−0.27–0.30)	0.94	−0.18 (−0.44–0.13)	0.23	0.16 (−0.54–0.37)	0.28	−0.06 (−0.15–−0.31)	0.69
Moderate intensity activity	0.60 (0.37–−0.77)	<0.001	0.55 (0.28–0.75)	<0.001	0.50 (0.24–0.70)	<0.001	−0.41 (−0.61–−0.13)	0.04	−0.42 (−0.60–−0.17)	0.003
Questionnaires										
DASI	0.69 (0.48–0.92)	< 0.001	0.62 (0.38–0.84)	< 0.001	0.65 (0.46–0.95)	< 0.001	−0.35 (−0.64–−0.07)	0.02	−0.54 (−0.80–−0.30)	< 0.001
EQ-5D index score	0.38 (0.12–0.73)	0.008	0.19 (−0.12–0.53)	0.204	0.21 (−0.10–0.61)	0.159	0.04 (−0.29–0.37)	0.801	−0.25 (−0.60–0.04)	0.088
EQ-VAS	0.62 (0.39–0.86)	<0.001	0.50 (0.24–0.76)	<0.001	0.51 (0.25–0.79)	<0.001	−0.23 (−0.53–0.06)	0.117	−0.46 (−0.71– −0.19)	0.001
SF-12 (PCS) score	0.57 (0.33–0.85)	< 0.001	0.49 (0.23–0.79)	0.001	0.35 (0.06–0.68)	0.02	−0.03 (−0.35–0.29)	0.85	−0.28 (−0.58–0.01)	0.06

Cardiopulmonary exercise variables	**$\dot{V}O_2$peak (ml.kg^{-1}.min^{-1})**		**Anaerobic threshold (ml O_2.kg^{-1}.min^{-1})**		**Peak power (Watts)**		**Ventilatory equivalent O_2**		**Ventilatory equivalent CO_2**	
SF-12 (MCS) score	0.21 (−0.09–0.52)	0.166	0.02 (−0.29–0.34)	0.874	0.19 (−0.12–0.51)	0.222	0.06 (−0.25–0.38)	0.683	−0.14 (−0.44–0.16)	0.342

*Table 4.7 Pearson correlation r coefficients (95% CI) for the linear associations of activity variables with cardiopulmonary exercise variables. DASI, Duke activity score index; r, Pearson correlation coefficient; SD, standard deviation; SF-12 (PCS), short form 12 physical component score; VO_2, oxygen consumption. *vigorous intensity activity classification not included as only two cases*

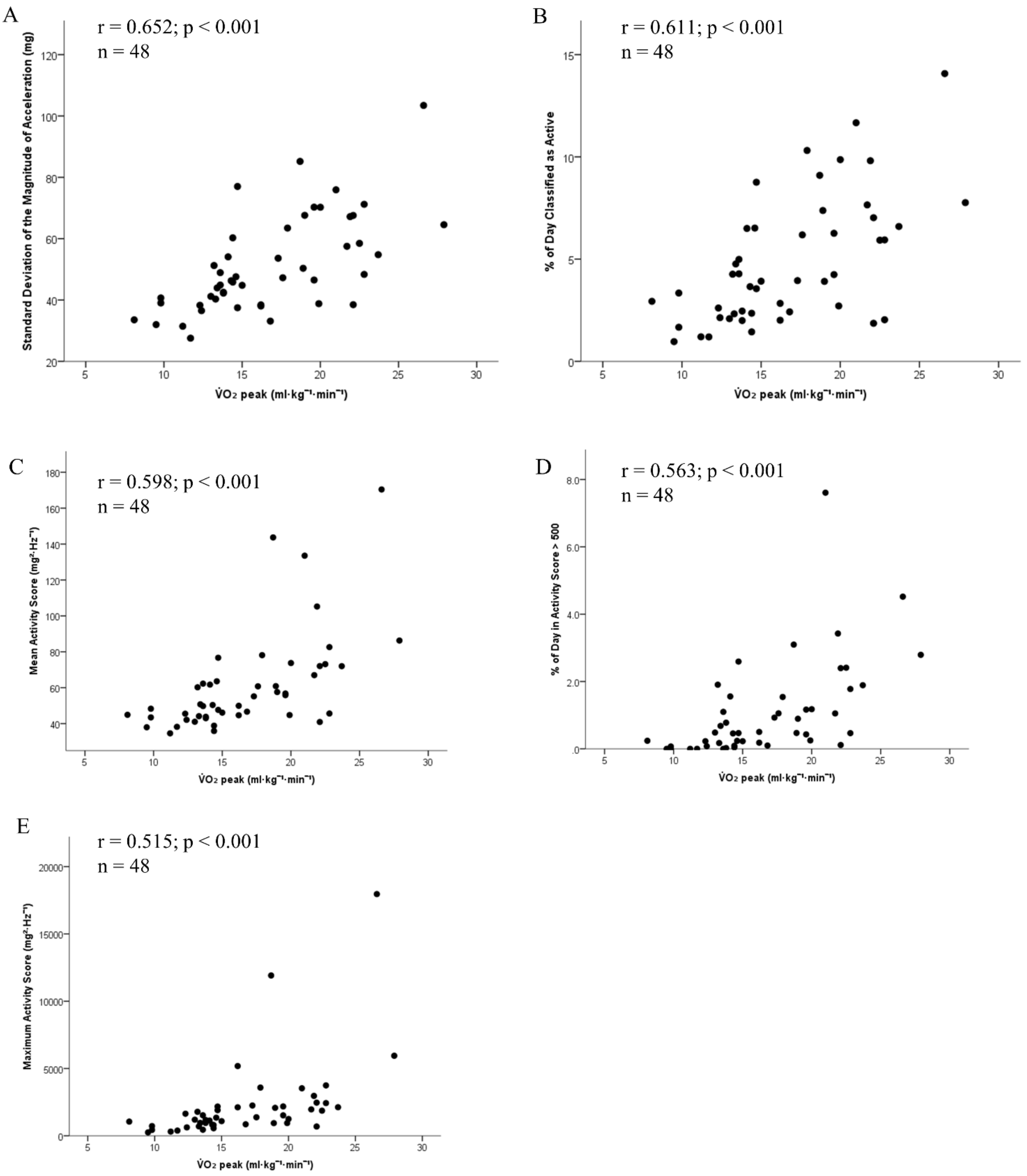


Figure 4.6 Relationship between activity variables and peak oxygen consumption (VO_2peak). A = Standard Deviation of the Magnitude of Acceleration, B = percentage of the day active (%Active), C = Activity Score, D = percentage of the day spent in activity over an Activity Score of 500 (%ASO>500), E = Maximum Activity Score measured. Black dots represent patients.

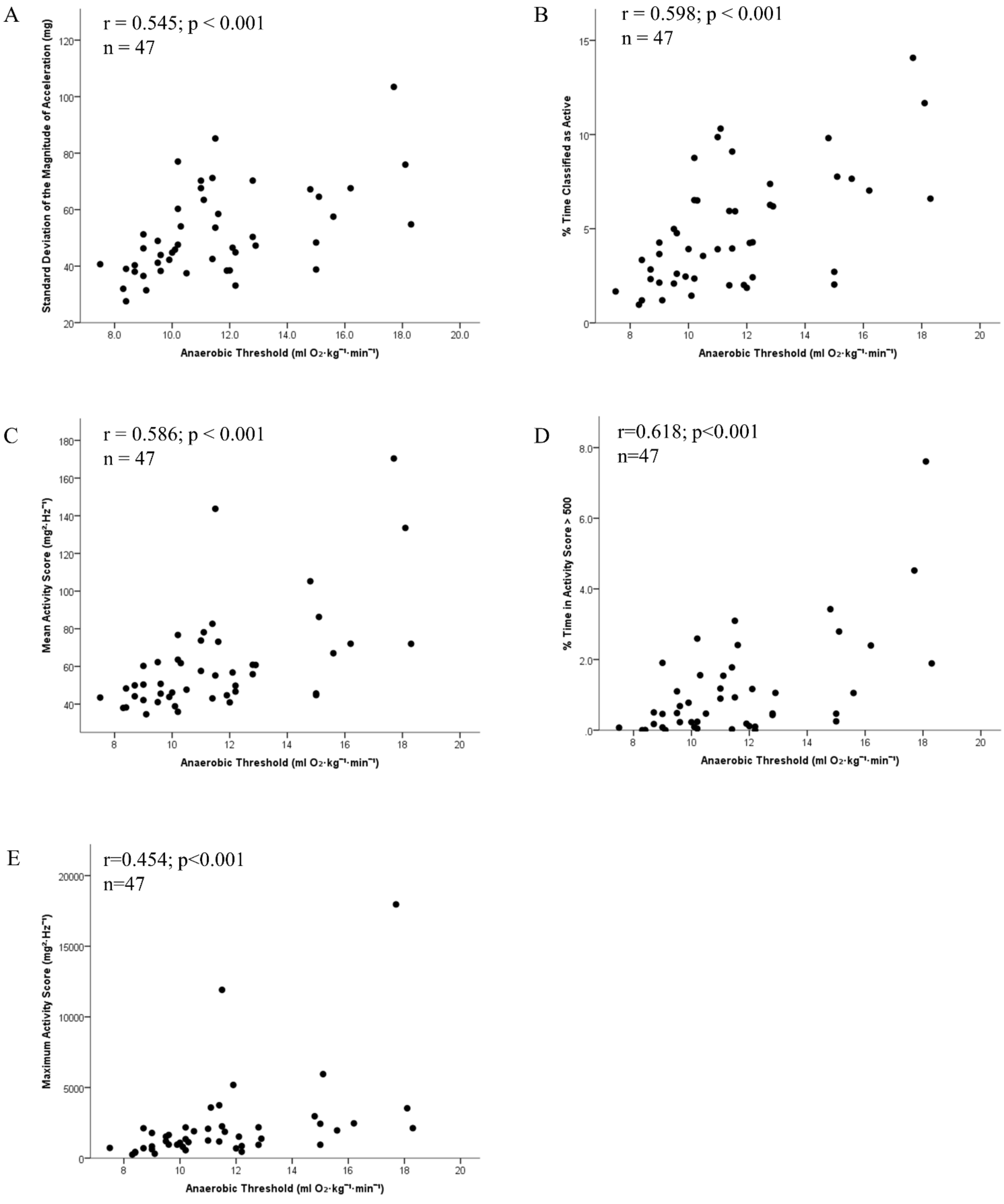


Figure 4.7 Relationship between activity variables and anaerobic threshold (AT). A = Standard Deviation of the Magnitude of Acceleration, B = percentage of the day classified as Active, C = Activity Score, D = percentage of the day spent in activity over an Activity Score of 500, E = Maximum Activity Score measured. Black dots represent patients.

4.5.8 Discrimination between ‘fit’ and ‘unfit’ patients

Table 4.8 shows a selection of activity variables that were significantly different between the groups of ‘fit’ or ‘unfit’ patients. The *Mean Activity Score* was significantly lower in high-risk or ‘unfit’ patients based both on a CPET $\dot{V}O_2$peak result below 15 $ml.kg^{-1}.min^{-1}$ (47.5 ± 10.2 vs. 72.9 ± 33.1, mean difference = −25.5, 95% CI (−39.4, −13.0), $t(48) = 3.678$, $p = 0.001$) and CPET AT result below 11 ml $O_2.kg^{-1}.min^{-1}$ (47.6 ± 10.2 vs. 72.8 ± 33.2, mean difference = −25.2, 95% CI (−39.1, −12.7), $t(48) = 3.629$, $p = 0.001$), compared to the ‘fit’ group of patients based on a CPET $\dot{V}O_2$peak ≥ 15 $ml.kg^{-1}.min^{-1}$ or AT ≥ 11 ml $O_2.kg^{-1}.min^{-1}$. The mean *Signal Vector Magnitude* was also significantly lower in high-risk or ‘unfit’ patients based both on a CPET $\dot{V}O2$peak result below 15 $ml.kg^{-1}.min^{-1}$ (median = 11.3, IQR = 9.6–13.7 in ‘unfit’ patients vs. median = 17.1, IQR = 13.0–20.0 in ‘fit’ patients, U = 498.5, p < 0.001) and CPET AT result below 11 ml $O_2.kg^{-1}.min^{-1}$ (median = 11.5, IQR = 9.8–13.6 in ‘unfit’ patients vs. median = 17.1, IQR = 12.4–20.0 in ‘fit’ patients, U = 484.5, p = 0.001) compared to the ‘fit’ group of patients based on a CPET $\dot{V}O_2$peak ≥ 15 $ml.kg^{-1}.min^{-1}$ or AT ≥ 11 ml $O_2.kg^{-1}.min^{-1}$. Other activity parameters that aim to represent the variability of activity over time (*Standard Deviation of the Activity Score,* the *Standard Deviation of the Magnitude of Acceleration* and the standard deviation of the SVM*)*; the duration of active periods (*%Active*); and an intensity of activity that may not be sedentary (*%ASO>500, Maximum Activity Score* and mean number of hours classified as moderate intensity activity using SVM cut-point), were also significantly higher in the ‘fit’ group of patients as measured by CPET, compared to the ‘unfit’ group (Table 4.8, Figure 4.8). The *%ASO>500* was approximately 5 times higher in the ‘fit’ group compared to the ‘unfit’ group (median of 1.07 vs 1.05% based on $\dot{V}O_2$peak category , and median of 0.23 vs 1.05% for AT category). The *%Active* and time in moderate intensity activity based on

SVM cut point were both approximately twice as high in the 'fit' group vs. the 'unfit' group of patients based on either $\dot{V}O_2$peak or AT result. Furthermore, *%Lying* and average number of hours in sedentary activity based on SVM cut-point, as measures of inactivity, also showed an ability to discriminate between the 'fit' and 'unfit' group despite not showing linear correlation to peak oxygen consumption or anaerobic threshold. *%Lying* (percentage of the day spent lying down) was significantly higher in the 'unfit' patient group as defined by both $\dot{V}O_2$peak (47.3 ± 12.6 vs. 37. 9± 10.5, mean difference = 9.4, 95% CI (2.6, 16.4), $t(48) = 2.817$, $p = 0.007$) and AT (46.1 ± 12.5 vs 39.0 ± 11.8, mean difference = −7.1, 95% CI (0.9, 13.4), $t(48) = 2.053$, $p = 0.046$).

The DASI, EQ-5D, EQ-VAS and SF-12 PCS questionnaires all had significantly higher scores in the 'fit' group of patients based on both CPET $\dot{V}O_2$peak and AT, compared to the unfit group of patients (Table 4.8). Most of the clinical patient variables did not show a significant difference between the 'fit' and 'unfit' categories based on CPET peak oxygen consumption and anaerobic threshold. The 'fit' group based on $\dot{V}O_2$peak had a lower BMI, and there were more than twice as many patients in the higher ASA classes (ASA ≥ 3) in the 'unfit' group based on anaerobic threshold.

Variable	Total cohort (n = 50)	V̇O2peak ($ml.kg^{-1}.min^{-1}$)		p value	AT (ml $O_2.kg^{-1}.min^{-1}$)		p value
		< 15 (n = 25) 'Unfit'	≥ 15 (n=25) 'Fit'		< 11 (n = 25) 'Unfit'	≥ 11 (n = 25) 'Fit'	
Age (years)	70.9 (9.9)	73.6 (9.64)	68.2(9.57)	0.056	73.3(9.40)	68.5(9.93)	0.083
Male	42 (84%)	21(50%)	21(50%)	1.000	22(52.4%)	20(47.6%)	0.702
BMI (kg/m^2)	27.8 (7.14)	30 (7.97)	25.7 (5.59)	**0.035**	29.6(8.26)	26.1(5.44)	0.089
Charlson Comorbidity Index	5 (3–6 [2–12])	5 (3–6.5 [2–12])	5 (3.5–5[2–7])	0.162	5(3–6.5[2–12])	5 (3.5–5 [2–7])	0.337
Smoking status positive*	39 (91%)	19 (48.7%)	20 (51.3%)	0.607	20 (51.3%)	19 (48.7%)	1.000
ASA ≥ 3	19 (38%)	12 (63.2%)	7 (36.8%)	0.145	13 (68.4%)	6 (31.6%)	**0.041**
Questionnaires							
Duke Activity Status Index (DASI) score	37.8 (26.3–50.8 [1.75–58.2])	27.0 (21.2–40.1 [1.8–50.7])	50.7 (37.8–58.2[18.0–58.2])	**<0.0001**	27.0(21.2–44.8 [1.8–50.7])	42.7 (35.7–58.2[18.0–58.2])	**0.001**
EQ-5D	0.83 (0.66–0.88 [−0.02–1.0])	0.74 (0.53–0.86 [−0.21–1.0])	0.84 (0.75–1.0 [0.53–1.0])	**<0.001**	0.74 (0.60–0.88 [−0.02–1.0])	0.84 (0.73–0.94 [−0.01–1.0])	**0.048**
EQ-VAS	70 (50–80 [35–98])	55 (50–72.5 [35–90])	77.50 (71.3–87.5 [45–98])	**0.02**	60 (50–75 [40–90])	75 (70–87.5 [35–98])	**0.001**

Variable	**Total cohort (n = 50)**	**V̇O2peak (ml.kg^{-1}.min^{-1})**		p value	**AT (ml O_2.kg^{-1}.min^{-1})**		p value
		< 15 (n = 25) ‘Unfit’	≥ 15 (n=25) ‘Fit’		< 11 (n = 25) ‘Unfit’	≥ 11 (n = 25) ‘Fit’	
SF-12 Physical Component Score (PCS)	44.1 (38.7–52.5 [21.9–58.4])	38.8 (33.6–44.1 [21.9–52.9])	51.8 (44.1–55.6 [38.8–58.4])	**<0.0001**	39.3 (34.0–47.5 [27.0–53.7])	51.2 (43.6–55.6 [21.9–58.4])	**0.001**
Activity parameters:							
Magnitude of Acceleration (m*g*)							
Mean Magnitude of Acceleration (m*g*)	1.01 (1.00–1.03 [0.93–1.06])	1.02 (1.00–1.03 [0.96–1.06])	1.02 (0.99–1.04 [0.93–1.06])	0.946	1.01 (1.00–1.03 [0.96–1.05])	1.02 (0.99–1.04 [0.93–1.06])	0.218
Standard Deviation of the Magnitude of Acceleration (m*g*)	0.05 (0.04–0.06 [0.03–0.10])	0.04 (0.04–0.05 [0.03–0.08])	0.57 (0.46–0.69 [0.33–0.10])	**0.002**	0.04 (0.04–0.05 [0.03–0.08])	0.06 (0.05–0.07 [0.03–0.10])	**0.001**
Acceleration in the Lateral Plane (m*g*)	0.68 (0.62–0.76 [0.53–0.89])	0.71 (0.65–0.78 [0.53–0.89])	0.66 (0.61–0.70 [0.54–0.84])	**0.043**	0.70 (0.62–0.75 [0.53–0.89])	0.67 (0.62–0.73 [0.54–0.84])	0.432
Acceleration in the Vertical Plane (m*g*)	0.58 (0.48–0.64 [0.31–0.74])	0.51 (0.43–0.62 [0.31–0.74])	0.63 (0.55–0.66 [0.40–0.74])	**0.004**	0.53 (0.45–0.63 [0.31–0.74])	0.62 (0.52–0.66 [0.40–0.74])	**0.028**

Variable	**Total cohort (n = 50)**	**V̇O2peak (ml.kg^{-1}.min^{-1})**		p value	**AT (ml O_2.kg^{-1}.min^{-1})**		p value
		< 15 (n = 25) 'Unfit'	≥ 15 (n=25) 'Fit'		< 11 (n = 25) 'Unfit'	≥ 11 (n = 25) 'Fit'	
Mean Tilt Angle (radians)	0.87 (0.14)	0.89 (0.12)	0.81 (0.11)	**0.016**	0.88 (0.13)	0.83 (0.11)	0.161
Activity Score (mg^2.Hz^{-1})							
Activity Score (mg^2.Hz^{-1})	60.0 (27)	47.5 (10.22)	72.9 (33.07)	**0.001**	47.6 (10.18)	72.8 (33.19)	**0.001**
Standard Deviation of the Activity Score (mg^2.Hz^{-1})	72.0 (38.7–52.5 [1.75–58.2])	43.5 (30.4–67.6 [16.7–133.7])	107.7 (75.1–187.1 [33.6–650.1])	**<0.001**	50.0 (31.0–72.0 [16.7–133.6])	107.7 (72.7–187.1 [30.5–650.1])	**<0.001**
Maximum Activity Score (mg^2.Hz^{-1})	1296 (780–2177 [249–17690]	832.1 (505–1271 [249–2176])	2122 (1312–3554 [688–17960])	**<0.001**	951 (569–1433 [249–2176])	2122 (1211–3554 [452–17960])	**<0.001**
Proportion of time spent in Activity Score above a threshold of 500 or 1000							
%ASO>500	0.47 (0.10–1.54 [0.00-7.61]	0.17 (0.01–0.58 [0.00-2.59])	1.05 (0.45-2.40 [0.10-7.61])	**<0.001**	0.23 (0.04-0.59 [0.00-2.59])	1.05 (0.34-2.40 [0.00-7.61])	**0.002**
%ASO>1000	0.10 (0.0–0.54 [0.0–3.09])	0.0 (0.0–0.09 [0.0–1.04])	0.40 (0.0–1.29 [0.0–3.09])	**<0.001**	0.0 (0.0–0.11 [0.0–1.04])	0.40 (0.57–1.29 [0.0–3.09])	**<0.001**

Variable	Total cohort (n = 50)	V̇O2peak (ml.kg^{-1}.min^{-1})		p value	AT (ml O_2.kg^{-1}.min^{-1})		p value
		< 15 (n = 25) 'Unfit'	≥ 15 (n=25) 'Fit'		< 11 (n = 25) 'Unfit'	≥ 11 (n = 25) 'Fit'	
Categorised activity based on Activity Score							
%Active	4.7 (3.1)	2.46 (1.8–4.3 [0.9-8.8])	6.19 (3.4-8.4 [1.9-14.1])	**<0.001**	2.61 (1.8-4.1 [0.9-8.8])	6.19 (3.3-8.4 [1.9-14.1])	**0.001**
%Stationary	53.0 (11.9)	50.0 (12.8)	55.9 (10.4)	0.078	51.1 (12.6)	54.8 (11.1)	0.282
%Lying	42.6 (12.6)	47.3 (12.56)	37.9 (10.52)	**0.007**	46.1 (12.51)	39.0 (11.84)	**0.046**
Maximum Time Active (minutes)	6.9 (3.0–11.4 [1.2–29.8])	4.0 (2.5–8.9 [1.2–22.5])	8.0 (3.3–16.8 [2.3–29.8])	**0.019**	3.2 (2.4–8.9 [1.2–22.50])	8.0 (3.6–16.8 [2.5–29.8])	**0.010**
OmGUI analysis of signal vector magnitude (SVM) (m*g*)							
Median SVM over 72 hours	13.4 (10.6-17.2 [7.5–30.9]	11.3 (9.6– 13.7 [7.5–18.3]	17.1 (13.0– 20.0 [9.5–30.1])	**<0.001**	11.5(9.8– 13.6 [7.5–18.3])	17.1 (12.4– 20.0 [9.5–30.1])	**0.001**
Standard deviation of the SVM over 72 hours	20.0 (14.2–27.7 [9.8–58.7])	15.2 (12.1– 20.1 [9.8–31.7])	27.0 (18.6– 34.1 [12.7–58.7])	**<0.001**	15.4 (12.9– 20.1 [9.8–31.7])	27.0 (17.6– 34.1 [11.6–58.7])	**0.001**
OmGUI analysis of cut-points using SVM (average no. of hours spent in each activity intensity category per 24-hour period)*							
Sedentary	18.4 (17.4–19.7 [14.6–21.7])	19.6 (18.2– 20.1 [16.0–21.7])	17.7 (16.4– 18.5 [14.6–20.7])	**0.001**	19.5 (18.0–20.1[16.0–21.7])	17.7 (16.4– 18.6 [14.6–20.7])	**0.005**

Variable	**Total cohort (n = 50)**	**V̇O2peak (ml.kg^{-1}.min^{-1})**		p value	**AT (ml O_2.kg^{-1}.min^{-1})**		p value
		< 15 (n = 25) 'Unfit'	≥ 15 (n=25) 'Fit'		< 11 (n = 25) 'Unfit'	≥ 11 (n = 25) 'Fit'	
Light activity	4.0 (3.2–4.7 [1.8–6.5])	3.6 (2.9– 4.7 [1.8–6.1])	4.2 (3.8– 4.7 [2.5–6.5])	**0.043**	3.6 (2.9– 4.5 [1.8–6.1])	4.2 (3.7– 4.5 [2.5–6.5])	0.181
Moderate intensity activity	1.3 (0.7– 2.3 [0.3–5.0])	0.87 (0.60– 1.60 [0.26–3.3])	2.2 (1.25– 2.93 [0.54–5.0])	**<0.001**	0.95 (0.67– 1.43 [0.26–3.27])	2.2 (1.2– 2.9 [0.34–5.02])	**0.001**

*Table 4.8 Summary of the measured predictor variables of cardiorespiratory fitness including patient characteristics, questionnaire results and activity parameters. Values are mean (SD), median (IQR [range]) or number (proportion). Comparison of means or medians tests which were significant at p<0.05 are highlighted in bold text. *vigorous intensity activity classification not included as there were only two cases.*

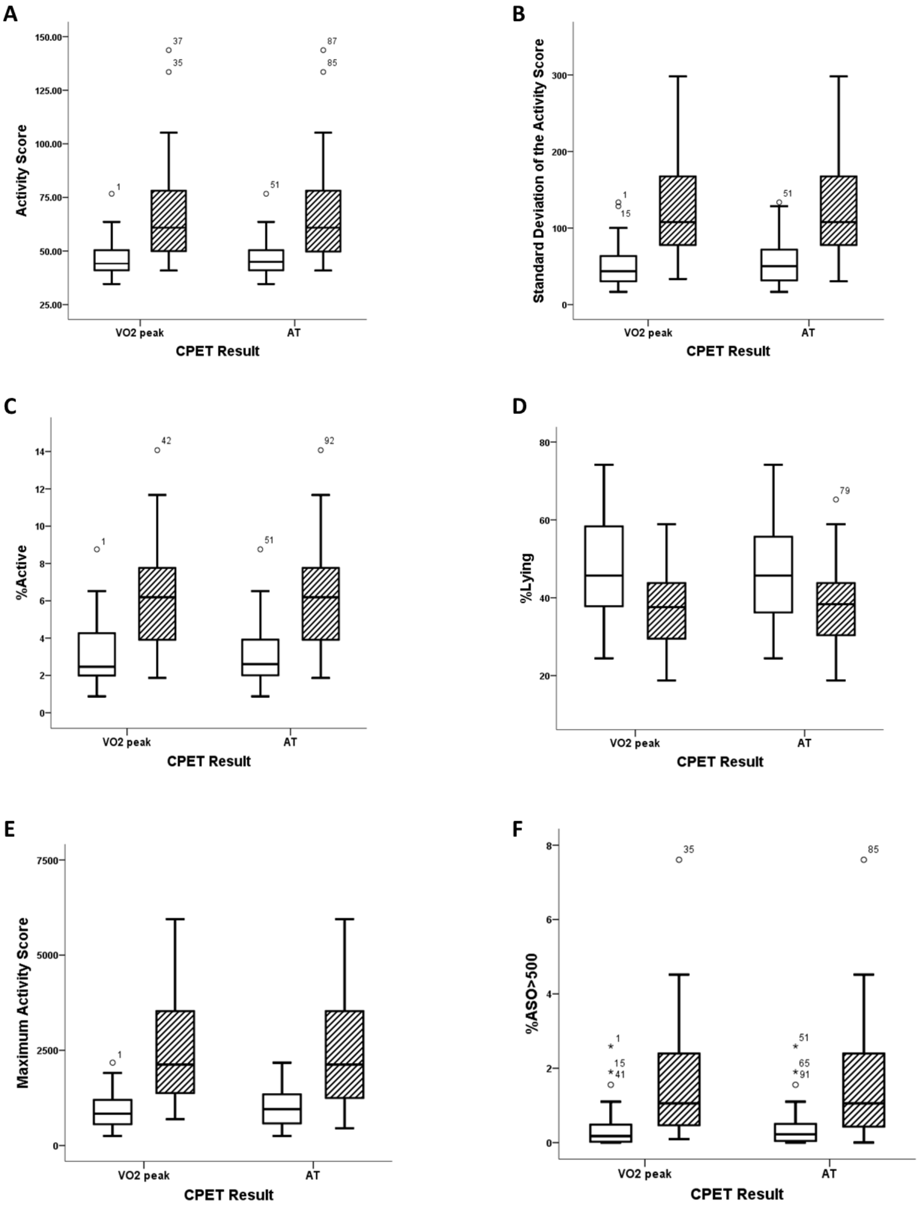


Figure 4.8 Boxplots showing distribution of six activity variables between patient groups of 'unfit' (based on CPET VO_2peak <15ml.mg^{-1}kg^{-1} or AT <11ml O_2.mg^{-1}kg^{-1}) or 'fit' (based on CPET VO_2 peak ≥ 15 ml.mg^{-1}kg^{-1} or AT ≥ 11 ml O_2.mg^{-1}kg^{-1}). The six activity variables shown are: A=Activity Score, B=Standard Deviation of the Activity Score, C=percentage of time spent being active, D=percentage of time spent lying down, E= Maximum Activity Score measured at any point during monitoring and F=percentage of time an activity score of over 500 was achieved. Comparisons between 'unfit' and 'fit' groups based on CPET VO_2peak or AT result are significant at $p<0.05$ (see Table 1 for p values) for all six activity variables. (Outliers are denoted with circles represent values that are 1.5 times the IQR.)

4.5.9 Postoperative assessments

4.5.9.1 Operations

36 patients underwent an operation at a median of 50 days (IQR = 21–96) after the CPET clinic date. 7 patients underwent neoadjuvant chemotherapy, of which 6 were patients before oesophagectomy, and 1 patient before gastrectomy. These 7 patients underwent their operation at a median of 44 days (IQR = 19–99) after their CPET clinic. Of the 50 patients recruited that did not have their scheduled operation, 5 patients were found subsequently to have inoperable disease or opted for palliative treatment, and 9 patients had radiotherapy or surveillance treatment instead of surgery. Table 4.9 lists the operations grouped by type of operation, as well as by classification of complexity. This complexity classification is based on the Oxford University Hospitals preoperative assessment proforma as of 2014-2017 (Figure 2.1). It is based on increasing requirements for higher level care, such that Group A is for operations which result in a tracheostomy and therefore Level 3 care, Group B are operations that are likely to require intensive care admission (Level 2 to 3 care) postoperatively, Group C operations are likely to require Level 1 to 2 care postoperatively, and Group D operations are likely to require day case or ward based care (Level 0) postoperatively.

31 patients completed postoperative activity monitoring for a mean of 3.13 days (SD = 0.49), with just one patient wearing it for less than 48 hours. 25 out of 31 patients wore the accelerometer for at least 3 days. The postoperative activity monitoring was commenced at a mean of 119 days (SD = 23) after the operation date.

		Number of patients
Did not have an operation		14
Operation type		
Whipples procedure / pancreatic bypass		2
Head and Neck (minor)		2
Head and Neck (open major)		3
Open gastrointestinal		3
Laparoscopic gastrointestinal		4
Abdominal wall / incisional hernia repair		3
Endovascular repair of abdominal aortic aneurysm		3
Open repair of AAA		4
Urology (cystectomy, partial nephrectomy)		4
Oesophagectomy, gastrectomy		8
Classification of operation complexity		
A	Head and neck requiring tracheostomy	1
B	Whipples, oesophagectomy, major head and neck, abdominal wall reconstruction	13
C	Major bowel and urology surgery, open AAA repair	15
D	Endovascular AAA repair, laparoscopic non-major bowel surgery	7

Table 4.9 Type of operations performed and classification by operation complexity.

4.5.9.2 Postoperative clinical outcomes

Of the 14 patients that did not have an operation, after one year of follow-up of patient records, 4 patients had died within four to eight months of their CPET clinic date. Of the 36 patients who did have an operation, there were no deaths within 30 or 90 days of the operation. One patient died 8-months post-op, and one patient died 1-year post-op. Postoperative outcomes were collected for the 36 patients who underwent surgery. The Clavien-Dindo complication grade was recorded as the highest grade-category recorded in the patient records during the immediate postoperative inpatient period. In total, 38 complications were recorded for the 21 patients who did experience a Clavien-Dindo grade 1 to 4 complication. Of the 12 patients who had a Grade 3 to 4 complication, only one was grade 4, necessitating return to theatre and intensive care admission in the oesophagectomy group.

Relationship between clinical outcomes and preoperative and postoperative assessments

Preoperative clinical, questionnaire, CPET and accelerometry results and postoperative clinical, questionnaire and accelerometry results were compared for any differences in distribution (using the Kruksal-Wallis test) between the increasing severity categories of complications recorded in the postoperative inpatient period (highest Clavien-Dindo grade of: 1) no complications, 2) Grade 1-2 or 3) Grade 3-4 recorded). There was no significant difference in the distributions of the results for age, sex, smoking, ASA grade, anaerobic threshold result, any of the preoperative or postoperative questionnaire results, and most of the preoperative and postoperative accelerometry results (Table 4.10). There was a significantly higher CPET $\dot{V}O_2$peak result for those with no recorded complications (median value = 21 $ml.kg^{-1}.min^{-1}$, mean rank = 20.4) compared to those patients who had Clavien-Dindo grade 1-2 complications (median value = 14.6 $ml.kg^{-1}.min^{-1}$, mean rank = 9.8); and between those with Clavien-Dindo grade 1-2 complications compared to grade 3-4 complications (mean rank = 20.1), $\chi^2(2) = 7.375$, $p = 0.025$). Contrary to expectations, the $\dot{V}O_2$peak mean rank for those with Grade 3-4 complications was *higher* than those with Grade 1-2 complications (Figure 4.9, boxplot A). There was no significant difference in AT between the Clavien-Dindo grade groups of complications.

	Number of patients	Length of inpatient stay, days (IQR [range])	Operation length (minutes)*	Clavien-Dindo Complication Grade, number (%)		
				None	Grade 1-2	Grade 3-4
Overall	36	12.7 (7–22.8 [1–64])	362 (193–414 [84–701])	15	9	12
Operation type						
Whipple procedure / pancreatic bypass	2	38 [23–38]	255 [155–255]	—	—	2 (100%)
Head and Neck (minor)	2	17.5 [1–34]	410	1 (50%)	1 (50%)	—
Head and Neck (open major)	3	15 [13–18]	483 [305–660]	1 (33%)	1 (33%)	1 (33%)
Open gastrointestinal	3	38 [5–54]	128 [84–168]	2 (67%)	—	1 (33%)
Laparoscopic gastrointestinal	4	8 [1–12]	182 [160–225]	2 (50%)	2 (50%)	—
Abdominal wall / incisional hernia repair	3	10 [7–10]	402 [384–420]	1 (33%)	1 (33%)	1 (33%)
Endovascular repair of abdominal aortic aneurysm	3	1 [1–2]	n/r	3 (100%)	—	—
Open repair of AAA	4	6 [3–10]	n/r	3 (75%)	—	1 (25%)
Urology (cystectomy, partial nephrectomy)	4	32.5 [14–64]	410 [227–701]	—	1 (25%)	3 (75%)
Oesophagectomy, gastrectomy	8	14 [9–56]	374 [327–476]	2 (25%)	3 (38%)	3 (38%)

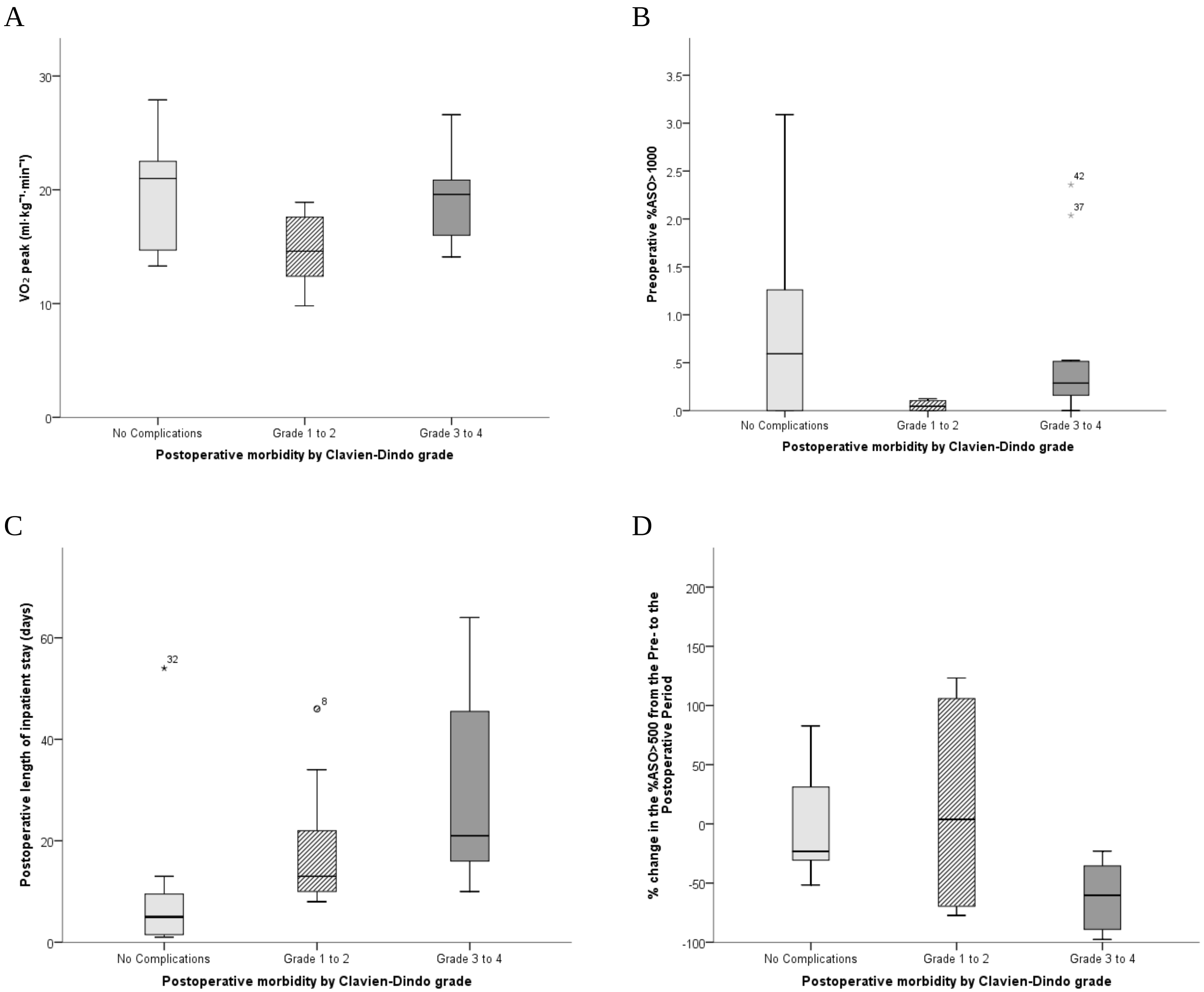
*Table 4.10 Postoperative clinical outcomes. Clavien-Dindo complication grade category is recorded as the highest complication grade reached during the inpatient postoperative period. *Operation length is missing for 12 of the 36 cases.*

The preoperative accelerometry feature *%ASO>1000* was also significantly higher in patients with no recorded complications (mean rank = 20.5) compared to those patients who had Clavien-Dindo grade 1-2 complications (mean rank = 13.7); and between those with Clavien-Dindo grade 1-2 complications compared to grade 3-4 complications (mean rank = 21.4), $\chi^2(2) = 6.151$, $p = 0.046$. This mirrors the same contrary finding as for $\dot{V}O_2$peak, where those who suffered Clavien-Dindo Grade 3-4 complications actually had higher preoperative activity levels as measured by the accelerometry feature *%ASO>1000*, compared to those who suffered Clavien-Dindo Grade 1-2 complications (Figure 4.99,boxplot B).

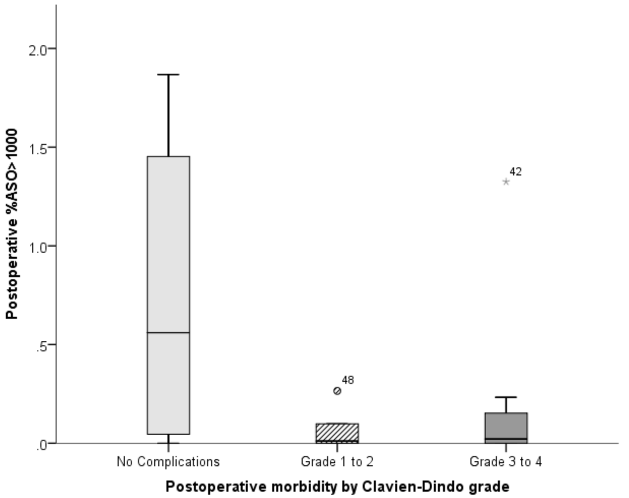
There was a significantly longer length of stay for patients with recorded Grade 1-2 complications (mean rank = 20.4) or Grade 3-4 complications (mean rank = 27.3), compared to no complications (mean rank = 10.3) and Grade 1-2 complications, $\chi^2(2) = 6.151$, $p = 0.046$ (Figure 4.9, boxplot C). There was no correlation between length of stay and CPET or accelerometry parameters.

The postoperative accelerometry features of the percentage change in the *%ASO>500* from the preoperative to the postoperative period ($\chi^2(2) = 8.995$, $p = 0.011$), and the postoperative *%ASO>1000* result, ($\chi^2(2) = 6.448$, $p = 0.040$) was also significantly higher in those patients with no recorded complications compared to those with Clavien-Dindo 1-2 or 3-4 grade complications (Figure 4.9 , boxplot D-E).

The impact of undergoing an operation classified as Group B (major hepatobiliary and upper GI), Group C (major gastrointestinal and urology) or Group D (endovascular or minor gastrointestinal laparoscopic) also affected the postoperative Clavien-Dindo grade, $\chi^2(2) = 0.041$, $p = 0.041$ (Figure 4.9, boxplot F).


A
VO₂ peak (ml·kg⁻¹·min⁻¹)
30
20
10
0
No Complications
Grade 1 to 2
Grade 3 to 4
Postoperative morbidity by Clavien-Dindo grade
B
Preoperative %ASO>1000
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
42
37
No Complications
Grade 1 to 2
Grade 3 to 4
Postoperative morbidity by Clavien-Dindo grade
C
Postoperative length of inpatient stay (days)
60
40
20
0
32
8
No Complications
Grade 1 to 2
Grade 3 to 4
Postoperative morbidity by Clavien-Dindo grade
D
% change in the %ASO>500 from the Pre- to the Postoperative Period
200
150
100
50
0
-50
-100
No Complications
Grade 1 to 2
Grade 3 to 4
Postoperative morbidity by Clavien-Dindo grade

E



F

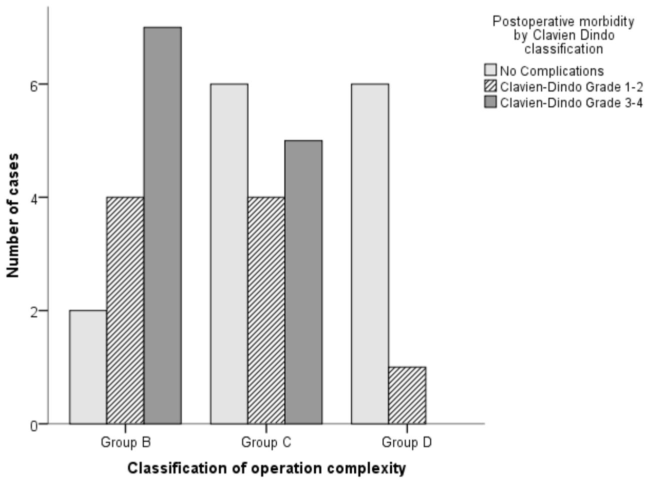


Figure 4.9 Preoperative and postoperative assessment variables compared across Clavien-Dindo grades for severity of postoperative complications.

4.5.9.3 Postoperative activity monitoring results

31 patients underwent activity monitoring in the postoperative period for a mean of 3.13 days (SD = 0.49). The postoperative activity monitoring was commenced at a mean of 119 days (SD = 23) after the operation date. Table 4.11 shows the summary results of the accelerometer features obtained during the postoperative monitoring period for all 31 patients and broken down by classification of operation complexity. These nine features were chosen to be represented as the results summary for the postoperative activity monitoring period as they represent the variables which showed some relationship to preoperative fitness as estimated using CPET.

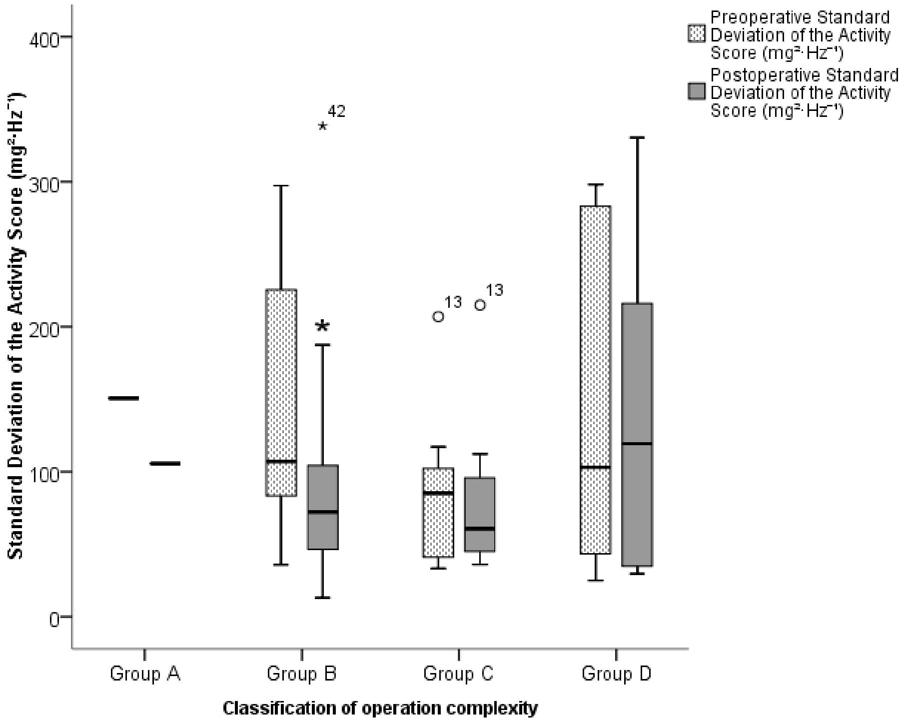
Comparison of accelerometry features between operation complexity group

There was no significant difference between the operation complexity groups (on Kruksal-Wallis testing) A to D for any of the accelerometry features. More patients in Group D achieved a higher result for the *Standard Deviation of the Activity Score* and the amount of time spent in non-sedentary level activity (*%ASO>500*) compared to Groups B and C, but the large spread of results meant that overall, Group D patients did not achieve significantly higher results for accelerometry features related to being active (Figure 4.10, boxplots A and C).

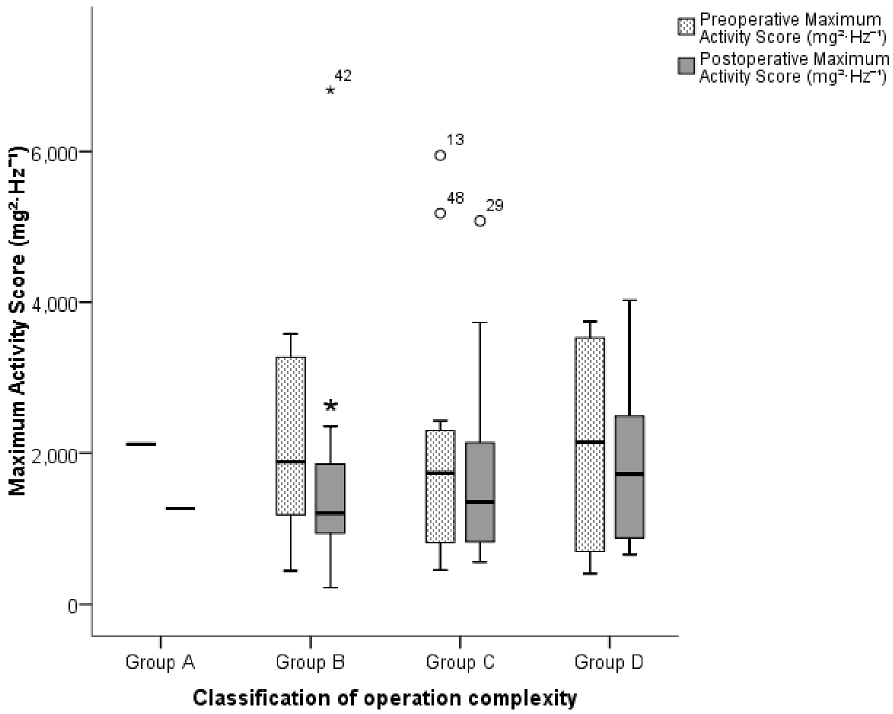
Postoperative accelerometry feature	Results for overall group n=31	Correlation with preoperative accelerometry feature result (Pearson r coefficient)	**Classification of operation complexity** **A** **(head and neck requiring tracheostomy) n=1**	**B** **(major head and neck, Whipple procedure, oesophagectomy, abdominal wall reconstruction) n=12**	**C** **(major bowel and urology surgery, open AAA repair) n=12**	**D** **(EVAR, laparoscopic non-major bowel surgery) n=6**
Activity Score (mg^2.Hz^{-1})						
Mean	**59** (21.9)	0.639	46	**57** (42–72 [33–116])	**49** (44–61 [43–89])	**62** (42–94 [40–112])
Standard deviation	**99** (82.5)	0.652	106	**72** (44–108 [13–338])	**61** (43–98 [36–215])	**119** (34–245 [30–330])
Maximum	**1297** (877–1999 [217–6813])	0.469	1270	**1207** (931–1930 [217–6813])	**1358** (805–2238 [560–5079])	**1724** (822–2875 [655–4027])
Time spent in activity score above a threshold of 500 or 1000						
%ASO>500	**0.43** (0.11–1.49 [0.–4.4])	0.764	1.34	**0.48** (0.05–2.35 [0–4.4])	**0.32** (0.08–0.60 [0.02–1.94])	**1.4** (0.1–2.7 [0.1–3.7])
%ASO>1000	**0.07** (0–0.54 [0–1.86])	0.696	0.60	**0.04** (0–0.16 [0–1.86])	**0.08** (0–2.57 [0–1.27])	**0.6** (0–1.7 [0–1.8])
Categorised activity						
%Active	**5.2** (3.3)	0.788	2.9	**6.3** (3.1–8.3 [0.3–15.3])	**4.1** (2.8–6.6 [2.1–8.0])	**5.0** (1.6–9.7 [1.0–9.8])
%Stationary	**46** (13.4)	0.184	54	**46** (39–58 [28–71])	**45** (33–56 [21–75])	**40** (33–52 [31–68])
%Lying	**52** (21.3)	−0.038	43	**48** (38–65 [26–167])	**49** (37–62 [21–78])	**51** (40–65 [29–68])
Maximum Time Active (mins)	**7.0** (2.8–11.3 [0.5–19.7])	0.488	10.7	**7.2** (2.7–13 [0.5–19.7])	**6.4** (3.2–10.1 [2.3–12.7])	**10** (2–13 [2–15])

Table 4.11 Postoperative activity monitoring results. Summary data for the accelerometry features are shown for all patients who underwent postoperative activity monitoring (n=31) and by operation complexity.

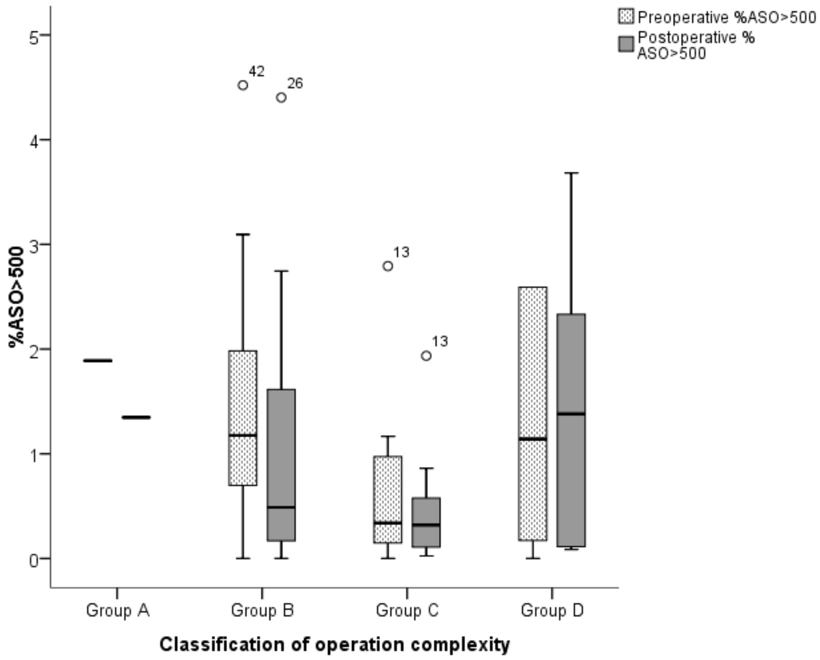
A


Preoperative Standard Deviation of the Activity Score (mg²·Hz⁻¹)
Postoperative Standard Deviation of the Activity Score (mg²·Hz⁻¹)
Standard Deviation of the Activity Score (mg²·Hz⁻¹)
400
300
200
100
0
42
13
13
Group A
Group B
Group C
Group D
Classification of operation complexity

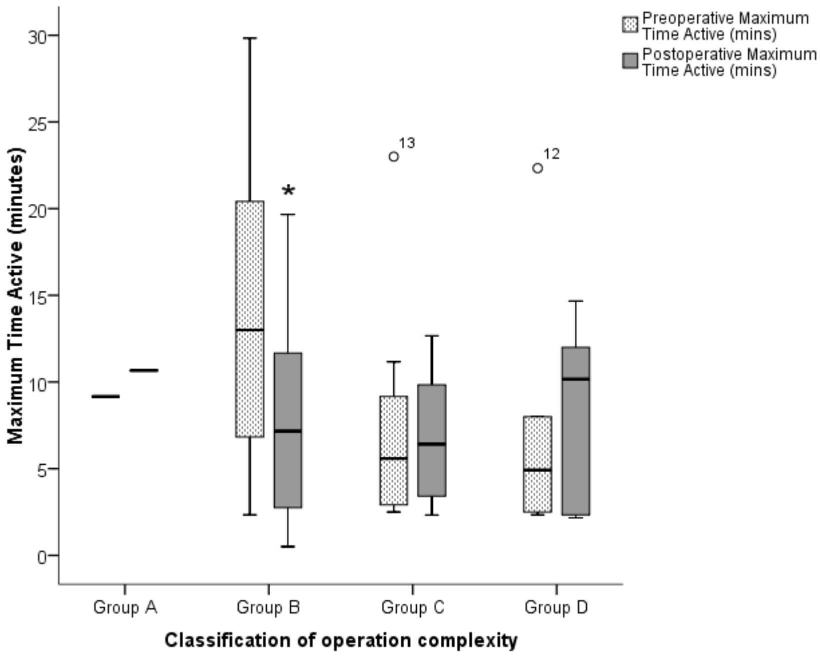
B


Preoperative Maximum Activity Score (mg²·Hz⁻¹)
Postoperative Maximum Activity Score (mg²·Hz⁻¹)
Maximum Activity Score (mg²·Hz⁻¹)
6,000
4,000
2,000
0
42
13
48
29
Group A
Group B
Group C
Group D
Classification of operation complexity

C


Preoperative %ASO>500
Postoperative %ASO>500
%ASO>500
0
1
2
3
4
5
42
26
13
13
Group A
Group B
Group C
Group D
Classification of operation complexity

D


Preoperative Maximum Time Active (mins)
Postoperative Maximum Time Active (mins)
Maximum Time Active (minutes)
0
5
10
15
20
25
30
13
12
Group A
Group B
Group C
Group D
Classification of operation complexity

E

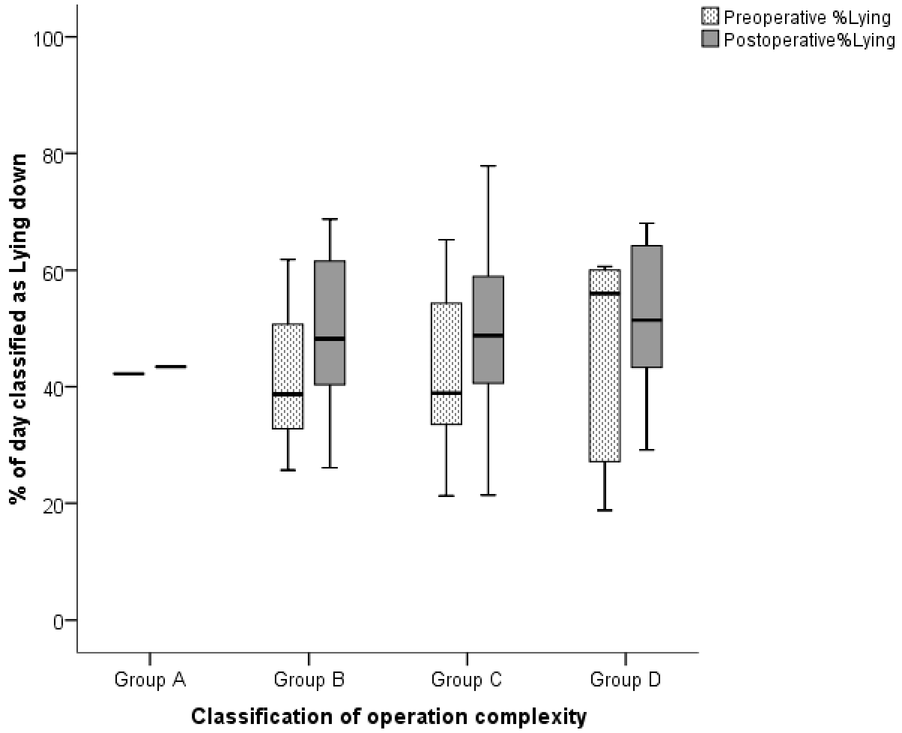


*Figure 4.10 Preoperative and postoperative accelerometry features (A, Standard Deviation of the Activity Score; B, Maximum Activity Score recorded; C, percentage of the day spent with an Activity Score over 500 (%ASO>500); D, Maximum continuous number of minutes classified as 'Active'; E, percentage of the day classified as Lying down, across the different groups of operation complexity. A * above a box denotes that the postoperative result was significantly different from the preoperative result for patients within the same group on Wilcoxon signed-rank test.*

Comparison of accelerometry features from the preoperative to the postoperative period

There was significant correlation ($p < 0.05$) between the preoperative and postoperative accelerometry feature results (Table 4.11), for all accelerometry features except *Maximum Activity Score*, *%Stationary* and *%Lying*. Features which showed a strong correlation between the preoperative and the postoperative results were *%Active* and *%ASO>500* ($r > 0.7$), and also the *Mean Activity Score*, the *Standard Deviation of the Activity Score* and *%ASO>1000* ($r > 0.6$).

A Wilcoxon signed-rank test showed that, for all 31 patients who completed postoperative activity monitoring, there was a statistically significant lower postoperative result for the accelerometry features of *Standard Deviation of the Activity*

Score ($Z = -2.077$, $p = 0.038$), the *Maximum Activity Score* ($Z = -2.391$, $p = 0.017$), the percentage of day spent in activity with Activity Score above 500 (*%ASO>500*) ($Z = -2.195$, $p < 0.028$), compared to their preoperative result. The accelerometry feature of the percentage of the day spent lying (*%Lying*) had a significantly higher postoperative result ($Z = -2.058$, $p = 0.040$) compared to the patient's preoperative time spent lying (Figure 4.10, boxplots A, B and E).

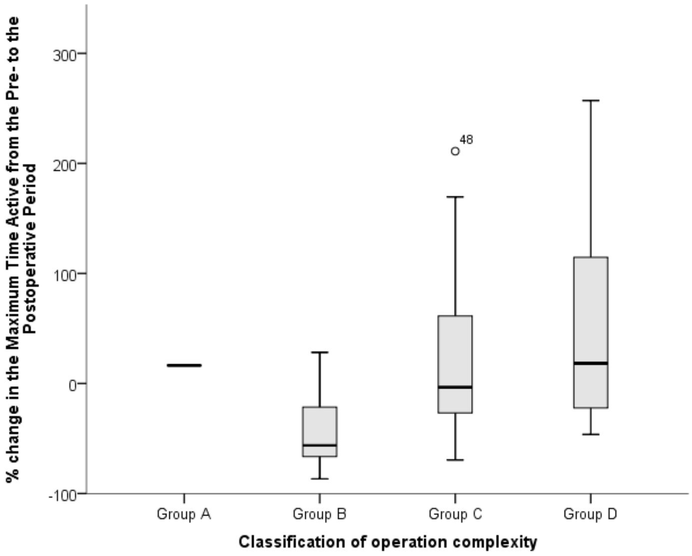
For each group B to D of operation complexity, Group B patients (n = 12) had a significantly lower *Standard Deviation of the Activity Score*, *Maximum Activity Score*, and *Maximum Time Active* (but no significant change in the *%ASO>500*) in the postoperative period compared to their preoperative result (Figure 4.10, boxplots A, B and E). However, Group C patients (n = 12) and Group D patients (n = 6) showed no statistically significant changes for any of the accelerometry features from the preoperative to the postoperative period.

Comparison of the percentage change in accelerometry features from the preoperative to the postoperative period between operation complexity groups

On Kruksal-Wallis test of the comparison between the groups of operation complexity, for the percentage change in each accelerometry feature from the pre- to the postoperative period, only the accelerometry feature of the percentage change in the *Maximum Time Active* showed a significantly different distribution between Groups A to D of operation complexity (Figure 4.11, boxplot A). The percentage change in *Maximum Time Active* was significantly higher in Group C (mean rank = 19.0) and Group D (mean rank = 21.3) compared to Group B (mean rank = 9.8), $\chi^2(2) = 9.27$, $p = 0.025$. The percentage change in the *Mean Activity Score* approached significance for being significantly different between the operation complexity groups, $\chi^2(2) = 7.787$, *p*

= 0.051 (Figure 4.11, boxplot B). The percentage change in the other accelerometry features from the pre- to the postoperative period showed no significant difference in distribution between the classifications for operation complexity.

A



B

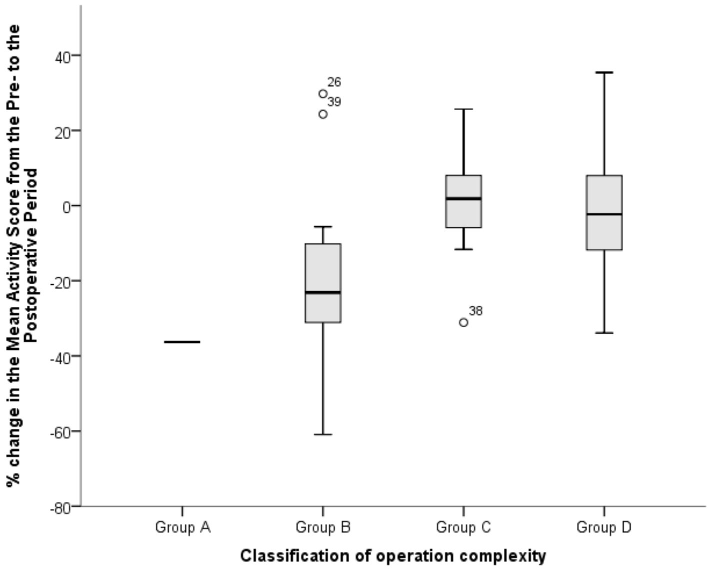


Figure 4.11 Comparison of the percentage change in A, the Maximum Time Active and B, the Mean Activity score, between groups of operation complexity.

Comparing accelerometry features between 'fit' and 'unfit' patients based on CPET

In addition to categorising patients by operation complexity, comparison of the percentage change (from the preoperative to the postoperative period) in accelerometry features between patients who were categorised as 'fit' or 'unfit' based on CPET results was also performed using the Mann-Whitney U test. This showed no significant difference in the percentage change in accelerometry features based on categorisation of 'fit' or 'unfit' using either $\dot{V}O_2$peak < 15 ml.kg^{-1}.min^{-1} or AT < 11ml O_2.kg^{-1}.min^{-1}. There was no significant correlation between the change in questionnaire score to the patient's preoperative CPET performance for all accelerometry features. The actual postoperative DASI and SF-12 score were significantly lower in the 'unfit' group of patients based on $\dot{V}O_2$peak < 15 ml.kg^{-1}.min^{-1}, and the postoperative DASI was significantly higher in the 'fit' group of patients based on AT < 11ml O_2.kg^{-1}.min^{-1}. This is the same finding as for the difference in preoperative questionnaire results between 'fit' and 'unfit' patients. Preoperative DASI, EQ-5D index score, EQ-5D VAS and SF-12 were all significantly lower in the 'unfit' group of patients.

4.6 Discussion

Few studies have investigated activity levels of patients before and after surgery using objective measures of activity and how this relates to patient physical fitness and outcomes. This study has investigated the relationship between preoperative CPET performance, preoperative and postoperative activity levels as measured using a wearable accelerometer, and preoperative and postoperative patient reported outcomes.

The aims of this study were to:

- Assess the feasibility of perioperative activity monitoring using a wearable accelerometer.
- To explore the associations between accelerometer variables measured at home with results from cardiopulmonary exercise testing (CPET) and patient self-reported activity levels.
- To investigate the ability of accelerometry features to discriminate for higher-risk patients.
- To identify which accelerometry features are useful as summary measures of daily physical activity in the preoperative fitness testing context.
- To explore if there was a relationship between patient self-reported function and quality of life measures and physical activity levels as measured using an accelerometer before and after surgery.

The way in which the results of this study relate to these aims are discussed below, including evaluation of the validity of this method of investigating patient fitness and limitations of the study.

4.6.1 Feasibility of activity monitoring in the preoperative and postoperative period

This study of 50 patients undergoing activity monitoring in the preoperative and postoperative period show that it is feasible and acceptable to patients. 94% of patients that were eligible went on to be recruited into the study. Only one patient said the device was uncomfortable to wear and the majority, (72% of patients preoperatively, and 81% postoperatively) wore the device for the requested period of 3 days preoperatively.

4.6.2 Relationship between preoperative accelerometer-based activity parameters and preoperative CPET results and patient self-reported activity levels

Current national and international preoperative assessment guidelines recommend formal assessment of aerobic fitness as part of preoperative assessment for patients undergoing major surgery.[50,140,141] A patient's highest achievable MET can be estimated using the DASI questionnaire or a formal exercise test. The DASI score results in this study, as expected, correlated strongly with $\dot{V}O_2$peak in this study (r = 0.69).[19] This study showed a moderately strong correlation (r = 0.6–0.65) between accelerometer-based activity parameters *Mean Activity Score* and the *Signal Vector Magnitude* and its co-correlated activity variables (*Standard Deviation of the Magnitude of Acceleration, %ASO>1000, %Active*, and the mean number of hours of moderate intensity activity per day), to CPET variables AT and $\dot{V}O_2$peak; and a moderately strong correlation between accelerometry parameters to the DASI questionnaire (r = 0.51). This is first time daily activity measured by an accelerometer has been compared to CPET and the DASI. These results show that there is a significant relationship between accelerometry parameters and traditional measures of patient fitness by MET estimation using CPET and the DASI questionnaire.

These results suggest that, for the purposes of predicting $\dot{V}O_2$peak and AT, use of DASI is likely to be easier to perform and as predictive as daily activity monitoring at home with a wearable accelerometer. However, given the evidence of the significant and positive relationship between accelerometer measured activity and CPET, the validity of using activity monitoring as part of preoperative assessment and optimisation is strengthened.

4.6.2.1 Predictive ability of the different summary measures of activity

On multivariable linear regression analysis, the accelerometer-based activity parameters that were most predictive for $\dot{V}O_2$peak and AT were those that measured the 'active' time periods. These included percentage of time active (*%Active*), the higher levels of activity (*Maximum Activity Score*, *%ASO>500*, the number of hours of moderate intensity activity as defined by SVM cut point), and the variability of activity (*Standard Deviation of the Magnitude of Acceleration*, the standard deviation of the SVM). These variables were similar in their predictive ability, contributing to explaining around 40% of the variation in $\dot{V}O_2$peak results which is similar to the ability of the DASI score to explain for $\dot{V}O_2$peak. Given that CPET is a measure of maximal exercise capacity, it is perhaps not surprising that the accelerometry parameters that aim to measure the higher levels of activity are more predictive of CPET performance.

Activity levels in this study were on average very low. It is not possible to gauge from the data available in the study as to whether this is expected for this age group, but it does provide insight as to the usual patient baseline activity level before preoperative exercise intervention. Worldwide, two-thirds of adults > 60 years are sedentary for more than 8.5 h of their waking day and in high-income countries, around 36% of adults were 'inactive'.[142,143] Although the majority of patients in this study were geriatric (78% were over 65 years), the accelerometer-based activity parameters suggests that this group of patients were still achieving well below the national activity recommendations which is 150 minutes of moderate to vigorous intensity physical activity (MVPA) per week, which should be done in bouts of 10 min or more for adults over 65 years.[67]

There is no established reliable method of classifying moderate intensity activity based on accelerometer data. The OmGUI software uses a validation dataset which has set cut-points based on signal vector magnitude from the AX3 device worn in different locations to differentiate for varying activity intensity. Using this method, this dataset showed that patients had a median of 1.3 hours (IQR = 0.7–2.3) of moderate intensity activity per day, based on 72 hours of activity monitoring. This would equate to over 500 minutes of moderate intensity activity per week, although the analysis was not restricted to only including bouts of 10 minutes or more. Other studies which have asked participants to estimate their time spent in MVPA per day, without consideration of bout time, using questionnaires, have shown this to be around 80-100 minutes per day.[144,145] Comparison of this estimate with an accelerometer shows moderate correlation, with the accelerometer estimating a similar number of minutes in MVPA.[144,145] It seems unlikely that this group of patients are exceeding the national guidelines for 150 minutes of MVPA exercise per week in bouts of 10 minutes or more, but the quantity of moderate intensity minutes measured is in line with patient self-reported estimates. It is likely that both patient-reported estimates and accelerometer-based estimate of MVPA are overestimating this classification of exercise intensity.

A small number of patients did achieve much higher activity levels. Two patients achieved a *Maximum Activity Score* of more than 10,000 mg^2.Hz^{-1} compared to the group median of 1296 mg^2.Hz^{-1}. According to SVM analysis, only two patients had any 60-second epochs which reached the threshold to be classified as vigorous intensity activity in the 72-hours. 7 patients achieved a Maximum Time in Continuous Activity with an *Activity Score* threshold >1000 i.e. at least light activity (MCTAS>1000) of more than 10 minutes compared to a group median of 2 minutes. These 7 patients all had a $\dot{V}$O2peak of more than 18 ml.kg^{-1}.min^{-1}. However, there is no clear cut off for activity parameters that guarantee a CPET performance above a certain level as can be seen in the scatterplots in Figure 4.6 and Figure 4.7.

In contrast to the evidence available for younger, fit adults, there is no standard accelerometry measure of activity that is known to be predictive of cardiorespiratory fitness in the older adult population.[146] By summarising the accelerometry data into variables related to activity and inactivity, these results suggest that being able to classify the higher intensity activities using accelerometers would be more informative in this context.

4.6.3 Ability of accelerometer-based activity parameters to identify 'fit' and 'unfit' patients preoperatively

In addition to the correlative relationship between accelerometer-based activity variables and CPET measured $\dot{V}O_2$peak and AT, there was also a significant difference in activity levels between patients categorised as 'fit or 'unfit' based on $\dot{V}O_2$peak and AT thresholds. The *Mean Activity Score* was more than 50% higher in the 'fit' group compared to the 'unfit' group (72.9 ± 33.1 vs. 47.5 ± 10.2). The accelerometry parameter, *%Lying*, did not show a significant correlation to CPET results, but was significantly different between the 'fit' and 'unfit' patients. 'Unfit' patients spent a greater proportion of the monitoring period classified as 'lying' than fit patients (47.3% ± 12.6 vs. 37. 9% ± 10.5).

A study of more than 2000 patients comparing accelerometer measured physical activity levels over at least one day to cardiorespiratory fitness measured by submaximal exercise testing found an inverse relationship between amount of time spent sedentary and cardiorespiratory fitness.[147] Although the amount of time spent doing 'exercise' level activities was more predictive of fitness in this study - each additional hour of daily exercise time was associated with a 0.88–1.37 higher achieved MET; sedentary time was also significantly associated with a lower achieved MET on exercise testing - each additional hour of sedentary time was associated with a −0.12 to −0.24 lower achieved MET.[147] Another study of oesophagectomy patients also found that patients who developed a postoperative pulmonary complications were more likely to be sedentary on activity monitoring preoperatively.[99]

I did not find any relationship between measures of inactivity on activity monitoring and the postoperative complication rate. However, national guidelines on recommended activity levels do emphasise the importance of reduction of sedentary time and this could be considered an important part of prehabilitation as will be discussed in Chapter 5. The patients in this study were mostly inactive, with a mean time of length of continuous activity of just 8.7 minutes. The mean percentage of the day in activity was low at 4.7% and the maximum time spent in activity which is just higher than being sedentary (i.e. an *Activity Score* of over 500 mg^2.Hz^{-1}) was a mean of only 1.04 minutes. Those patients who achieved even small amounts of time with an *Activity Score* of over 500 mg^2.Hz^{-1}, which suggests they were slightly more active than sedentary, were shown to have achieved better CPET performance in this study (1.05% vs. 0.7% of *%ASO>500)*.

In summary, for the discrimination of 'fit' and 'unfit' patients, it can be argued whether these thresholds for $\dot{V}O_2$peak and AT are inherently useful for prognosticating the outcome of patients. However, the use of CPET in this study was as a 'gold standard' measurement of cardiorespiratory fitness and the recommended test for preoperative fitness assessment. These results indicate that there is a difference in daily activity levels based on CPET performance and that the addition of activity monitoring variables may be useful in identifying higher risk patients for surgery.

4.6.4 Utility of summary measures of activity derived from accelerometry data

In previous studies, various statistical methods have been used to take raw accelerometry data and apply algorithms that can classify for a certain type of activity, or to estimate daily step count, or to estimate energy expenditure. This has provided a body of evidence which suggests accelerometry data is useful for measuring physical activity and predicting physical fitness. However, there is no consensus within, or across specialties, as to how to summarise raw accelerometry data into useful activity parameters and which activity parameters should be reported and their predictive value for cardiopulmonary fitness [29]. This is especially important in a preoperative population for major elective surgery as the activity levels will be generally low with a fewer range of recordable activities than the general population.

The UK Biobank study of population based accelerometry measurements over 7 days used the Euclidean norm of the acceleration in x/y/z axes of the accelerometry data and summarised the data as the mean vector magnitude in 5 second epochs.[87] This was able to demonstrate differences in activity levels between groups of patients based on sex and age and time of day, but this kind of summary activity data may be harder to utilise in a clinical context for an individual patient.[87] My study aimed to summarise the data based on both the mean vector magnitude (designated as the signal vector magnitude (SVM) by the OmGUI software), as well as the frequency of acceleration, (the *Activity Score)* as the two primary methods of accelerometer data analysis. The SVM analysis is similar to the Biobank analysis method as both use the mean vector magnitude, however, the Biobank data was based on wrist worn AX3 accelerometers and so is not directly comparable. The Biobank data did not use further cut point analysis to classify for time spent in different activity intensities as was done in this study. Identification of MVPA rather than just the average of all 24-hour activity would be an important function of accelerometers in monitoring exercise prescription. Time spent in moderate intensity activity (based on the OmGUI analysis of SVM cut points) was moderately strongly correlated to CPET measured peak oxygen consumption (r = 0.60) and AT (r = 0.55). This is compared to the weaker correlation of sedentary and light activity time to CPET performance, suggesting that identifying higher levels of activity is more important for accelerometry use in this context.

The use of the *Activity Score* in this study shows promise as a measure of activity that can be sensitive to differences and changes in activity levels needed for monitoring across the perioperative period. This may be because the *Activity Score* summarises the raw accelerometry data based on the distribution of the frequency peaks over a period of time rather than just the magnitude of acceleration, Although, both the SVM and the *Activity Score* were strong co-correlated, there is suggestion of a non-linear relationship based on scatterplot. On the other hand, the SVM and the time spent in moderate intensity activity based on SVM cut point was strongly correlated to *%Active* (which is based on an *Activity Score* cut-point) with a tighter linear relationship on scatterplot than the relationship between *Activity Score* and *%Active*. This suggests that the SVM may be better measure of the intensity of activity than measures based on the frequency of acceleration.

The results from this study demonstrate that many variables are co-correlated with relation to measuring amounts of activity based on time and magnitude of acceleration. However, it has also provided useful information that some parameters are not useful, in terms of having no significant correlation to CPET performance, such as the *Magnitude of Acceleration* overall and in the lateral and vertical planes, the *Tilt Angle*, and the amount of time spent stationary or in light activity (see Table 4.7). This is one of the few studies that have attempted to analyse raw accelerometer data and produce summary measures that are likely to represent patient fitness and be understandable to patients and clinicians looking to optimise patient fitness.

Although further evidence for CPET as a prognostic tool itself is still required, the comparative results with this CPET from this study form a basis on which to classify raw accelerometer data to better represent patient fitness.

4.6.5 Postoperative outcomes and utility of postoperative activity monitoring

The results of the postoperative monitoring period in this study have provided some useful insights into how activity levels may change before and after surgery and how this relates to patient reported outcomes after surgery.

4.6.5.1 Preoperative activity levels and clinical outcomes

The most important question for studies of preoperative fitness assessment is whether baseline level of fitness does prognosticate for postoperative outcomes and whether improving baseline fitness is protective against adverse postoperative outcomes. This study was not designed to investigate whether preoperative assessments predicted for postoperative outcomes. However, the results can give us some information how postoperative clinical outcomes may be related to preoperative CPET and activity monitoring results. Reassuringly, the $\dot{V}O_2$peak was significantly higher (median result 21 ml.kg^{-1}.min^{-1} vs 14.6 ml.kg^{-1}.min^{-1}, $p = 0.025$) in those who had no recorded complications compared to those with Clavien-Dindo grade 1-2 complications. However, there was no difference in $\dot{V}O_2$peak values between patients with no complications ($n = 15$) compared to those with Grade 3 to 4 complications ($n = 12$). The only preoperative accelerometry parameter which was significantly different between Clavien-Dindo complication grade groups was *%ASO>1000*. There was no relationship between preoperative CPET and accelerometry parameters and postoperative length of inpatient stay. The ability of CPET results to predict for morbidity (in the types of operations included in my study) is much weaker in evidence base than its prognostic value for mortality and length of stay.[24] However, unlike my study which showed no relationship between preoperative AT and postoperative complications, AT remained an important predictor of mortality and mortality for several intrabdominal operations in a systematic review.[24] My study has shown no evidence that preoperative levels of activity are associated with clinical outcomes, but this is largely due to study design and the heterogeneity of operations included.

A recent review by Steffens and colleagues (2019) concerning this question looked at 13 studies that reported either an objective or subjective measure of physical activity level preoperatively and at least one postoperative clinical outcome measure.[148] Of the 9 studies that investigated whether preoperative activity levels were associated with postoperative complications, only one study of radical hysterectomy patients reported a significantly lower rate of cystitis or dysuria in those with higher preoperative activity levels. None of the other studies showed a significant association between preoperative activity levels to postoperative complication rate or specific postoperative complications.[148] One study of colorectal patients found a significantly lower length of stay in those with higher preoperative physical activity measured using a subjective questionnaire.[148,149] Overall, on meta-analysis of the results from 8 studies, the Steffens and colleagues found that, higher preoperative activity levels were significantly associated with lower and length of stay and higher quality of life, but not with postoperative complications.[148]

4.6.5.2 Relationship between preoperative and postoperative activity levels

The postoperative monitoring results show that preoperative activity levels, CPET measured cardiorespiratory fitness and quality of life indicators are closely related to postoperative activity levels and quality of life indicators. This is largely to be expected that more active and happier patients preoperatively will also likely be the more active and happier ones postoperatively. The change in activity level from the pre- to the postoperative period was also not correlated to preoperative activity level, suggesting no protective element of high preoperative activity level against the fall in activity level postoperatively. Given the difference in complexity levels of the operations the patients received and only small numbers of patients in each operation category, it is not possible to draw conclusions on how preoperative activity levels affect the change to postoperative activity levels.

Few studies, other than bariatric surgery, have examined the change in objectively measured activity levels before and after abdominal surgery. A subset of 455 patients in a major study, the Longitudinal Assessment of Bariatric Surgery study (LABS-2), were given activity monitors which counted steps as a measure of physical activity before and after surgery.[150] Physical activity levels increased significantly after surgery, and after controlling for procedure, gender, age and BMI, more preoperative physical activity independently predicted for more postoperative physical activity.[150]

The evidence base for the relationship between postoperative activity levels, and postoperative complications and quality of life is poor. My study did show some effect of postoperative complications on postoperative activity levels and quality of life. The percentage of change between the preoperative and postoperative *%ASO>500* and *%ASO>1000* result was significantly different between patients with no recorded complications and those with Clavien-Dindo grade 1-2 or 2-4 complications (Figure 4.9, boxplot D and E).

The results in this study showing a relationship between preoperative assessments and postoperative outcomes is inconclusive but does show that postoperative monitoring is feasible and does represent the physical components of quality of life outcomes. For bariatric surgery and musculoskeletal surgery postoperative physical activity levels can indicate success of surgery for weight loss and function. However, given its lack of relationship with other quality of life indicators in this study, there may be an argument that measuring postoperative physical activity levels is not helpful for certain operations as an indicator of how preoperative patient activity and fitness affect postoperative outcomes, and that postoperative physical activity does not relate to outcomes important to the patient.

4.6.6 Study limitations

The limitations of the study included variability with CPET assessment and heterogeneity of operation types, the lack of sample size calculation, the use of CPET to classify for fitness category and limitations of use of the accelerometer to measure activity level.

Although the anaesthetists performing CPET followed a standard protocol, there were 4 different anaesthetists carrying out CPET which would have introduced greater bias in some of the more subjective elements of CPET execution and reporting. This could be examined for risk of bias by performing inter-observer correlation analysis.

For the postoperative results, the degree of variation in the operation types precludes meaningful inter-patient comparison of activity levels and quality of life measures but does still allow for intra-patient comparisons before and after surgery. This also limited the study in being able to assess preoperative activity levels as a predictor for postoperative outcomes and quality of life. Contrary to previous studies which have found significant associations between preoperative activity levels and length of stay and postoperative quality of life, this study found no convincing similar associations. However, only 2 of the previous studies which examined this out of 13 included in a review used an accelerometer, with most using activity questionnaires. Furthermore, only 3 studies measured postoperative quality of life, and this was with a single question of ‘how would you describe your quality of life in the last week / month’ with a range of 0 to 6 provided.[148] Further limitations of my study are discussed below.

4.6.6.1 Sample size

For this study there was no *a priori* sample size calculation for the comparison of means testing performed to look for a significant difference between accelerometer variables between those patients who were categorized as ‘fit’ or ‘unfit’ based on CPET thresholds for peak oxygen consumption and anaerobic threshold. When designing this study, the expected distribution of the accelerometer variables in this context was unknown and therefore precluded meaningful calculation of the sample size. The precedent set from previous studies which investigated CPET and patient reported measures of physical activity were used to estimate the sample size of 50 patients.[137,138] The results from this study and a recently published study using UK Biobank patients who wore a similar accelerometer have now been published, providing data on the distribution of accelerometer variables in this context.[87]

Based on the results from this study, a retrospective sample size calculation based on the mean and standard deviation of the accelerometer variables in the ‘unfit’ versus the ‘fit’ groups of patients show that the sample size was likely large enough to be able to detect a statistically significant difference on Mann Whitney U test. For example, the variable of *Standard Deviaiton of the Magnitude of Acceleration* is significantly higher in the 'fit group of patients based on a $\dot{V}O_2$peak ≥ 15 ml.kg^{-1}.min^{-1} compared to the 'unfit group' (0.058 ± 0.017 vs. 0.044 ± 0.010, $t(48) = -3.513$, $p = 0.001$) on independent samples t-test. Retrospective sample size calculation for this variable using the overall standard deviation for this variable of 0.015, and a power of 80% and 5% level of significance with a two-tailed test, produces a required total sample size of 38 which is lower than the estimated sample size of 50 patients used for this study.

4.6.6.2 Use of CPET threshold to classify for 'fit' or 'unfit' patients

The choice of setting the CPET thresholds for AT and $\dot{V}O_2$peak to classify patients into a higher category of risk for surgery may have misclassified some patients as there is current debate on how the thresholds should be set. A recent systematic evaluated 37 studies of CPET as a risk-assessment method before intra-abdominal surgery.[24] This review suggests that different thresholds should apply to different types of surgery and that subgroups of fitness based on CPET results may be preferable to using a single cut-off point. However, it did conclude, based on the available evidence for CPET thresholds and subsequent outcomes of surgery, that for abdominal aortic aneurysm operations a $\dot{V}O_2$peak threshold of 15 ml.kg^{-1}.min^{-1} should be used. Similarly, for intra-abdominal surgery, an AT threshold of 10.9 ml O_2.kg^{-1}.min^{-1} is associated with increased risk of mortality and patients with an AT of 10.1 to 12 ml O_2.kg^{-1}.min^{-1} should be treated with caution. The CPET thresholds were not altered according to operation in the design of this study as this was a heterogeneous population which also included patients undergoing major head and neck surgery, for which there is less evidence for the value of preoperative CPET.

4.6.6.3 Using accelerometer data to represent daily physical activity

Wearable accelerometers were used in this study to provide an objective and detailed measure of patient activity, in an aim to improve on previous measurements techniques based on patient self-reported activity levels. However, the extent to which physical activity levels can be represented by a wearable accelerometer and how the data from accelerometers should be summarised to give the best surrogate for physical activity levels is not known. A discussion of some of the issues surrounding validity of accelerometer data to represent physical activity in this study are discussed.

Accelerometer position

The AX3 accelerometer was positioned in the middle of the chest location, were soft-tissue interference was unlikely and attachment with a plaster was easy and reliable. Adding one further accelerometer on the hip would likely have improved classification of the type of activity being performed but may have reduced patient compliance with wearing two devices.[151] However, almost all of the validation studies for accuracy of accelerometers to classify activity and estimate energy expenditure involved healthy volunteers, and therefore less is known about measuring ambulatory activity in a more elderly and less active population. In the context of preoperative patients with overall low activity levels as shown in my study, the chest worn accelerometer may offer better sensitivity for lower intensity activities. The chest position is thought to be more sensitive to picking up lower intensity movement but may have underestimated activity levels in those more active patients who had greater range of upper limb and lower limb movements.[109,124]

Furthermore, in terms of being able to compare results to other studies, epidemiological studies of population activity prefer to use the wrist location as this is more convenient for the wearer and thus results in very high compliance in wear-time, and may be superior to measuring ambulatory activities more likely seen in the household than walking activities.[87,152] This has posed a barrier for being able to compare the results of my study, using the chest location, to population studies with results using the wrist location. For example, the UK Biobank data, which offers the best population comparison, has used the same AX3 accelerometer but in the wrist position, and another recent study of perioperative activity monitoring using the AX2 also used the wrist location.[87,153] This has resulted in an open-source software platform which uses their analysis method, but this would not be usable on the data from this study as the algorithms cannot be translated to the chest location. No other validation datasets for activity classification exist for the chest location, and therefore, use of the OmGUI software based on a validation study using the waist location is the best approximation. If future population studies will continue to use wrist based devices then chest-based validation data may become irrelevant.

Accelerometer wear time

Participants in the study were asked to wear the accelerometer for 72 continuous hours with 75% of patients achieving at least 72 hours of monitoring. This period was chosen as an optimal balance between trying to achieve good compliance with the wear time and recording enough activity data to represent daily physical activity levels. There is no consensus on the duration that an accelerometer should be worn to gain a representative sample of the patient's daily activity. Previous studies haves suggested that between 2 days, with at least 10 hours of monitoring per day, to 7 days of monitoring are required to get a reliable measure of habitual physical activity.[87,154,155] Studies have also shown that the difference between weekends and weekdays is not significant enough to influence reliability if the monitoring covers different numbers of weekend or weekday days.[154] A study of 92 healthy participants found that the "day of the week" effect accounts for only 1-8% of variance in activity data, and at least 3-4 days of monitoring are required to achieve 80% reliability.[156] The UK Biobank study of 96,600 participants who wore an AX3 accelerometer on the wrist for 7 days, showed that vector magnitude of the accelerometry readings were higher at weekdays except for those aged 45-54 years, but the mean effect size for these days difference was small (0.10).[87] They also concluded that at least 72 hours of wear were needed to be within 10% of the true stable seven-day measure of habitual physical activity.[87]

Summarising raw accelerometry data to represent physical activity

In collaboration with the engineers at McLaren Applied Technologies and using their expertise of how to summarise and classify raw accelerometry data, I developed a new set of activity classifier variables as described in Table 4.1. The aim was to classify accelerometry data into more clinically understandable variables that can be used as summary measures of activity level which may be useful for future studies, such as those implementing preoperative exercise interventions.

However, this method was not based on a validation study using indirect calorimetry to measure energy expenditure associated with accelerometry variables. The *Activity Score* thresholds used for defining an 'active' epoch and the classification into *Activity Score* categories of above 500 or 1000 were based on a small experimental dataset in healthy individuals without comparison to a method measuring energy expenditure. Although the *Activity Score* did show correlation to CPET results, it is difficult to compare *Activity Score* results to other studies which largely use the mean vector magnitude method of analysis, rather than the MAT method of using the frequency domain of the accelerometer signal for summarising actvitiy data.

Reassuringly, the results show, that using the mean vector magnitude method generated similar conclusions to the results using *Activity Score* with strong correlation between SVM and *Activity Score* (r = 0.90). Although SVM appears to linearly correlate most strongly with *%Active* (r = 0.92) suggesting SVM may be more sensitivie to higher activity than the Activity Score. Therefore, this study has shown that both using the vector magnitude and frequency domain analysis approach to raw accelerometry data yeilds similar correlation and predictability to CPET results.

Accelerometry results in the context of other studies

The analysis of average vector magnitude in the preoperative accelerometry data in this study allows for some ability to compare with other studies that have used this method of analysis in a similar population. The UK Biobank study results of the subset of the sample that were aged 65-74 years (n=40,874) showed a mean acceleration vector magnitude of 26.1 m*g* based on their method of average vector magnitude summarisation of the data.[87] In the subgroup of patients aged 75 to 79 years (n=3064) the mean vector magnitude was 23.4 m*g*. The results of my study showed a lower median SVM of 13.4 m*g* (IQR = 10.6-17.2), although it is difficult to make a comparison due to different accelerometer positioning (chest vs. wrist) and different analysis algorithms. Although the Biobank analysis used 5 second epochs rather than the 60 seconds epochs used in my study, analysis using 5 seconds epochs in my study yielded the same results for SVM over 72 hours as using a 60 second epoch.

Further comparison can be made with another study from Grimes and colleagues using the AX3 on the wrist location for 34 preoperative patients who wore the accelerometer for at least 72 hours.[153] The mean age of the sample in this study was 79.9 years, and included patients who were undergoing orthopaedic operations (57%), urology, gynaecology, vascular and breast operations. There was a higher proportion of patients classified as ASA 3 (77%) compared to my study which comprised 38% of patients. The median baseline physical activity using average vector magnitude analysis was 14.3 m*g* (IQR 9.75–22.04) in the Grimes and colleagues study, which is lower than the Biobank average for a similar age group, and closer to the SVM found in my study of 13.4 m*g*.[87,153] After a period of prehabiliation in the Grimes and colleagues study, the median vector magnitude increased to 20.91 m*g*. The authors found no significant correlation between accelerometer measured activity and self-reported activity using a questionnaire, and no change in self-reported activity before and after the prehabilation intervention.[153]

Given the results of the Grimes and colleagues study and findings in my study, the activity levels of the surgical population do appear to be lower than that found in the general population. My study results show a difference in median SVM of 11.3 mg vs 17.1 m*g* between the 'fit' vs the 'unfit' group of patients as classified by CPET peak oxygen consumption. It is not known how changes in accelerometry variables relate to changes in cardiorespiratory fitness as measured using CPET. It is suggested that an increase in preoperative $\dot{V}O_2$peak of at least 1.5 to 2 $ml.kg^{-1}.min^{-1}$ is a clinically significant increase that confers benefit to improving postoperative outcomes.[157,158] The degree of change needed to be observed in accelerometry values to relate to a change in $\dot{V}O_2$peak requires further research. Only with this understanding can activity monitoring as part of exercise prescription be used to determine if cardiorespiratory function is changing.

Validity of classification of activity intensity using accelerometer data

Further manipulation of the raw accelerometry data can attempt to estimate activity intensity based on a cut point of the vector magnitude or frequency of acceleration, or by applying pattern recognition for specific types of activity such as walking, running, upper limb activity or cycling. Threshold-based systems, such as the cutpoint analysis used by the OmGUI software can provide an estimate of activity intensity from sedentary to vigorous, but this is based on one validation study, and external validity outside of the populations the cutpoints were developed from is questionable.

The thresholds used by the OmGUI software for activity intensity was based on a study by Esliger and colleagues study. This study used the GENEA triaxial accelerometer in the waist position, and measured SVM in 60 healthy volunteers aged 40-65 years, performing a series of structured tasks with concurrent metabolic gas analysis.[103] The tasks ranged from lying, to sitting computer work, domestic chores, to treadmill walking, and included two free-living activities of brisk walking and running. The peak oxygen uptake results from the gas analysis was converted into metabolic equivalents which corresponded to different activity intensity categories (sedentary <1.5 METs, light 1.5–3.99 METs, moderate 4.00–6.99 METs, or vigorous ≥7 METs). ROC analysis was used to estimate optimal cutpoints for SVM thresholds for each intensity category.[103]

In the absence of other similar datasets to the population in my study, this validation dataset was used as a close approximation to give an indication of what a meaningful threshold for a higher level of activity may be. However, important differences exist between this validation dataset used by Esliger and colleagues and my study including difference in population age, the accelerometer used and positioning.[103] In additions, the same issues with using absolute vs. relative activity intensity would apply to validation studies of an older, less fit population such as the perioperative cohort who would be referred for CPET. As patient comorbidities such as cardiopulmonary disease limiting ventilation capacity, vascular and orthopaedic and neurological conditions affecting mobility come into play, the more difficult it is to develop a generalisable cutpoint analysis for accelerometry values to classify for activity intensity amongst one age group or disease state.

Furthermore, moving from laboratory-based validation studies to application for activity monitoring in the free-living environment, the validity of the accelerometer parameters to be able to represent free-living activity for any one individual is not certain. This is difficult to determine and there is not usually a pragmatic solution available for this patient population. In order to validate for the type or intensity of activity, or energy expenditure during activity, laboratory type conditions are usually required or the use of cumbersome equipment measuring indirect calorimetry. Body-worn cameras and patient diaries can help prove the activity taking place but are limited in the scope of information that can be given to contextualise and validatate accelerometer data, as well as being inconvenient for patients.[159]

Summary of the limitations of accelerometry assessment of functional capacity as part of preoperative assessment

Use of activity monitors to count steps is relatively well established, but automated identification of activities and the ability to classify for activity intensity is still not well validated and developed. In the free-living environment, the number, location and type of wearable sensors used will be limited by participant tolerability. Sensors will vary in their signal output across different subjects and for the same individual. Errors can arise from user variability in how the sensor is worn.[110] The need to clean the sensor data can consitutute a large workload and multiple algorithms to correct for wrong positioning or non-wear periods. Non wear periods can be hard to identify and almost impossible if the sensor if not worn but still being moved around for example in a pocket or bag. A summary of the ideal activity classification is quoted below from a review by Preece and colleagues:

> *"The ideal activity classification scheme works off-the-shelf, using data from a range of previous subjects to identify activities from an unseen individual. However, sometimes this is not possible, and an intra-subject classification scheme is currently all that can be achieved for some problems. With this approach, example data are required for a given individual before classification can be performed."*[110]

This is indeed a learning point from my study, that inter-subject activity classification and comparison is very difficult, and even for intra-subject classification, this is likely to require a set of example data with which to compare future accelerometry data to in order to make sense of free-living activity monitoring.

4.7 Conclusions

This study is the first to investigate the utility of activity monitoring using a wearable accelerometer as a novel tool for assessment of functional capacity in preoperative patients. The results from this study has informed this aim by providing the following key findings:

- Accelerometer measured parameters relating to the variance of the magnitude of acceleration, the frequency-domain of the accelerometer signal, the higher levels of activity as well as some measures of inactivity have been shown to have utility in representing patient fitness level before surgery. The results do not show that activity monitoring provides enough information to be able to replace CPET testing in terms of reliably assessing functional capacity but does show that it can be used to estimate baseline patient fitness.

- This utility is demonstrated both in the correlation between certain activity monitoring parameters and CPET performance, as well the discriminatory ability to distinguish between ‘fit’ and ‘unfit’ patients.
- Preoperative physical activity level is associated with postoperative physical activity level and some quality of life measures.
- Preoperative physical activity level in this group of patients before major surgery is generally low but also hugely variable between patients. Therefore, in planning prehabilitation exercise intervention, preoperative baseline physical activity level as well as functional capacity measured using CPET is likely to be helpful to guide dosage of exercise prescribed to an individual patient. The results from this study forms a basis to understand the range and variance of activity expected in this population to guide further studies of activity monitoring in this population.

The real value of being able to measure physical activity in the preoperative period is likely to be seen in preoperative exercise interventions where dynamic, real-time information on activity levels can help inform exercise prescription, patient motivation and adherence to exercise programs. This potential use and a clinical study to investigate this is discussed in the next chapter.

5 Clinical study of prehabilitation with activity monitoring before major urological surgery

5.1 Introduction

Prehabilitation was originally an academic term to describe the concept of preoperative rehabilitation. It is now being used more in the clinical environment to mean the process of enhancing the functional capacity of an individual to withstand a stressful event.[160] For surgical patients, this will refer to the process spanning the duration between the diagnosis and decision for surgery to the operation itself.

Several prehabilitation interventions have been investigated for surgical patients and some have been adopted into clinical practice. A recent survey of prehabilitation interventions available in the UK by the Macmillan Cancer Support charity shows that physical activity is always present as an element of prehabilitation for cancer patients, dietary support and psychological wellbeing are often present; with anaemia management, smoking cessation and alcohol reduction, respiratory exercises, medication and comorbidities review being sometimes present.[160]

Exercise intervention as part of prehabilitation is a relatively new component but has generated a great deal of research interest, coinciding with the increased availability and uptake of cardiopulmonary exercise testing. A review of the evidence of prehabilitation studies is presented below. Prehabilitation in urological surgery patients is discussed here as this is directly relevant to the patient population to be investigated in this study. One full RCT and one feasibility RCT have been conducted using preoperative exercise intervention as part of prehabilitation in urological surgery.

5.1.1 Evidence for preoperative exercise intervention

RCTs of prehabilitation have included interventions that are mostly comprised of one or all of the following elements: inspiratory muscle training with the aim of reducing postoperative pulmonary complications (PPCs), aerobic exercise training (which can be low or high intensity, supervised or unsupervised), and muscle strengthening or resistance training.

Since 2013, at least 13 systematic reviews of studies of prehabilitation in abdominal or cancer surgery have been published.[38,161–172] Several of these systematic review have included a combination of patients undergoing both abdominal and lung cancer surgery.[161,163,172] Given the remit of this thesis is for patients undergoing non-cardiothoracic surgery, the reviews and studies discussed in this chapter will be predominantly for prehabilitation studies on abdominal cancer surgery patients.

A recent 2018 systematic review, by Luther and colleagues, of prehabilitation before major abdominal surgery included 16 studies of which ten were RCTs (including 4 pilot RCTs) and the remainder were cohort studies.[166] Interventions in studies ranged from one or more of: inspiratory muscle training, exercise intervention, nutritional support and smoking cessation, although no single study included all four elements. 5 out of 16 studies did not include exercise intervention. The authors found that the effect of inspiratory muscle training and exercise intervention was variable on postoperative clinical and functional outcomes with some evidence of benefit.[166] Five studies included preoperative exercise therapy and measured clinical outcomes postoperatively. Exercise interventions ranged from unsupervised exercise programmes for patients to do at home,[173] to a combination of supervised in-hospital sessions combined with unsupervised exercise at home,[174–176] to completely supervised.[177] Two further studies of preoperative aerobic exercise intervention did not measure clinical outcomes, but used the 6 minute walk test (6MWT) as the primary outcome for functional capacity.[178,179] A summary of recent, full randomised controlled trials is listed in Table 5.1.

Author	Year	Journal	Operation	Total number of patients (number in intervention group)	Mean age (yrs)	Intervention(s)	Control group	Outcomes measured
Carli et al.[178]	2010	British Journal of Surgery	Colorectal surgery	112 (58)	60	• Aerobic exercise 20-45 mins/day • Weight training 3x week • Home based; stationary bike provided • 1 home visit • 1 weekly telephone call • 4-week duration	• Walk daily for 30 mins • Deep breathing exercises 5 mins / day • 1 home visit • 1 weekly telephone call	• Primary: 6 MWT at 10 weeks postop • HADS • Complications • Physical activity questionnaire
Gillis et al.[179]	2014	Anaesthesiology	Colorectal cancer resection	77 (38)	66	• Aerobic and resistance exercises, 50 mins, 3 x a week • Home based • Moderate intensity • Relaxation exercises • 4-week duration	• Rehabilitation, same procedures as intervention group • 6 weeks after surgery	• Primary: 6MWT at 8 weeks postop • Self-reported physical activity • SF-36 • HADS • Post-operative complications
Jensen et al.[180]	2015	Scandinavian Journal of Urology	Radical Cystectomy (mini laparotomy or robotic assisted)	107 (50)	70	• Aerobic and resistance exercise 15 mins twice a day • Home based; step trainer provided • 2-week duration • Telephone call after 1 week	• Standard of care with enhanced recovery principles	• Primary: LOS • Secondary: complications, readmissions, mortality
Barakat et al.[177]	2016	Annals of Surgery	AAA surgery (open or endovascular)	124 (62)	73.4	• Aerobic and resistance exercise classes • 3 x 1 hour a week • Hospital supervised • 6-week duration	• Standard care • Normal lifestyle • Avoid any additional unsupervised exercises	• Primary: composite endpoint of cardiac, pulmonary and renal complications • Secondary: LOS, APACHE II score, CPET at end of preop period in some patients
Dunne et al.[181]	2016	British Journal of Surgery	Liver resection for colorectal metastases	38 (20)	62	• 12 x 30-minute exercise sessions on a cycle ergometer • Moderate to vigorous intensity • Supervised • 4-week duration	• Standard of care	• Primary: change in VO_2 max from baseline • Secondary: SF-36, duration critical care stay, complications, inpatient stay, readmission

Author	Year	Journal	Operation	Total number of patients (number in intervention group)	Mean age (yrs)	Intervention(s)	Control group	Outcomes measured
Barberan-Garcia et al.[176]	2018	Annals of Surgery	Major abdominal surgery (Inc. oesophagectomy, colorectal cancer resection, liver resection, gastrectomy)	144 (73)	71	• Unsupervised home personalised exercises and walking with use of motivational interviewing • Supervised high intensity cycle ergometer 1-2 sessions per week • 6-week duration	• Standard of care including advice on exercise, nutrition, smoking.	• Primary: incidence of postop complications • Secondary: LOS, 6MWT, SF-26, HADS, endurance time on cycle ergometer

Table 5.1 Summary table of recent randomised controlled trials of exercise prehabilitation before abdominal surgery. (APACHE II, Acute Physiology and Chronic Health Evaluation II; HADS, Hospital Anxiety and Depression Scale; SF-36, Short Form 36 health questionnaire; SIRS, systemic inflammatory response syndrome; 6MWT, Six Minute Walk Test)

5.1.2 Randomised controlled trial of exercise intervention before and after radical cystectomy

Jensen and colleagues conducted a RCT of preoperative and postoperative exercise intervention in 107 patients undergoing radical cystectomy via either a robotic approach or with minilaparotomy.[180] The control group (n = 57) received standard care with enhanced recovery principles. The intervention group (n = 50) received training from a physiotherapy to undertake a twice daily unsupervised home exercise program on a step trainer, plus six different muscle strengthening and endurance exercises, for two weeks. The intervention group also received one postoperative week of in-hospital supervised exercises. The primary outcome was length of stay, and secondary outcomes were postoperative complications, readmission rate and mortality. Compliance to the prehabilitation program (defined as completion of at least 75% of the program as determined by a phone call after one week) was 59%. There was no significant difference in both length of stay as the primary outcome, or severity of complications as the secondary outcome, between the intervention and control group.[180,182] Factors that may have contributed to no difference between the groups were: a too short preoperative intervention time of two weeks; the use of less invasive methods of radical cystectomy and good application of enhanced recovery after surgery (ERAS) principles that delivered a general reduction in length of stay and complication severity; and the lack of objective evidence of compliance to the home exercise program given that it was unsupervised with only a telephone call to check compliance.[180,182]

5.1.3 'Prehabilitation for radical prostatectomy: A multicentre randomised controlled trial'

Mina and colleagues conducted a feasibility RCT, which randomised 86 men, to either a control group (n = 42) that received a lifestyle support booklet and pelvic floor exercise instructions; or to exercise intervention (n = 44) comprised of home-based moderate intensity exercise (as well as pelvic floor exercises) prior to either open or robotic-assisted radical prostatectomy.[183] The intervention consisted of a personalised exercise prescription of 60 minutes of unsupervised home-based exercise, 3-4 days a week for the duration of time from consent for surgery to the operation date which was an average of 6 to 7 weeks. A heart rate monitor was used to allow the patients to reach heart rate-based training zones during aerobic exercise at home, and an exercise manual, video and equipment was also provided. Adherence was measured using a logbook completed by the researcher during weekly communication. The adherence was measured to be 69% in the exercise group of meeting the minimum target exercise volume. This feasibility study found a decreased level of anxiety (measured using HADS anxiety score) and body fat percentage in the intervention group from baseline to before surgery and significantly greater increase in 6MWT distance in the intervention group compared to the control group at four weeks postoperatively. The exercise intervention group returned to baseline 6MWT distance at 4 weeks postoperatively compared to 12 weeks in the control group.[183] No clinical outcomes were examined in this feasibility study. No conclusions on efficacy of prehabilitation in radical prostatectomy patients can be drawn from this study, although it shows it is feasible in this setting and may confer some mental health and functional benefit.

The learning points from this study and other studies reviewed here are discussed in the next section, as the basis for the design of the prehabilitation study conducted as part of this thesis.

5.2 Study rationale

Across the number of the systematic reviews of prehabilitation studies, most have concluded that there is limited evidence in demonstrating physiologic improvement in patients undergoing prehabilitation and it is difficult to show an improvement in clinical outcomes such as postoperative mortality, length of stay and postoperative complications. This may be due to a number of factors including: lack of adherence to the exercise programme, difficulty in choice of physiological endpoint to measure, difficulty ascertaining which components of the exercise regime contribute to an optimal exercise program, difficulty in defining the optimal duration of prehabilitation necessary, lack of consideration for which patients would benefit most from prehabilitation and lack of distinction between types of operation including open versus laparoscopic surgery.[166,169,184,185] These are issues which should be addressed in future prehabilitation studies. This next section discusses some of the main issues that have been highlighted in previous studies and systematic reviews, which form the basis of the study design chosen in this thesis.

5.2.1 Risk stratification of patients for inclusion

Given that the benefits of prehabilitation are to improve postoperative outcomes, and that high-risk surgical patients comprise the majority of those who have adverse postoperative outcomes, effective prehabilitation may only be shown if there is accurate risk stratification of patients for inclusion into prehabilitation interventions.

In the previous study, daily activity monitoring levels and use of functional questionnaires were compared to risk stratification as decided by CPET and the results showed that both the activity level parameters and the DASI offered good predictive ability compared to the gold standard of CPET.[186]

Therefore, the DASI questionnaire was used as a triaging tool in this study to identify patients who are likely to have low baselines levels of daily physical activity and would likely benefit most from prehabilitation.

5.2.2 Adherence to prehabilitation intervention and behaviour change techniques

Adherence to exercise prescription in prehabilitation studies is high in protocols requiring hospital visits and supervised exercise.[185] When trialling partial supervision with a community or home based exercise regime, methods to improve adherence are required as not all patients will be well motivated or have good opportunities to be able to exercise. This requires a strategy of trying to change patient behaviour using behaviour change techniques or BCT to either participate in an exercise prehabilitation program or to increase physical activity for those already motivated to participate. As my study will be home exercise with remote supervision, consideration of BCTs as part of the methodology will be crucial to the success of the exercise intervention.

In a review of prehabilitation programs for cancer patients, the most commonly reported and often only BCT employed for prehabilitation was patient education and information provision which, used alone, is known to be insufficient for behaviour change.[187] Few studies used additional BCTs, which included provision of activity monitors, goal setting, motivational interviewing, self- monitoring, and behaviour change consultations led by nurses.[187]

To improve the behaviour change aspect of prehabilitation, a 2020 consensus statement entitled *'Psychological support and behaviour change interventions during the perioperative period for people with a cancer diagnosis'* was authored by Macmillan, the Royal College of Anaesthetists and the National Institute for Health Research.[187] This statement recommends that all prehabilitation interventions should be underpinned by behaviour change theory with an understanding of each patient's capability, opportunity, and motivation according to the COM-B system of developing a behaviour change intervention.

The COM-B model allows for a systematic approach to developing a behaviour change intervention for any target behaviour. This model was developed by incorporating what is known on behaviour change theory based on a review of 19 pre-existing behaviour change models by Michie and colleagues.[188] The components of the COM-B model are: capability, opportunity and motivation which interact to generate behaviour which in turn influences these components (Figure 5.1).[188] Capability refers to whether a person has the knowledge, skills and abilities required to engage in a particular behaviour. Opportunity refers to the external factors which make the execution of a particular

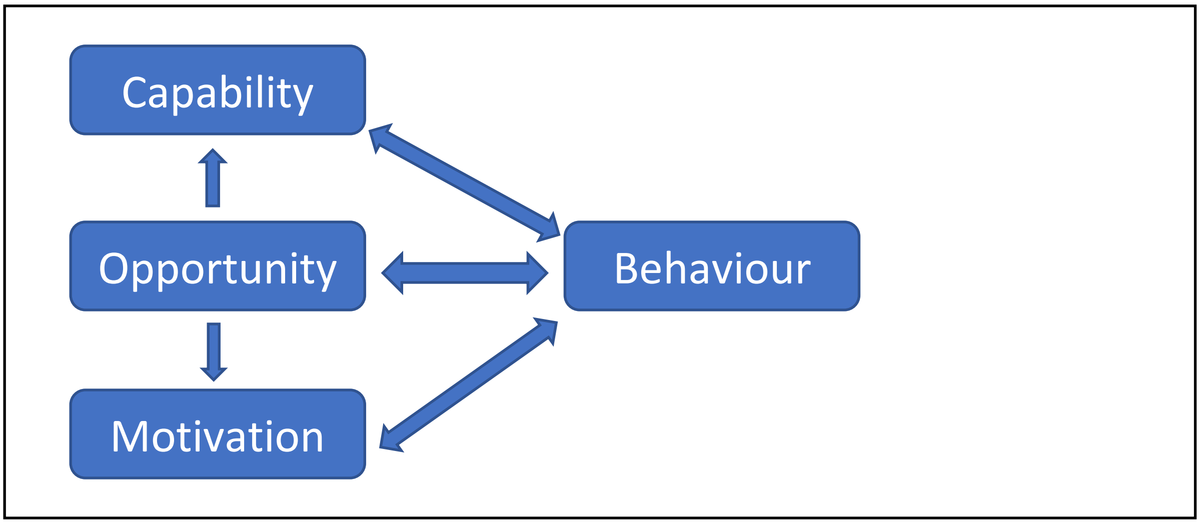


Figure 5.1 The COM-B framework for understanding behavioural change based on Michie et al (2011)[188].

behaviour possible. Motivation refers to the internal processes which influence a person's decision making and behaviours. Within the COM-B model, each component can be divided into two aspects and definitions of each component of the COM-B model is detailed in Table 5.2.[187]

COM-B Model		**Description**	**Examples**
Capability	Physical capability	Having the necessary physical skills, strength or stamina	Skills, abilities or proficiencies acquired through practice
	Psychological capability	Having the knowledge, understanding and confidence to perform the behaviour	Knowledge, memory, attention, decision, processes, behavioural regulation
Opportunity	Physical opportunity	Opportunities provided by the environment	Access to time, location, and resources Physical barriers
	Social opportunity	Opportunities as a result of social factors	Interpersonal influences from friends, family and healthcare social pressure, norms and cues, conformity, social comparisons
Motivation	Reflective motivation	Reflective processes such as making plan and evaluating things that have already happened	Beliefs about capabilities and consequences of behaviour, roles, identity, intentions, goals, optimism
	Automatic motivation	An individual's automatic processes or emotional reactions, desires, impulses, inhibitions and reflex responses	Emotions, reinforcement, such as rewards, incentives, punishment

Table 5.2 Definitions of the sub-categories of the components of the COM-B model of behaviour change.[187]

Motivational interviewing helps behavioural change in this framework by identifying which aspects of the COM-B need to change in order for a target behaviour, in this case increasing physical activity, to occur.[187] The exercise intervention can then be tailored to meet individual needs after assessment of their capability, opportunity and motivation to change their physical activity behaviour. For a particular patient, the only barrier may be opportunity whereas for another it may be capability. The rationale for the methods of prehabilitation exercise intervention used in my study are therefore based on the findings in the prehabilitation and BCT literature. Although activity monitoring is a cornerstone of the intervention, this must be accompanied by face-to-face interaction and other BCTs to be effective at increasing physical activity levels.

5.2.3 Intensity and format of exercise intervention

The prescribed exercise as part of prehabilitation in earlier trials were mostly based on moderate to high intensity exercise with the goal of increasing functional capacity quickly in a relatively short period of time before surgery.[189–192] More recently, the merit of low to moderate intensity exercise has been considered, especially as, for an elderly population, aiming for improvements in peak oxygen uptake measured by CPET with a high intensity exercise program may not be feasible or effective.[193]

The previous study in this thesis of a group of preoperative patients scheduled for major elective surgery shows a very sedentary population.[182] This study addresses this gulf between desired exercise intervention programs previously studied and the reality of what patients in the elderly preoperative population can be expected to achieve. The focus of the exercise is on achieving bouts of moderate intensity exercise as recommended by the WHO and UK physical activity guidelines.[27,70] This is also the conclusion of the recent systematic reviews.[167,170]

The recent systematic review of prehabilitation studies in major abdominal surgery by Hijazi and colleagues has recommended:

> *'A daily exercise intervention that is amenable to patients with minimal disruption and can be undertaken in their local environment is desirable. This is likely to achieve better compliance rates as well and therefore be more effective.'*[185]

This study aims to address these recommendations through implementation of a home based, remotely supervised exercise intervention. There will be personalization of the exercise prescription to the patient and their environment, with standardized exercises that patients can perform without the need of specialist equipment.

5.2.4 Choice of physiological outcome to measure

The choice of physiological endpoint and how this relates to the intervention will have a significant impact on whether a study shows an effect of exercise intervention on functional capacity. It is not known the best method to measure a clinically significant change in cardiorespiratory fitness and previous studies have used both CPET and a range of field tests of submaximal exercise capacity. The expected change in CPET parameters from a period of exercise intervention has not been shown in patients undergoing pulmonary rehabilitation for chronic obstructive pulmonary disease, whereas measures of exercise capacity such as the 6MWT and Intermittent Shuttle Walk Test have been validated in assessing physiological outcomes after exercise intervention.[194] Given the challenges with longitudinal CPET assessment in terms of time and resource, the 6MWT has been chosen as a representative physiological endpoint in this study.

5.2.5 Use of qualitative data in prehabilitation studies

The qualitative aspect is one of the largest gaps in knowledge for prehabilitation study design and can contribute to the better design of future prehabilitation trials requiring remote patient monitoring. Prehabilitation studies have largely focused on investigating the efficacy of preoperative exercise intervention to improve physiological parameters in the preoperative period and the impact on postoperative outcomes. However, few studies have also included qualitative data collection on patient views and experiences of prehabilitation as well as the impact of exercise prehabilitation on patient quality of life.[195] This is likely to be important when designing prehabilitation programmes, to ensure they are feasible, acceptable, and meet the patient's needs as well as the needs of the intervention. This is likely to lead to better patient motivation, compliance to prehabilitation interventions and longer lasting behaviour modification.[196]

Qualitative data also provides the opportunity to assess preoperative psychological factors which are known to impact postoperative psychological, functional as well as physiological outcomes such as postoperative pain and speed of recovery. Psychological intervention preoperatively can improve patient well-being and quality of life, by improving anxiety, depression and self-efficacy.[196]

The behaviour change techniques (BCT) employed in this study included patient education, motivational interviewing, use of self-monitoring, feedback and reinforcement aided by provision of activity monitors and timely feedback data, and physiotherapy supervision. The qualitative data was collected using end-of-study patient interviews to provide insight into patient attitudes to prehabilitation and their experience of the study. Development of complex interventions that result in successful behaviour change should include an explanation of how mechanism of action of the BCTs as recommended from the NICE guidance on 'Behaviour change: individual approaches'.[196] The design of the exercise intervention in this study was modelled on the COM-B model of behaviour change as outlined in Section 5.2.2 of the study rationale. Thematic analysis of the qualitative data aimed to use the insight gained from the patient interviews to guide development of effective BCTs for prehabilitation exercise intervention. This has provided useful context for understanding patient needs as well as help draw conclusions on the effectiveness of the behaviour change aspect of the study, including the novel use of remote monitoring and feedback of activity levels.[195]

5.3 Aims and Objectives

This study was designed to assess the feasibility of a method of low intensity, remotely supervised, prehabilitation exercise intervention with specific focus on optimisation of patient adherence and objective measurement of improvement in activity levels. Patient selection was designed to include only higher risk patients into the study, as determined by using the Duke Activity Status Index (DASI) score to estimate patients' METs. The objective measurement of activity level as part of prehabilitation will be improved with the use of wearable accelerometers with ability to provide remote, contemporaneous feedback to aid personalisation of and adherence to a prescribed preoperative exercise intervention. The study will focus on the preoperative period only and how effective this method of prehabilitation is at increasing daily activity levels and functional capacity as measured using the 6 Minute Walk Test.

	Objectives	Outcome Measures
Primary	To establish the rate of recruitment, compliance and suitability of home activity monitoring for this patient population, to help design a future randomised, controlled trial.	The following will be measured using the patient reported outcomes from the questionnaires and interviews and assessing the rate of compliance and reasons for non-compliance or drop-out: Suitability of exercise intervention, activity monitoring and feedback Suitability of the patient reported outcome data The following will be measured using the results of the accelerometry data: Feasibility of collecting the activity data and delivering the activity feedback online Suitability of the accelerometry outcome data Other feasibility measures: Recruitment rates and demographics of participants
Secondary	To determine whether a preoperative exercise intervention contributes to a change in physical activity levels and/or physical fitness.	Comparison of the number of minutes spent doing moderate or vigorous intensity activity over 4 days, pre- and post-intervention (measured using a wearable accelerometer). Comparison of the distance walked in the 6 Minute Walk Test, pre- and post-intervention period.
Secondary	To evaluate patient reported outcome measures related to function, quality of life and psychological well-being which may be secondary effects related to participating in the study.	Change in score from pre- to post intervention in the following questionnaires (completed pre- and post-intervention): EQ-5D-5L questionnaire IPAQ questionnaire GAD7 questionnaire PHQ9 questionnaire
Secondary	To gain insight into patient attitudes and viewpoints on prehabilitation in general and the interventions employed in this study To assess factors related to the COM-B model of behaviour change which are important for the design of exercise prehabilitation interventions	Thematic analysis of patient end-of-study interviews

Table 5.3 Synopsis of aims and objectives of the study. EQ-5D-5L, generic health status questionnaire; IPAQ, International Physical Activity Questionnaire; GAD7, Generalised Anxiety Disorder assessment; PHQ9, Patient Health Questionnaire for severity of depression.

5.4 Study design

This study was a single centre, randomized, feasibility study of preoperative exercise intervention in patients likely to undergo major urological elective surgery. This study was approved by the London Bloomsbury Research Ethics Committee (18/LO/0177). Patients who were referred to the urology department on an NHS 62-day treatment pathway for a possible diagnosis of urological cancer which was likely to require future major urological surgery (consisting of nephrectomy, cystectomy or prostatectomy) were recruited into the study with informed consent. Inclusion criteria included: achieving a score of 50.70 or lower on the DASI which would indicate the patient has reduced functional capacity and may benefit from prehabilitation; and the ability to access internet and email to be able to transmit their accelerometer data back to the research team and receive personalised feedback. Exclusion criteria included: medical comorbidities which would preclude the patient from being able to undertake the exercise intervention, a period of less than 6 weeks before the planned operation date, and lack of 3G phone signal at home to enable transmission of activity monitoring data.

Baseline assessments included: patient demographic and medical information; assessments of physical activity level and functional capacity (using the DASI questionnaire, International Physical Activity Questionnaire (IPAQ), 6 Minute Walk Test distance and 4 days of home activity monitoring using a wearable accelerometer with a heart rate sensor worn with a chest strap during waking hours); and quality of life assessments (the Generalised Anxiety Disorder GAD7 questionnaire, the PHQ9 questionnaire for depression severity and the EQ-5D questionnaire of generic health status). See Appendix B for copies of the IPAQ, GAD7 and PHQ9 questionnaires.

After baseline assessments, participants were randomised to the control or intervention arm in a 1:1 ratio using a web-based randomisation system. Those in the control arm received standard of care in the preoperative period and did not receive any exercise recommendations or daily activity monitoring at home during the intervention period of 4 weeks. Participants in the intervention arm underwent a second scheduled visit to formulate a personalised exercise plan with a physiotherapist, after which, they undertook 4 weeks of the prescribed exercise intervention with daily activity monitoring using the wearable accelerometer.

Feedback on their daily activity levels was provided via a web platform to which they could log in, as well as emailed activity feedback reports 3 times a week and a weekly phone call with the physiotherapist (see Figure 5.2 for the process of feedback on activity levels using the wearable accelerometer).

All participants in both the control and intervention arm underwent a further 4 days of daily activity monitoring at home at the end of the intervention period. At the end of the study, both groups completed the same questionnaires as the baseline assessment period, as well as repeating the 6 Minute Walk Test to assess for any change of distance achieved as a measure of change in functional capacity.

All participants were also interviewed by an external researcher to provided qualitative information on the feasibility of the study and effectiveness of the intervention. The total study period was 6 weeks and did not include recording of any postoperative clinical outcomes.

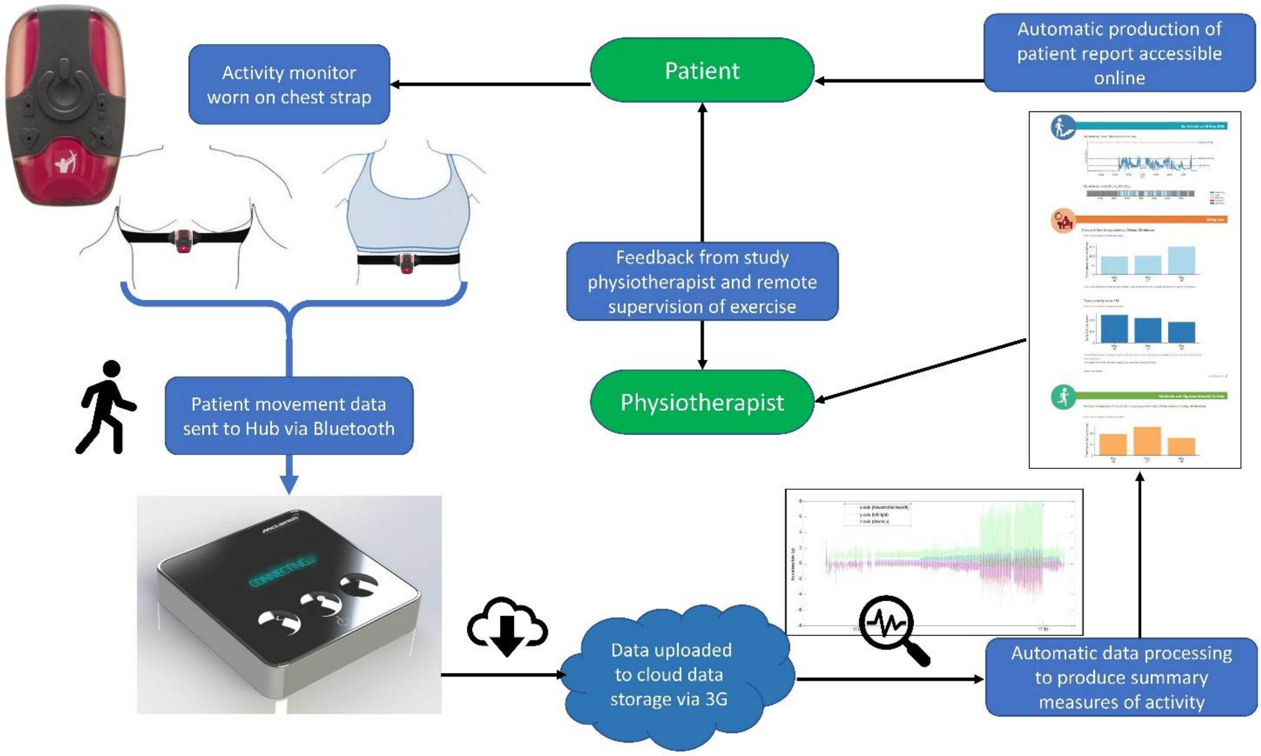


Figure 5.2 Process of activity monitoring, data analysis and feedback report generation during the study.

5.5 Study procedures

5.5.1 Study schedule

The flow chart for the study is shown in Figure 5.3.

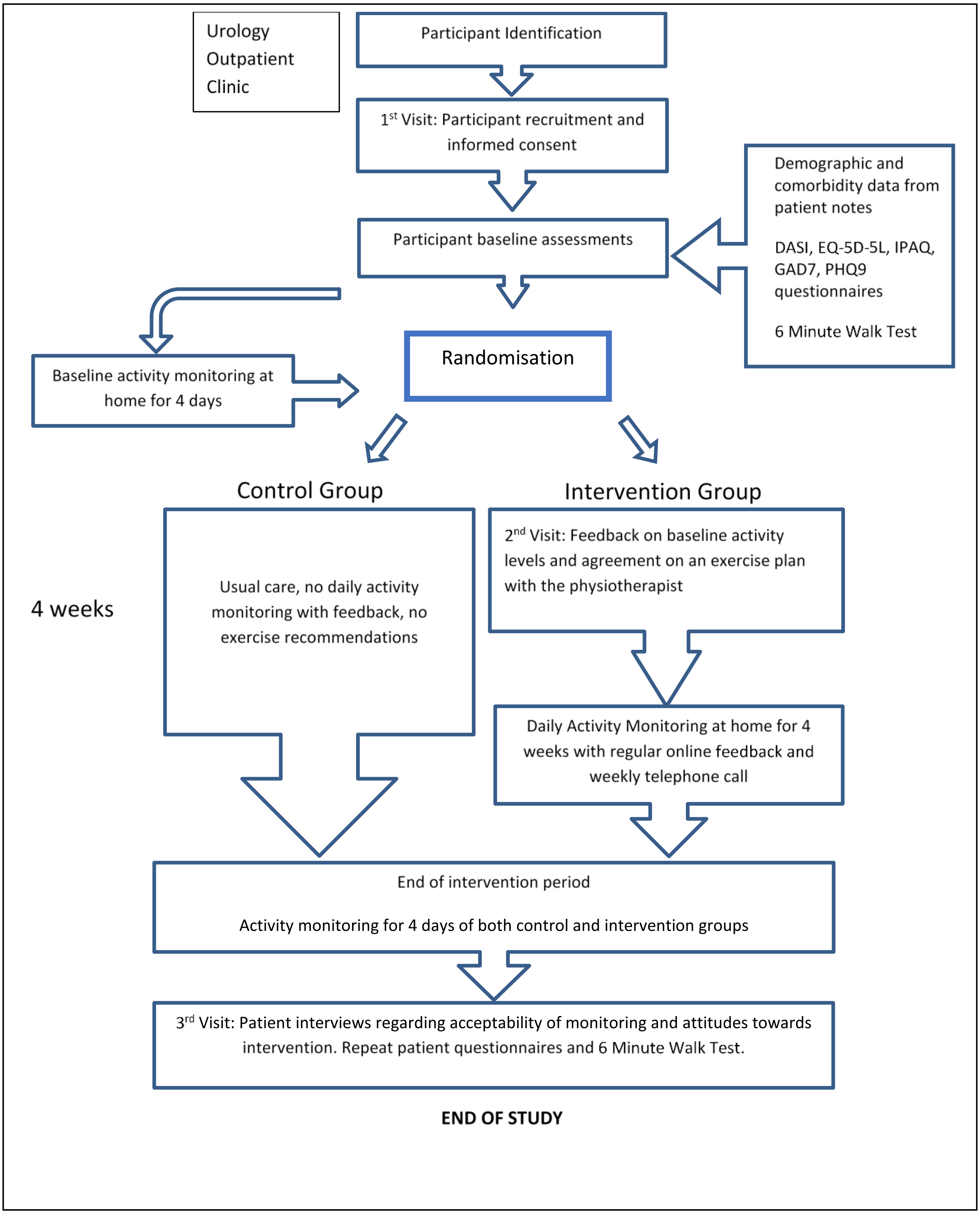


Figure 5.3 Flow chart of study events.

5.5.2 Randomisation and blinding

Once the participant had completed the 4 days of baseline activity monitoring at home, at which point all baseline assessments were complete, the patients were randomised on a 1:1 ratio to the control or intervention arm.

Researchers performing the outcome assessment of the 6MWT during the third visit and assessing activity levels measured by the accelerometer during the final monitoring period will be blinded to treatment arm. Participants will be reminded not to discuss their treatment arm with the researcher conducting outcome measurements.

5.5.3 Exercise intervention

Participants randomised to the intervention arm received a personalised, home exercise intervention. After baseline assessments and randomisation, the intervention arm patients returned for a second visit consisting of feedback on their baseline activity levels recorded during the initial 4-day period of monitoring followed by a 45-minute counselling session with the study physiotherapist. This consisted of a discussion between the participant and the physiotherapist on the formation of a participant home exercise plan aiming to achieve 150 minutes of moderate intensity aerobic exercise per week. Participant views on exercise including positive and negative experiences of exercise and exercise preferences were discussed with the aim of overcoming fears about exercise and finding pragmatic solutions for the participant to increase activity levels and reduce sedentary time. Motivational interviewing techniques were used to encourage patient empowerment and motivation to achieving their exercise goals. The 150 minutes of moderate intensity exercise could be comprised of any aerobic activity which is accessible and acceptable for the participant to undertake and can include brisk walking, jogging, cycling, swimming etc. The physiotherapist also advised the participant on performing resistance exercise twice a week as per current NHS physical activity guidelines for adults.[197] This is in accordance with the Chief Medical Officer Guidelines on activity recommendations for adults.[67]

The home exercise was tailored to each participant by considering their usual activity levels as evidenced by the International Physical Activity Questionnaire (IPAQ) and the initial activity monitoring data collected as part of baseline assessment. Based on usual activity levels at baseline, a progressive exercise dosing over the four weeks was formulated. To measure the exercise dose given to patients, the progressive increase in exercise dosing was set for all intervention arm participants. This comprised of a target of an average of at least 2.5% increase in number of minutes spent doing moderate or vigorous intensity exercise per day, over each week. Barriers to exercise and participant mobility will also be taken into consideration by the physiotherapist. Participants will be educated by the physiotherapist on what constitutes moderate intensity exercise and how to perceive exertion subjectively using the Borg Rating of Perceived Exertion (RPE) scale.[198,199] Patients left this session with a copy of their 'Personalised Exercise Plan' detailing the goals set out with the physiotherapist (see Figure 5.4).

Participants received activity monitoring feedback which included a visual representation of their activity levels divided by intensity, and a reminder of their weekly targets for minutes of moderate intensity activity (Figure 5.5 to Figure 5.8). This feedback was emailed to the participant three times a week, or the participant could check their feedback report by logging in to the online website with their username and password. The feedback report contained feedback from the accelerometer data that directly related to their 'Personalised Exercise Plan' including visual representation of the amount of time spent in sedentary, light, moderate or vigorous intensity activity. The method by which this was classified using the accelerometer data is described in the next section.

Participants received a 15-minute weekly phone call from the study physiotherapist to encourage compliance to the exercise plan and to complete a telephone administered IPAQ (short form) questionnaire. These telephone calls will be made by a study physiotherapist who has had trial specific training to deliver these interventions consistently to all intervention arm participants. Adherence to the exercise programme was recorded in the Case Report Form from the activity monitoring data and the telephone administered IPAQ.

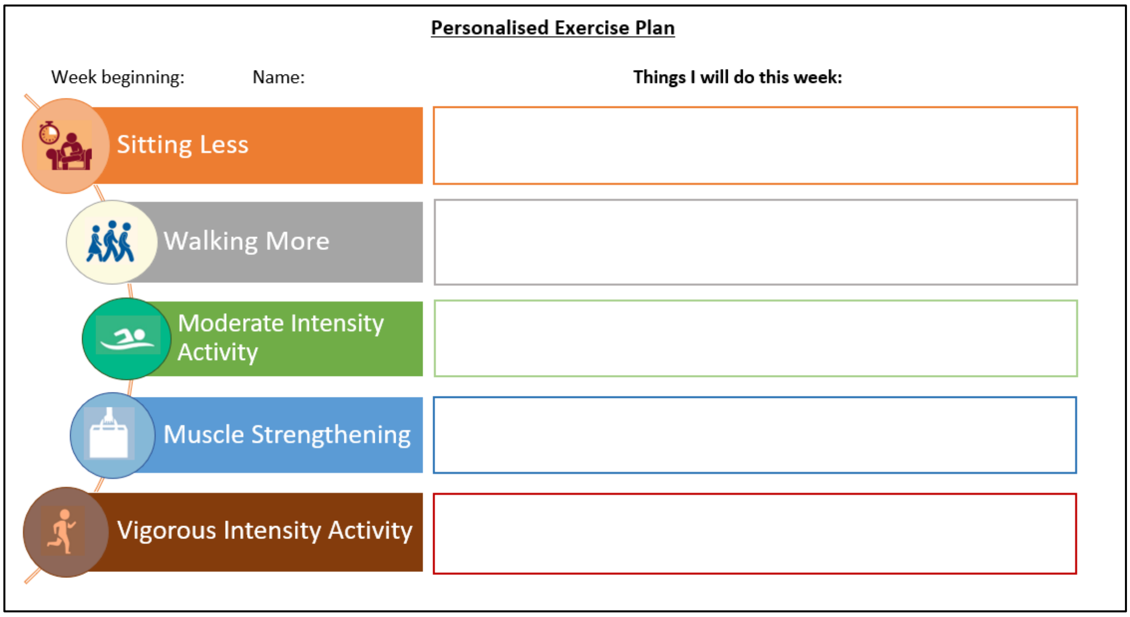


Figure 5.4 Format of personalised exercise plan completed during the initial counselling session between the participant and the physiotherapist to record agreed exercise prescription.

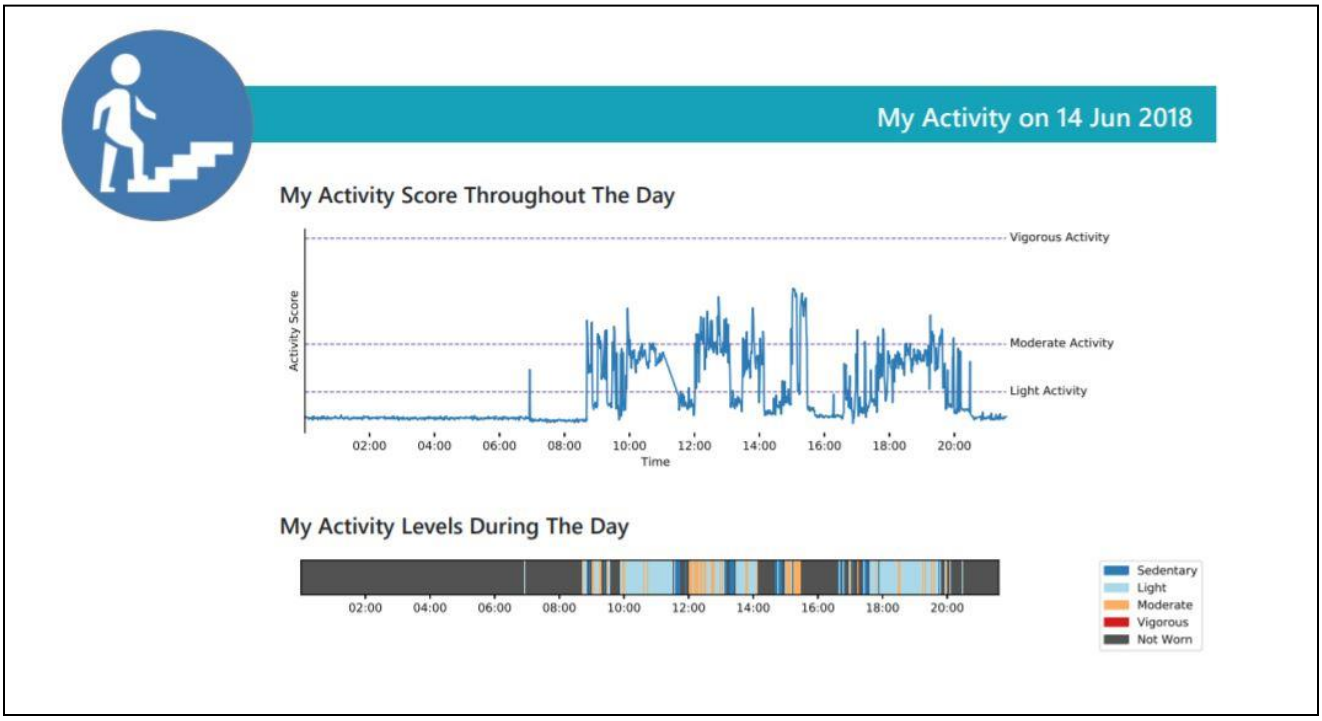


Figure 5.5 Example of activity feedback report received by patients. This first section shows the activity score on a certain day expressed as a line plot and heat map which distinguishes between periods classified as sedentary, light, moderate or vigorous intensity activity and periods when sensor is classified as 'not worn'.

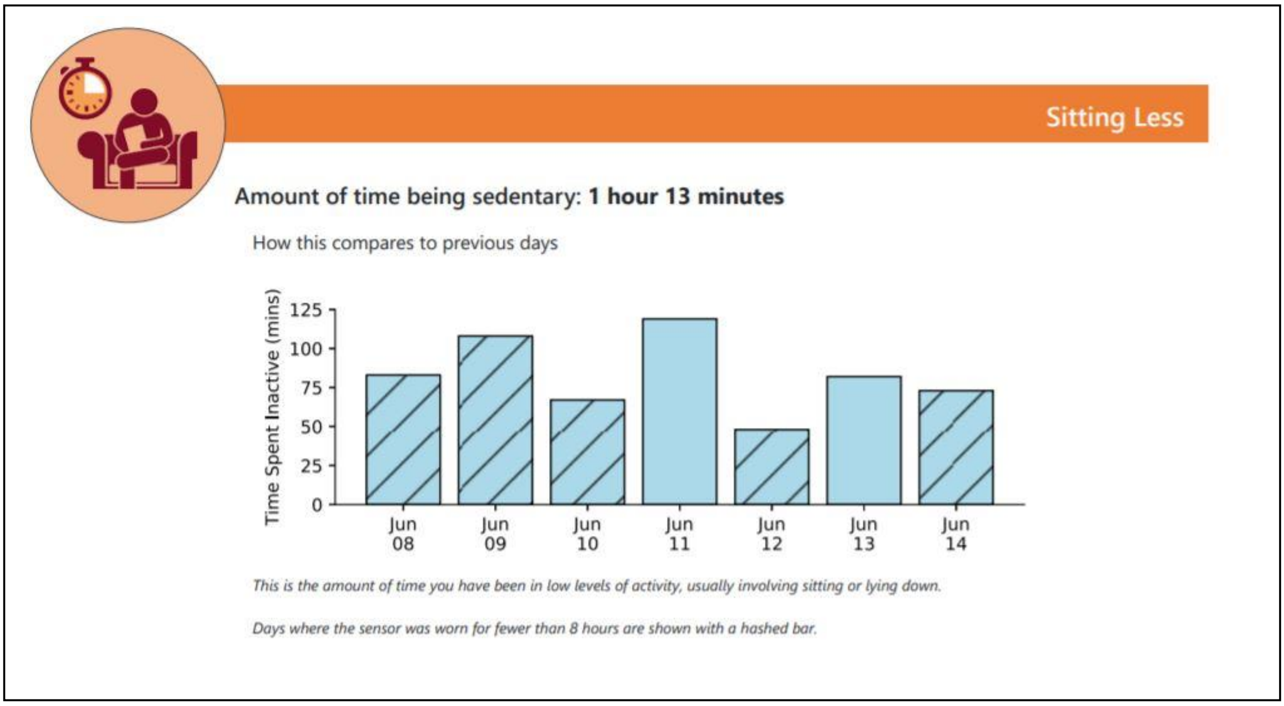


Figure 5.6 Second section of the activity feedback report provided to participants shows the amount of time being sedentary over the period of monitoring. Hashed bars indicate days when the monitored was likely to have been worn for less than 8 hours which may result in underestimation of sedentary time.

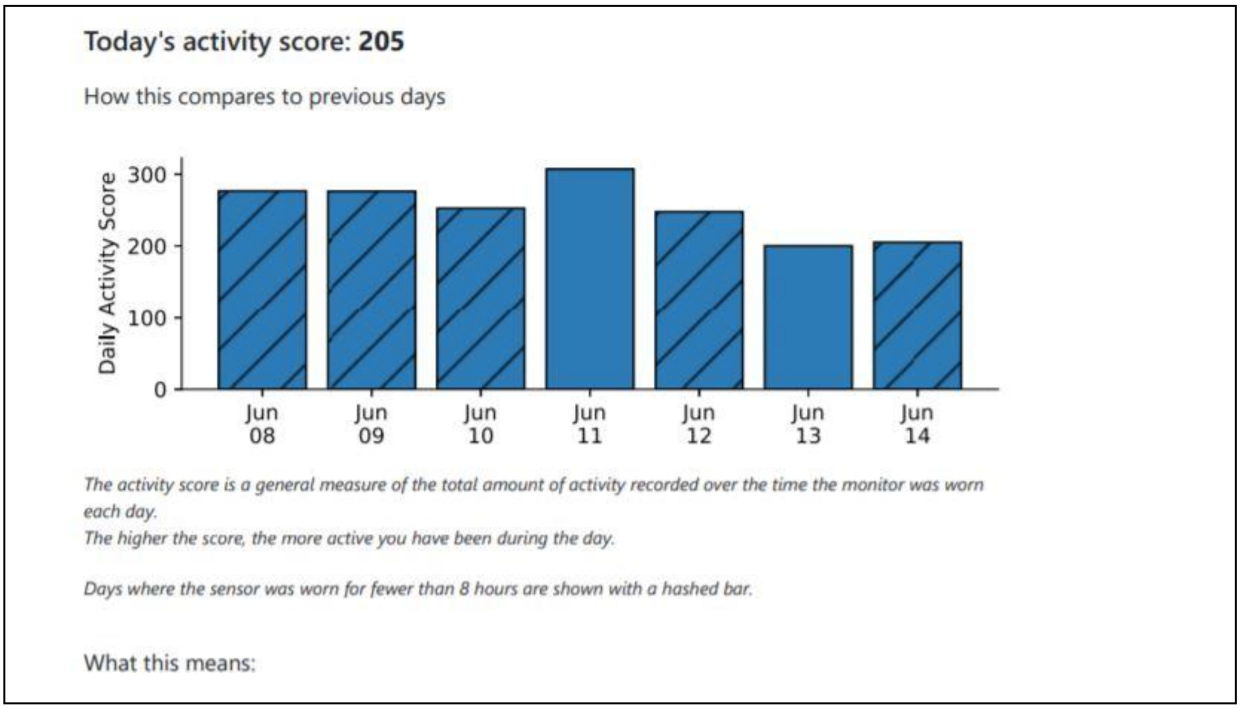


Figure 5.7 Third section of the activity feedback report provided to patients shows the total daily activity score over the period of monitoring.

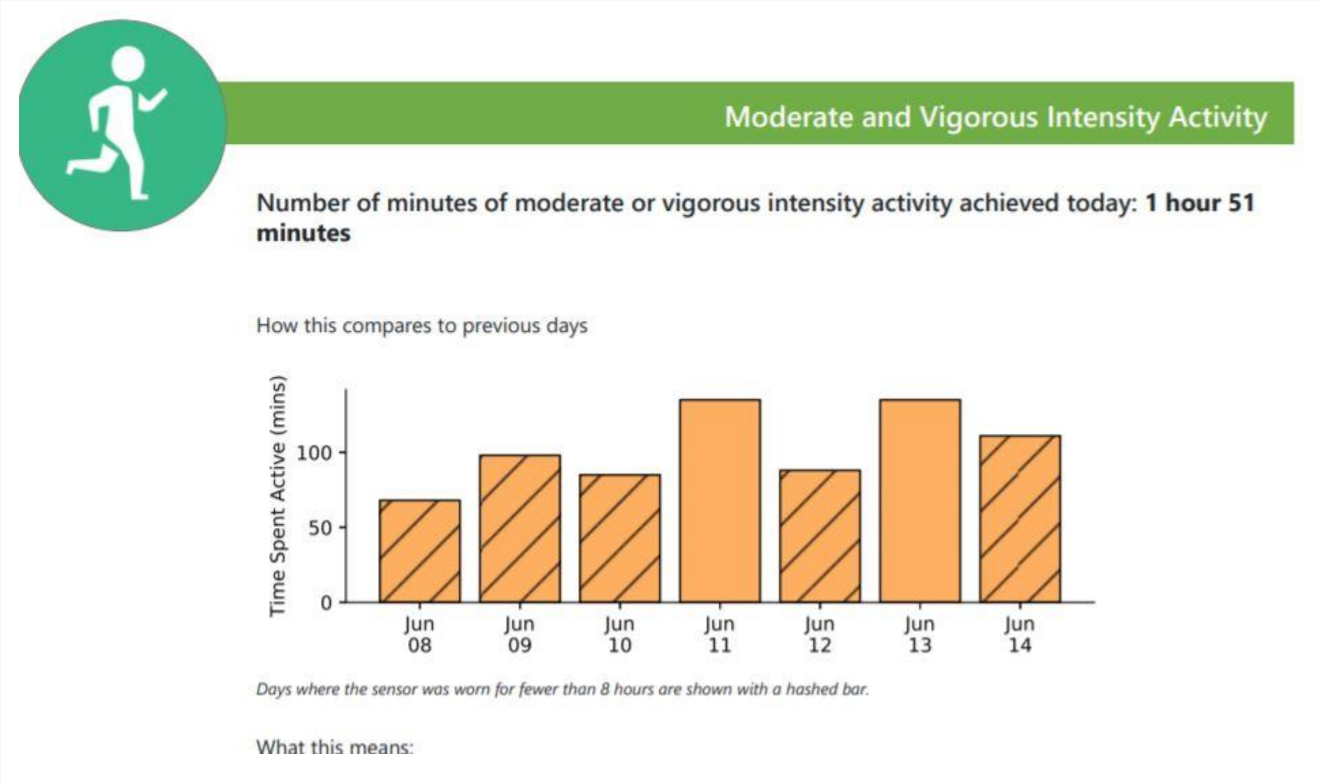


Figure 5.8 Final section of the activity feedback report provided to participants shows the total number of minutes recorded as moderate to vigorous intensity activity per day over the monitoring period.

5.5.4 Activity monitoring using a wearable accelerometer

5.5.4.1 Wearable accelerometer

The accelerometer used in this study was the eMotion Faros 180◦ sensor and chest strap, a CE marked (0537) and FDA cleared device manufactured by Mega Electronics Ltd which has been used in a variety of fields to measure movement and heart rate.[200–202] The device weighs 13g and is of size 48mm x 29mm x 12mm (Figure 5.9). This has a 3D accelerometer (sensor) that also has the capability for heart rate monitoring using ECG sampling when worn with a chest strap. The device has Bluetooth capability which allows it to upload accelerometer data to the Hub which then allows this data to be pushed from the Hub to the secure cloud. The participant was provided with the sensor itself, the chest strap, charging plug, micro USB cable and a Hub. It has a recharging time of around 2 hours and a memory capacity of 20 to 30 days recording.

Figure 5.9 Appearance of the Faros^{TM} 180 accelerometer with heart rate monitoring. Modified from http://ecg.biomation.com/faros.htm.

5.5.4.2 Hub device

The LifeInsight Hub model 2.0 was developed by McLaren Applied Technologies as a platform to enable easy, real-time transmission of data for research purposes (Figure 5.10). The Hub has a unique identification number so that data can be associated with a specific participant.

The Hub receives data from the sensor via secure Bluetooth wireless signal every 2mins. The Hub then automatically uploads the data in real-time (every 10 minutes) to secure servers at McLaren Applied Technologies via a secure connection on the 3G mobile phone network. The Hub has its own SIM card to be able to use the 3G phone network. The Hub also has sufficient memory to retain a copy of all data generated for a subject at a site for the duration of the study. At the end of the study this will be wiped clean as the primary source of data will be the secure server. Use of this biotelemetry system allows data to be analysed and assessed remotely from the participant in a timely manner to enable feedback to the participant on daily activity levels.

Figure 5.10 Appearance of the LifeInsight Hub device.

5.5.4.3 Accelerometer data analysis to estimate intensity of activity

This study used a wearable accelerometer which was also capable of measuring heart rate. The chest location was again chosen due to both sensitivity and validity of picking up relevant movements but also as this allowed accurate measurement of heart rate using a chest strap.

In order to measure intensity of activity, the previous study attempted to do this using the *Magnitude of the Activity Score*, as a measure of the frequency of activity, and using thresholds to estimate when activity was likely to have been sedentary or more than sedentary in intensity. However, validity was poor, as movements pertaining to different types or intensities of activity cannot be assumed to be similar between individuals and are difficult to create an automated algorithm to detect. Intensity of activity or exercise can be subjectively or objectively assessed. Subjective assessment using the Borg exertion scale has been used in previous studies to allow patients to judge when they have reached a moderate intensity level of exercise or above when undertaking an unsupervised exercise intervention. Objective assessment can be made by measuring METs or by using a target range of heart rate. If the activity monitoring could pick up when the patient was within 50-70% of their maximal heart rate this would equate to a moderate intensity level of exercise. Combined with movement analysis, this should improve the validity of activity monitoring to be able to measure real-world activity. This has not shown great promise for classifying activity, but for the purpose of exercise prescription based on intensity, the addition of heart rate monitoring could improve feedback to the patient and clinicians on whether moderate intensity exercise levels or above are being achieved.

As preparation for this prehabilitation study, work was undertaken with the engineers at McLaren Applied Technology on the process of automating activity classification into categories of sedentary, light, moderate and vigorous intensity activity as well as being able to recognise non-wear time. This was important, as the participants were instructed to wear the chest strap with accelerometer during waking hours, with an aim to wear for at least 10 hours a day. The participant was advised to turn the accelerometer off when not worn but if this did not happen then any non-wear time had to be correctly classified to avoid misclassification of the other activity categories.

Previous studies have used activity 'counts' as provided by the accelerometer software to estimate activity intensity or estimate METs. As we are not using commercial software and McLaren Applied Technologies wished to develop their own in-house algorithms work was undertaken to develop a classification scheme based on our previous work with the Axivity accelerometer and the *Activity Score* in combination with the new availability of heart rate using the Faros accelerometer. Firstly, the Faros accelerometer was shown to be comparable to the Axivity accelerometer in the chest location to be able to produce similar results for activity score. McLaren Applied Technologies collected accelerometer and heart rate data from four volunteers doing different intensities of activities ranging from: sitting still, sitting and working at a desk (both sedentary), walking at approx. 1.7 mph (light activity), walking at approx. 3.4 mph (moderate intensity activity), cycling, and jogging at 5mph (both vigorous intensity). Table 0.1 in Appendix C shows the results from these subjects. Cycling did show an increase in heart rate but not much movement on the accelerometer which is as expected for an accelerometer in the chest position. Overall there is good separation for the heart rate and activity score between the different intensities of activity.

Results from a publicly available database were also used to develop the algorithm. The University of California, Irvine, has a machine learning repository including a data set of ‘activity recognition from a single chest-mounted accelerometer data set’.[203] This used a Colibri triaxial accelerometer and hear rate monitor, worn on the chest, hand and ankle in 9 subjects, aged between 24 and 32 years, performing a series of 11 activities, with different MET estimations ranging from sedentary to vigorous intensity. Results from this database were used by McLaren Applied Technologies to develop an algorithm to classify accelerometer and heart rate data into categories of sedentary, light, moderate and vigorous intensity activity for each 30 second window of data collected (see Appendix C Figures 0.1 to 0.4). This algorithm was then sanity checked with free living data from the Faros accelerometer collected by me to ensure the classification system was working. However, further validity testing of this algorithm in the free-living environment with the Faros sensor was not possible with the resources available for this study. As part of the feasibility aims of this study, one was to test the algorithm in these participants to see how it related to their IPAQ results of time spent during the week in different activity intensities.

5.5.5 Qualitative data analysis of patient interviews

5.5.5.1 Qualitative data collection

4 patients who consented to an end-of-study interview are invited to a 45-minute semi-structured interview facilitated by a researcher (RS) not previously involved in the study and not involved their usual care. 2 patients were in the control group and 2 in the intervention group. Interviews took place during the final study visit, after the physiological assessment. The researcher RS facilitating the interviews was a female physiotherapist who was clinically active and involved in physiotherapy research studies, with training in quantitative and qualitative exercise physiotherapy research. Patients were aware of the interviewer's professional background and goals of the qualitative research. A flexible interview guide for the facilitator was used (see Appendix B ix) which contained open-ended questions that encouraged the patients to talk about their motivations for taking part in the study, their experience with the process of the study and their viewpoint on how prehabilitation could be improved. All interviews were recorded with a digital voice recorder.

5.5.5.2 Qualitative data analysis

Interviews were transcribed verbatim by the facilitator RS. An inductive qualitative descriptive approach, guided by Braun and Clarke description of thematic analysis, was used to analyse the data.[204] The analysis aimed to take a latent and constructionist approach to try and understand the underlying ideas and the sociocultural contexts and conditions that relate to the themes generated from the interview data. The analysis involved initial reading of the interview transcripts independently by me and RS with subsequent identification of informative sections that provided an understanding of patient perspective relevant to the research questions. Data in the form of quotes from these informative sections were coded (Appendix D), and shared ideas and similarities from the codes were developed into key themes and sub-themes which were further reviewed and refined (Appendix E). Lastly, a rich description of each theme was developed after discussion and agreement by me and RS taking into account our interpretations of the data in relation to the research question.

5.6 Results

The primary objective of this study was feasibility to recruit and conduct this method of exercise intervention before major urological surgery for a full randomised controlled trial. Although, this feasibility study was not able to be completed, useful feasibility and qualitative data from the patients that were recruited was gained. The reason for not completing the study was due to problems with the Hub which meant that the monitoring of patients in the intervention arm could not be continued. During the process of trying to amend this problem, reorganisation of the research group meant that McLaren Applied Technologies could no longer provide the engineering resources to the study and therefore the study could not be continued according to the original protocol. A total of 6 patients were recruited to the study of which, 5 completed baseline assessments and 4 patients completed the study. One patient did not complete baseline activity monitoring as they could not find the available time to undertake this. One patient did complete baseline assessments but did not respond to starting the intervention period. Therefore, 4 patients, two in each arm of the study completed all study procedures. The results available from this feasibility study are presented below.

5.6.1 Feasibility of recruitment and compliance with study procedures

The primary objective was to test the feasibility of recruitment to this study and acceptability and compliance to the study procedures. In a period of one month at a single centre, 11 patients were screened from urology clinics who met the initial eligibility criteria. One patient declined to participate because they were too busy, two patients declined due to lack of internet access or phone signal and the remaining 2 patients were too fit to meet inclusion criteria, as they score higher than 50.70 on the DASI questionnaire. Of the 4 patients who took part in the patient interviews at the end of the study, of which there were 2 who were in the intervention group and 2 in the control group, all 4 stated no issues with being randomised to the control or intervention arm.

Of the 6 patients recruited, 4 patients completed study procedures. All patients completed the baseline 6 Minute Walk Test. One patient did not complete the baseline activity monitoring as they were too busy. One patient was randomised to the intervention arm but did not respond to attend the initial counselling session with the physiotherapist to start the study intervention. The other 4 patients attended all necessary study visits.

With regards to compliance to wearing the accelerometer with the chest strap, 5 participants completed the baseline activity monitoring period, of which all but one completed 4 days or more of monitoring (see Table 5.4). One patient only had monitoring data for one day, despite the patient reporting wearing it for 4 days. This may have been due to difficulty turning the monitor on and off which was small button that had to held down on the front of the accelerometer. Given this potential difficulty, participants were advised to keep the monitor on during the whole period of monitoring to avoid problems with failure to turn back on. The recommended wear time per day over 4 days was 10 hours. Of the other 4 participants who wore it for 4 days, only one achieved less than 40 hours, with a total wear time over 4 days of 32 hours.

Patient ID	Days of baseline monitoring achieved	Total hours of baseline monitoring
A	1	13
B	5	61
C	—	—
D	4	32
E	4	40
F	4	45

Table 5.4 Table showing compliance with using the accelerometer during the baseline activity monitoring period.

5.6.2 Participant characteristics and baseline assessments

Patient demographics and results of baseline assessments are shown in Table 5.5. All patients were male and patient age ranged from 57 to 84 years. The DASI scores of those randomised to the control group were lower than the intervention group, although no patients scored less than the equivalent of 4 METs on the DASI questionnaire. 5/6 patients were assessed as mildly depressed on the PHQ9 questionnaire, with one patient scoring 7 for moderately depressed. One patient did not complete the GAD7, and the other 5 patients were assessed as mildly anxious. The 6 Minute Walk Test total distance walked ranged from 329 metres to 548 metres. Patients completed the IPAQ for the number of minutes in different types of activity in the last 7 days. The amount of time spent in activities of moderate or vigorous intensity could then be calculated. This has been shown as average number of minutes per day to compare with baseline activity monitoring results. Although patient E and F did show similarity between IPAQ calculated and accelerometer measured moderate intensity minutes per day, other patients showed large differences between self-reported and accelerometer measured time spent in moderate intensity activity. The accelerometer did not classify any periods of vigorous intensity activity across the patients. All patients except patient C appeared to be achieving the national exercise recommendations of 150 minutes of moderate or vigorous intensity exercise per week based on their IPAQ and accelerometer estimated mean moderate intensity minutes per day.

	Control Group			Intervention Group		
Patient ID	A	C	E	B	D	F
Sex	Male	Male	Male	Male	Male	Male
Age (years)	84	75	57	67	73	67
Operation due	Radical nephrectomy	Radical cystectomy	Radical prostatectomy	Radical prostatectomy	Radical prostatectomy	Radical prostatectomy
ASA grade	II	II	II	II	II	II
DASI score	23.45	39.45	36.70	50.70	50.70	50.70
DASI estimated METs	5.62	7.58	7.25	8.97	8.97	8.97
CCI	8	7	3	5	5	3
EQ-5D score	0.879	0.796	0.837	0.837	0.768	0.837
EQ-5D VAS	90	65	80	95	80	75
PHQ9	2	7	3	4	5	1
GAD7	n/r	2	5	2	5	3
6MWT distance (m)	379	329	456	548	428	451
IPAQ questionnaire baseline results						
IPAQ mean moderate intensity minutes per day	17	1.4	119	34	171	176
IPAQ mean vigorous intensity minutes per day	8.6	0	64	34	0	171
Accelerometer measured baseline activity results						
Days of accelerometer measured baseline activity monitoring	1	—	4	5	4	4
Total hours of baseline activity monitoring	13	—	40	61	32	45
Mean light activity minutes per day	366	—	293	297	343	123
Mean moderate intensity minutes per day	83	—	220	96	42	166
Mean no. of bouts (at least 10 minutes continuous) of moderate intensity activity per day	3	—	7	4	1	6

	Control Group			Intervention Group		
Mean vigorous intensity minutes per day	0	—	0	0	0	0
50% of maximal heart rate	68	73	81	77	74	77
Mean number of minutes per day heart rate above 50% of maximal heart rate	614	n/r	86.50	576	87.25	334

Table 5.5 Patient demographics and baseline assessments. ASA, American Society of Anesthesiologists grade, II is mild systemic disease; DASI, Duke Activity Status Index score, 0 (least fit)to 58.2 (fittest); DASI estimated METs, minimum =2.74, maximum = 9.89 METs; CCI, Charlson comorbidity index, high score indicates more comorbidities; EQ-5D generic health status questionnaire score, minimum -0.59 to 1.0 maximum best health status; EQ-5D VAS; visual analogue scale of patient self-perceived health status from 0 worst health they can imagine to 100 best health they can imagine; PHQ9, patient health questionnaire for depression, score 0 to 27, 0-5 mild depression, 6-10 moderate depression; GAD7, generalised anxiety disorder questionnaire, 0-5 = mild anxiety; IPAQ, International Physical Activity Questionnaire.

5.6.3 Feasibility and suitability of the exercise intervention with activity monitoring feedback

5.6.3.1 Results of activity monitoring and IPAQ in the intervention group

Of the 3 patients randomised to the intervention group, 2 patients completed the intervention period and one patient withdrew from the study before the intervention period. The results of the activity monitoring and IPAQ during the intervention period are shown in Table 5.6 to Table 5.9 for patients B and D. Both patients increased their time spent in moderate intensity activity over the 4-week intervention period, including increasing the amount of time doing moderate intensity activity in bouts of at least 10 minutes. Patient B increased their 6MWT distance from 548 metres to 596 metres, and patient D increased their 6MWT distance from 428 to 480 metres. Estimating activity level using accelerometer classification or patient reported activity using the IPAQ were not comparable. The number of minutes classified as moderate or vigorous intensity based on accelerometer and heart rate measurements did not relate to IPAQ results for similar metrics.

Patient B	Mean light intensity minutes per day	Mean moderate intensity minutes per day	Total moderate intensity minutes over 7 days	Mean no. of bouts (at least 10 minutes continuous) of moderate intensity activity per day	Total no. of bouts of moderate intensity activity in 7 days	6MWT distance (m)
Baseline	297	96	n/a	4.2	n/a	548
Week 1	204	94	474*	4.4	22*	
Week 2	251	121	849	5.1	36	
Week 3	295	132	930	5.1	36	
Week 4/ end of intervention	206	126	633*	6.4	32*	596

*Table 5.6 Results of activity monitoring during the intervention period for patient B. * denotes a week where only 5 days of monitoring was available.*

Patient B	Accelerometer			IPAQ	
	Total moderate intensity minutes over 7 days	Total no. of bouts of moderate intensity activity in 7 days	Total vigorous intensity minutes over 7 days	Total no. of moderate intensity minutes in last 7 days	Total no. of vigorous intensity minutes in last 7 days
Baseline	n/a	n/a	0	240	240
Week 1	474*	22*	0	210	0
Week 2	849	36	0	840	150
Week 3	930	36	0	420	210
Week 4	633*	32*	0	160	80

*Table 5.7 Comparison between accelerometer measured and IPAQ estimated moderate and vigorous intensity activity over each week of the intervention period for patient B. * denotes a week where only 5 days of accelerometer measured activity was available.*

Patient D	Mean light intensity minutes per day	Mean moderate intensity minutes per day	Total moderate intensity minutes over 7 days	Mean no. of bouts (at least 10 minutes continuous) of moderate intensity activity per day	Total no. of bouts of moderate intensity activity in 7 days	6MWT distance (m)
Baseline	343	42	n/a	0.75	n/a	428
Week 1	312	43	303	1.14	8	
Week 2	192	33	232	1	7	
Week 3	306	52	364	1.14	8	
Week 4 / End of intervention	311	49	345	1.7	12	480

Table 5.8 Results of activity monitoring during the intervention period for patient D.

Patient D	Accelerometer			IPAQ	
	Total moderate intensity minutes over 7 days	Total no. of bouts of moderate intensity activity in 7 days	Total vigorous intensity minutes over 7 days	Total no. of moderate intensity minutes in last 7 days	Total no. of vigorous intensity minutes in last 7 days
Baseline	n/a	n/a	0	1200	0
Week 1	303	8	0	—	—
Week 2	232	7	0	0	0
Week 3	364	8	0	105	0
Week 4	345	12	0	780	80

Table 5.9 Comparison between accelerometer measured and IPAQ estimated moderate and vigorous intensity activity over each week of the intervention period for patient D.

5.6.3.2 Feasibility of the exercise intervention

3 patients were randomised to the intervention arm. One patient withdrew before the intervention period started and no reason was given as the patient did not respond to being contacted. 2 patients completed all intervention period procedures including weekly telephone calls. The patients did not report any adverse events during the exercise programme.

5.6.3.3 End of study assessments

Four of the six patients initially recruited completed end of study assessments, including repeating the baseline assessment questionnaires on patient reported outcomes and the 6MWT (Table 5.10). The two patients in the intervention group did increase their 6MWT distance to a greater extent than the control group patients (increase of 48m and 52m vs 1m and 14m). All 4 patients had similar EQ-5D-5L generic health status results. Patient A had a large fall in EQ-5D VAS. There were no large changes in the PHQ9 and GAD7 results across all 4 patients. Patient E in the control group did report increases in exercise time according to his end of study IPAQ results compared to baseline, and also stated in his end of study interview that he was consciously increasing the amount of exercise he was doing to try and lose weight and get fit.

	Control Group			**Intervention Group**		
Patient ID	A	C	E	B	D	F
Age (years)	84	75	57	67	73	67
Operation due	Radical nephrectomy	Radical cystectomy	Radical prostatectomy	Radical prostatectomy	Radical prostatectomy	Radical prostatectomy
Outcome measures (results in brackets indicate change from baseline)						
EQ-5D score	1.0 (+0.121)	—	0.837 (0)	0.767 (-0.07)	0.795 (+0.027)	—
EQ-5D VAS	50 (-40)	—	85 (+5)	93 (-3)	85 (+5)	—
PHQ9	2 (0)	—	1 (-2)	5 (+1)	2 (-3)	—
GAD7	0	—	2 (-3)	3 (+1)	1 (-4)	—
6MWT distance (m)	380 (+1)	—	470 (+14)	596 (+48)	480 (+52)	—
IPAQ mean moderate intensity minutes per day	17 (0)	—	205 (+86)	22 (-12)	111 (-60)	—
IPAQ mean vigorous intensity minutes per day	17 (+8.4)	—	235 (+171)	11 (-23)	25 (+25)	—

Table 5.10 End of study assessments. EQ-5D generic health status questionnaire score, minimum -0.59 to 1.0 maximum best health status; EQ-5D VAS; visual analogue scale of patient self-perceived health status from 0 worst health they can imagine to 100 best health they can imagine; PHQ9, patient health questionnaire for depression, score 0 to 27, 0-5 mild depression, 6-10 moderate depression; GAD7, generalised anxiety disorder questionnaire, 0-5 = mild anxiety; IPAQ, International Physical Activity Questionnaire.

5.6.4 Qualitative data results and thematic analysis

Four patients completed end of study in-depth interviews with a physiotherapy researcher who was not part of the study team. Two of the interviewed participants were in the interventional group (labelled as E1 and E2) and underwent the study intervention of preoperative exercise intervention with remote activity monitoring. The remaining two of the interviewed participants (labelled as C1 and C2) were in the control group and had baseline and end of study remote activity monitoring but no exercise intervention or feedback from the activity monitoring. A number of results were gained from the interview data which are reported according to the following areas of research interest:

1) Patient attitudes and viewpoints on prehabilitation
2) Patient feedback on the study procedures
3) Factors related to the COM-B model of behaviour change which are important for the design of exercise prehabilitation interventions.

The first two areas were addressed with descriptive reporting of the interview data. The last aim was addressed using thematic analysis (see Appendix E for thematic analysis development) of the data to develop themes that are important for the understanding of behaviour change techniques useful for exercise prehabilitation. The coding reference for patient quotes are included in parentheses and are listed fully in Appendix D.

5.6.4.1 Patient attitudes and viewpoints on prehabilitation

The participants were asked on their understanding of the aims of the study and the value of preoperative exercise. All 4 participants expressed that the aims of the study were made clear to them, although only one (E2), expressed confidence that he understood the aims of the study and of prehabilitation, whilst the other three were less sure. There was some basic understanding of how baseline health factors were important before having surgery, but no patients displayed a good understanding of the relationship between preoperative fitness and postoperative outcomes.

E2 expressed that he acknowledged the importance of preoperative factors, however, this was framed as factors which may make him ineligible to have the operation rather than positive factors to improve outcomes from the operation.

> *'little things like that cumulatively can affect whether or not you go for surgery, and I don't think the general public grasp that'* (I2, 71)

C1 understood the aim was to *'physically prepare people without…necessarily medication'* (86) whereas C2 was not sure whether the aims were focused on the preoperative or the postoperative period.

> *'it's basically for the pre-op thing or whether it's mainly afterwards. I don't know. I'm not quite one hundred percent sure about that'* (C2, 105).

The two participants in the control group did not express a strong preference to be in the intervention group, with C2 saying he *'just went along with it'* (I2, 87), suggesting that they were not participating in the study with hope of receiving exercise intervention as the benefit. On the other hand, the two participants in the intervention group both felt that the study, combined with their cancer diagnosis, was a motivator to think about exercise before surgery, and also believed they would continue to exercise after the operation.

> *'it made me think about it… a motivator for sure. And, maybe everyone should be encouraged to take part in it…as a motivator to get going.'* (I2, 82)

> *'I've been hit with the shock of…prostate cancer… I thought, well anything I can do to get me a little bit fitter and to help in the future is worth doing' (I2, 2)*

One of the control group patients (C2), had a strong desire to lose weight as this was emphasised to him by the surgeon. C2 cited this as his main motivation for exercise, which he had already initiated himself by the time he joined the study. Although this motivation for exercise aligned with the aims of prehabilitation, the patient expressed this in terms of the fear of not being able to have the surgery rather than the motivation to improve recovery after the operation.

> *'I had to lose the weight for the operation…I was worried that…he said if I haven't lost the weight by then, they might think about doing another MRI, another biopsy and I don't want to go through all that again… if there was no motivation there, I probably wouldn't have done the gym I'll be honest'* (C2, 125, 129)

However, C2 also understood the importance of physical exercise aside from weight loss in *'improving recovery time'* and reducing the *'chance of heart attack and stroke'* (132). Again the opinion of the surgeon counselling C2 in clinic was crucial to him forming the viewpoint of the importance of weight loss and exercise before surgery.

All participants also cited wishing to be involved in research and to help others as a motivator to taking part in the study, with the two participants in the control group particularly emphasising this aspect.

> *'I feel that what I'm doing with you is more for other people in the future than myself, but that's ok'* (C1, 103)

Therefore, the level of understanding of the purpose of prehabilitation varied between patients, but no patients expressed a strong motivation to undertake prehabilitation for the aims that were described to them during the study. This may have been due to a lack of education during the study or pre-existing established motivations to take part in the study.

5.6.4.2 Patient feedback on study procedures

Study aims and exercise prescription

The positive features of the study mentioned by the two participants in the intervention groups included clear study aims and realistic goal setting (E1,4; E2, 32), good support from the study staff (E2, 84) including the advantage of receiving phone calls from the physiotherapists once a week which helped refocus their exercise regime (E1, 15). Both participants in the intervention group talked about enjoying their prescribed exercise including walking and cycling.

> *'the walks have been very pleasant'* (E2, 70)

> *'(we) cycled for 10kms which is something we've never done before.. I tell you the coffee afterwards is just to die for'* (E2, 70)

Although both participants had come to a joint agreement with the physiotherapists on their own exercise plans, both reported difficulties or reasons for not doing the exercise prescribed. The participant E1 found that the exercise prescription was realistic but felt he was not motivated to do the exercise, partly because he felt he was already *'strong enough'* and because he felt he lacked *'willpower'*.

> *'they were realist if I had the sort of nonce and willpower to do them. Oh yeah, the goals were easy.*' (E1, 11)

On the other hand, the participant E2, felt that the exercise prescribed underestimated his abilities which led him to take up cycling.

'I was fairly active anyway and there wasn't much they could recommend. Apart from doing a brisk 10 minute walk as often as I could…I decided not to do that and didn't tell them but took up cycling instead because I prefer that.' (E2, 53)

Because of his strong self-efficacy to formulate his own exercise plan, E2 also found that the physiotherapy phone calls were not helpful to him, and interestingly suggested the phone calls were more helpful to the research team rather than to aid him.

'I don't know if they were helpful. They might have been helpful to the physios. I don't know they were particularly helpful to me in any way, other than to say, I'm not doing a lot of walking…' (E2, 58)

The main barrier to the other participant E1 to adhering to the prescribed exercise was his role as a carer for his disabled wife.

'I don't tend to go out for really long periods because of (my wife)… she's really unsteady and I don't want her falling over.' (E1, 16)

Two of the participants, E2 and C2 also brought up the barrier of physical symptoms as a factor in the amount and type of exercise they could do. E2 had symptoms related to his sleep disturbance and urinary symptoms, and the side effects of his medications, as well as a previous back injury, and C2 also complained of back pain limiting exercise.

'about 7 or 8 years ago, I fell off a ladder and injured my back, which makes walking awkward or painful sometimes, but cycling is a doddle' (E2, 54)

These comments from the patients in the intervention group suggest that the study was well supported but that the exercise prescription as not well aligned to their baseline exercise habits both in terms of existing exercise capability and motivation for exercise.

Process of remote activity monitoring

The feedback on using the activity monitoring equipment was mixed. Three participants stated the accelerometer on the chest strap did not restrict them and was not overtly noticeable. Despite this, two of the three also reported they felt ‘irritation’ to start with and the strap was tight. The fourth participant from the control group found wearing the accelerometer uncomfortable and *‘too tight’* (C1, 102). Three out of four participants also experienced a technical issue which necessitated contacting the study team or having the hub changed. One participant was also concerned they had damaged the accelerometer whilst wearing it. Three of the four participants found the equipment easy to use, and got into the habit of remembering to wear the strap and charging the accelerometer. However, C1 did not like using the accelerometer, and his negative experience may have also been down to lack of interest as he was in the control group and did not receive any feedback from his own activity monitoring.

> *‘it’s just fiddly. A bit boring. I mean I didn’t really know what the point of it was. I just did what (they) told me.’* (C1, 101)

The technical issues experienced during the study with the monitoring equipment showed that this was not a reliable system of remote monitoring. The additional burden of the discomfort with wearing the accelerometer and managing the hardware associated with it suggests that this was also not a patient-friendly method of remote monitoring.

Usefulness of individual activity monitoring feedback

The two participants from the intervention group who received their baseline activity monitoring results in the form of visual reports found this information interesting. Both expressed surprised at seeing how inactive they were, and were conscious that their activity would show up on the monitor.

'the first week, Dr X sent me the results which were quite interesting. I was staggered to see how much time I spent sitting around. That was really quite a shock…not doing anything especially vigorous' (E2, 59)

'I was surprised how little I did. I thought, God, I'm sure I've done more than that. I was surprised just how inactive I was really.' (E1, 9)

Both patients from the control group expressed no interest in the specifics of what the accelerometer was measuring other than that it would pick up activity, with one participant believing it was just measuring heart rate.

However, only one of the two participants found the visual data in the form of charts interesting, both for the amount of inactivity and the regularity of exercise, but his interest in the feedback was only as a baseline and did not feel the need to keep reviewing the data after the first week.

'I was lumping the exercise together when I should have been spacing it out… that was very apparent in the graphs that I saw and that was useful…I printed out the first lot… the second, the third week… didn't do a lot of comparison' (E2, 62)

The activity monitoring feedback categorised recorded activity as sedentary, light, moderate and intense. Both intervention group participants mentioned these categories and showed understanding that these were represented in their activity reports. However, E2 also reported that, at times, there would a mismatch in how active he felt he had been compared to the activity reports.

'but conversely on 2 days in a weekend… I really didn't do very much for those 2 days but it came up as quite active on the charts.' (E2, 59)

No mention was made by the two participants in the intervention group on how the activity reports related to their exercise goals or the use of the activity score to quantify the total amount of exercise. This suggest the content and the format of the feedback data was not understandable and not of interest to the patients. Therefore, the feedback from the remote monitoring of activity data to the participants was interesting only for the time spent in sedentary activity, and did not appear to contribute to patient motivation for adherence to the prescribed exercise.

5.6.4.3 Themes related to the COM-B model of behaviour change

In addition to the feedback on the tangible aspects of the prehabilitation as designed in this study, the interviews provided a data source to explore the participants attitudes and behaviours towards taking part in prehabilitation that can help to understand how best to implement behaviour change techniques (BCT) as part of prehabilitation. Although the participants themselves did not have opinions on how prehabilitation should best be implemented, the issues that they felt were important provided insight into how these would influence their attitudes and behaviours during preoperative exercise intervention. Table 5.11 lists the main themes and sub themes developed during thematic analysis (see Appendix E for thematic analysis development process) of the four patient interviews, taking into account all of the topics discussed by the participants both in the control and exercise group, including issues which are not directly related to study procedures. These main themes and sub-themes and how they relate to each other is represented in Figure 5.11. Detailed reporting of the thematic analysis results related to the COM-B model is included in Appendix F.

Main Themes	Sub Themes	COM-B component
Self-identity	Identity related to work and impact on retirement	Reflective motivation
	Reliance on work for physical activity	Physical opportunity
	Life priorities not related to cancer diagnosis and treatment	Reflective motivation Social opportunity
	Perception on own self-efficacy and importance of individual responsibility	Reflective motivation Psychological capability
	Perception of ageing	Reflective motivation Social opportunity
Experience of exercise	Previous degree of self-efficacy to do exercise	Reflective motivation Physical capability
	Exercise role models in family members and society	Social opportunity Automatic motivation
	Boredom as a barrier to doing exercise	Automatic motivation
	Feeling enjoyment of exercise	Automatic motivation
	Knowledge of what is effective exercise	Psychological capability Physical capability
Purpose of exercise	Weight loss	Reflective motivation Social opportunity
	Exercise as sport and competition	Reflective motivation
Prehabilitation context	Perception of own risk for surgery	Reflective motivation Psychological capability
	Jeopardy of the operation being delayed or cancelled	Reflective motivation
	Understanding of prehabilitation	Psychological capability
Barriers to exercise	Boredom as a barrier to doing exercise	Automatic motivation Reflective motivation
	Having good days and bad days according to mood and physical symptoms	Automatic motivation
	Judgment of healthcare professionals	Social opportunity Psychological capability
	Physical symptoms and pre-existing conditions	Physical capability

Table 5.11 Main themes and sub themes from qualitative analysis of patient interviews

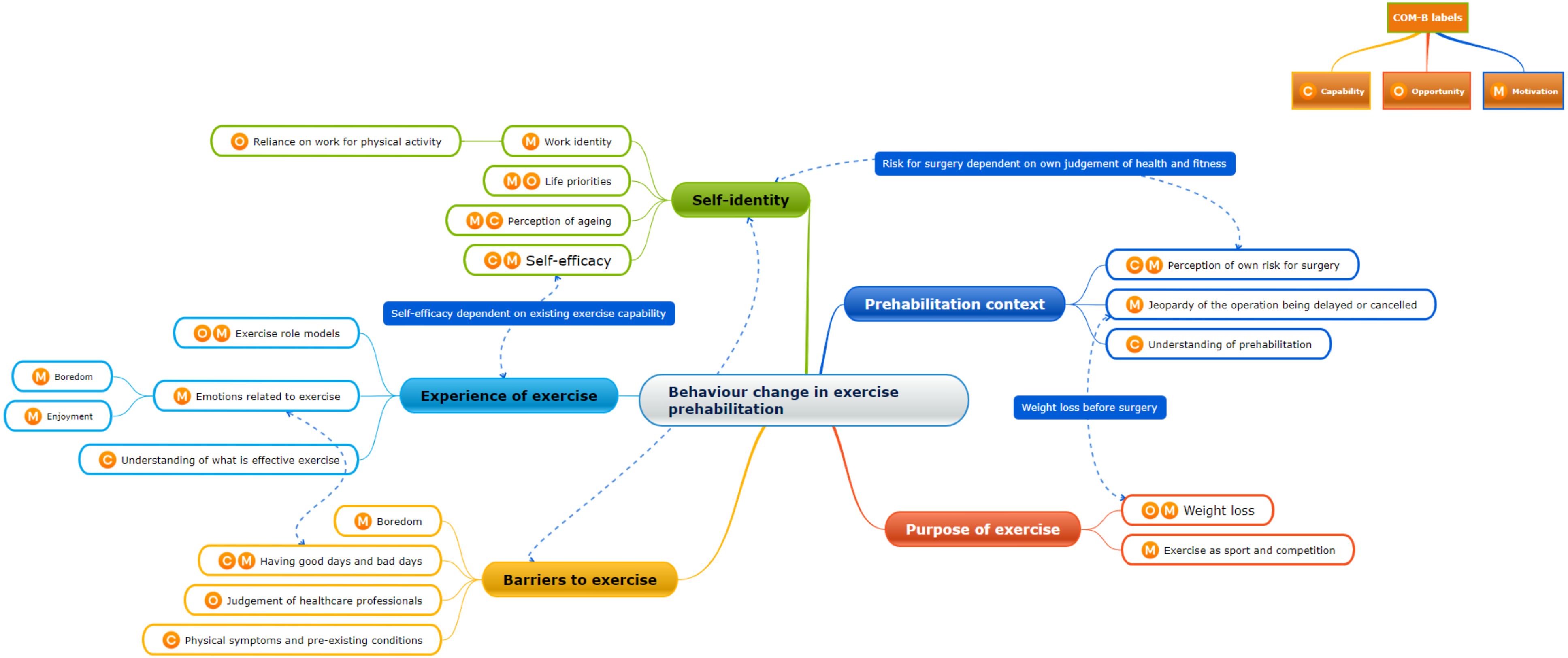


Figure 5.11 Diagram of main themes and sub-themes developed from the thematic analysis of the interview data with labelling to show which themes may impact on the COM-B model of behaviour change.

5.6.4.4 Summary of qualitative data results

The four participant end of study interviews provided insight into their opinion of the study procedures and potentially important themes to consider for the research question of how to implement behaviour change techniques as part of preoperative exercise intervention. The participants expressed positive attitudes to participating in the study but the degree of understanding of the aims and benefits of prehabilitation was varied and patient motivations for exercise were very individualistic. The remote monitoring was effective in showing the exercise group participants their level of inactivity but did not appear to achieve its aim of providing longitudinal feedback to show their progress over the course of the intervention and increase motivation. Although the participants were not dissatisfied with the technical faults of the monitoring equipment, most found it slightly uncomfortable to wear as a chest strap. Themes identified that were relevant to the COM-B model of behaviour change related to patient self-identity, their experience of exercise and view on the purpose of exercise, their understanding and attitudes of their cancer diagnosis and forthcoming surgery (‘prehabilitation context’ and potential barriers related to physical symptoms and relationship with healthcare professionals. The relevance of these themes to behaviour change techniques targeting capability, opportunity and motivation will be detailed in the discussion of the qualitative data in Section 5.7.6.

5.7 Discussion

The results show that, in this small group of patients, it is feasible for recruit into a prehabilitation study for patients undergoing major urological surgery, within a 62-day cancer treatment target. A 4-week exercise duration was able to be accommodated within the patient cancer pathway and patients were willing to be randomised. The recruitment rate was 6 patients in one month with an approximately 50% recruitment rate from screening which is similar to previous prehabilitation RCTs, which reported a recruitment rate from screening of around 46% to 80%.[127,177,180,205] Several learning points came out of the process of designing and running the study which are discussed below.

5.7.1 Choice of baseline assessments and outcome measures

Several different measures of physical activity and functional capacity were used in this study. The DASI is a valid tool that estimates functional capacity and was used to screen patients that would likely be at higher risk for surgery and therefore benefit from prehabilitation. The threshold score of 50.70 was used, which included patients who could undertake all activities on the DASI questionnaire except for the last activity of ‘strenuous sports’. Patients in the previous study who had answered positively to this question and therefore scored the maximum score of 58.2 were all classified as ‘fit’ having achieved well above the thresholds to discriminate for higher risk patients on CPET. However, a previous study comparing CPET to the intermittent shuttle walk test and DASI had concluded that those who scored above 46 on the DASI score all achieved CPET results above the threshold to be determined ‘fit’ and not at higher risk for surgery.[137] This was also the threshold used by Barberan-Garcia and colleagues for their recent RCT in prehabilitation in high risk patients undergoing elective major abdominal surgery.[176] Two of the recruited patients achieved high levels of moderate intensity exercise based on IPAQ and activity monitoring and therefore would likely not have benefited from the exercise intervention as they were already likely achieving over 150 minutes of moderate to vigorous intensity exercise per day. A consideration for future studies would be to lower the DASI score for inclusion and consider using the IPAQ in conjunction with the DASI score to screen for higher risk patients with low levels of baseline activity. However, as with all subjective questionnaires, caution needs to be taken to rely on patient reported levels of exercise.

The choice of physiological measure is an important one to be able to objectively assess whether exercise intervention has improved functional capacity which is the hypothesised mechanism by which postoperative outcomes can be improved with exercise prehabilitation. The gold standard outcome would be CPET measured peak oxygen uptake and anaerobic threshold. Performing CPET before and after exercise intervention was too expensive for the budget of this study and therefore the 6 Minute Walk Test as submaximal exercise test of functional capacity was chosen. This was because it is easy to instruct the patients to perform and requires no specialist equipment. Several previous prehabilitation studies have used the 6MWT as a physiological outcome measure and this test has been shown to correlate to CPET results.

However, several RCTs, including the major recent RCT by Barberan-Garcia and colleagues, which did show a significant reduction in postoperative complications in the exercise intervention group, showed no significant difference in change in 6MWT distance between the control and intervention group.[127,174,176,179,205] The Barberan-Garcia and colleagues RCT did however show a significant improvement in endurance time as measured by a cycling constant work-rate exercise testing at 80% of peak oxygen uptake.[176] The 6MWT is not as strenuous as a cycle-based exercise test or other field tests such as the Intermittent Shuttle Walk test, which has a stronger correlation to CPET performance. One concern is that the distance walked in the 6MWT is largely influenced by voluntary patient effort and motivation, and when not restricted by dyspnoea, as is often the case with COPD patients for which the 6MWT has been widely used to measure effectiveness of pulmonary rehabilitation, the 6MWT may not be sensitive to changes in functional capacity.

Reference distances for performance in the 6MWT in the elderly population can be found, with a mean distance of 572 metres, 527 metres and 417 metres reported in male patients in the age ranges of 60-69, 70-79, and 80-89 years respectively.[206] In the 6 patients in my study, all patients achieved below the mean distance expected for their age group at baseline 6MWT suggesting there was room for improvement. There has not been a study to validate what is a meaningful change in 6MWT in preoperative prehabilitation population, but drawing on studies in the geriatric population, a small meaningful change is thought to be an increase of 20 metres, and a substantial meaningful change an increase of 50 metres walked on 6MWT.[207] Based on this, the two patients in the intervention group do appear to have had a substantial meaningful improvement in 6MWT distance, with improvements of 48 metres in patient B and 52 metres in patient D compared with increase of only 1 metre and 14 metres in the two control group patients (Table 5.10). These numbers are too small to draw any conclusions on the efficacy of the exercise intervention or suitability of the 6MWT as the physiological outcome measure. Consideration should be given in future studies that performance in 6MWT may not preclude effectiveness of exercise intervention. Therefore, the choice of a meaningful physiological outcome to measure effect of prehabilitation will depend on the nature of the exercise intervention and the comorbidities of the patient population. Exercise interventions which focus on walking or exercise bike training will tend to improve performance on 6MWT and cycle ergometer related exercise tests respectively. Use of the 6MWT in patient populations without restrictive dyspnoea or ischaemic pain may not be sensitive to changes in functional capacity.

5.7.2 Duration of prehabilitation intervention

With regards to the optimal duration of a prehabilitation, this is influenced by urgency of operation required, with oncology operations having a shorter preoperative time frame in which to implement prehabilitation. The duration of the intervention in the 7 randomised controlled trials included in the two recent systematic reviews ranged from the day before to a maximum of 6 weeks.[166,167] Exercise intervention is thought to be more effective in terms of improvement in physiological parameters if the duration is prolonged or the intensity or frequency is increased. However, of the studies that used aerobic exercise intervention, with a target of achieving moderate intensity exercise, no conclusions can be drawn on optimal duration of exercise intervention. 3 studies showed a difference in physiological outcome measures of 6MWT[179] and CPET performance[190,191]; and 3 studies showed no significant difference between the control and intervention group in their main physiological outcomes such as peak oxygen uptake,[178,190] PWC-170[192] and 6MWT distance.[174,176,190] Most studies choose a period of between 4 to 12 weeks. Cancer patients usually have a period of 2 to 4 weeks from date of decision for surgery to the operation date. Patients undergoing neoadjuvant chemotherapy before surgery can have around 12 weeks. Therefore, this study aimed to be pragmatic, by working within the timeframe of a preoperative period for a given operation, as well as pragmatic in what the patient can be expected to achieve in terms of exercise duration and intensity within this time frame. This would facilitate ease of implementation, improved adherence and a good basis on which to build further elements of prehabilitation.

5.7.3 Intensity of exercise prescribed

It is not known the ideal 'quantity' of exercise that should be prescribed for exercise intervention as part of prehabilitation. If the rationale is to prioritise prehabilitation in the most 'unfit' patients, with DASI score <46, as has been used in a previous RCT, then the dilemma is how to prescribe exercise that is feasible and safe for the patient, but also to likely to improve their cardiorespiratory fitness or functional reserve in a short space of time. The traditional thinking is that this can only be achieved with high intensity exercise, or sometimes known as high intensity interval training (HIIT) which aims to achieve short bursts of vigorous intensity exercise. HIIT aims to exercise at a level that achieves a high percentage of maximal heart rate (e.g. >80%), high percentage AT, peak oxygen consumption and power output in short bursts (e.g. 30 seconds to 4 minutes). Most previous prehabilitation studies have used moderate-intensity training interventions, to achieve 40-85% of maximal heart rate, or 50-60% of maximal oxygen uptake or achieving a perceived effort of 12-14 on the Borg scale.[208] The most recently published prehabilitation recommendations from Macmillan Cancer Support do not specify that high-intensity exercise is a required, instead choosing to use the advice of the Bristol prehabilitation programme:

> '*As long as the activity means you feel hot, sweaty and a bit out of breath afterwards it will be of benefit.*'[160]

This study has chosen to take on board the recommendations from previous systematic reviews on the potential benefits of home semi-supervised exercise interventions that can be moderate in intensity to achieve lower resource use and be more acceptable to patients. The 2 patients in the intervention group did increase their number of minutes of moderate-intensity exercise as well as number of 10-minute bouts of moderate-intensity exercise over 4 weeks. However, patient D only achieved an average of 1.7

bouts per day which would not have reached the recommended 15 bouts of 10 minutes of continuous moderate-intensity exercise per week. Therefore, this study does show the potential difficulty of ramping up exercise intensity and quantity using this delivery method.

HIIT regimes show evidence of being able to improve cardiorespiratory fitness within a shorter period of time in comparison to moderate-intensity exercise regimes in studies of non-surgical patients.[208,209] Surgical prehabilitation RCTs which have incorporated high-intensity exercise have shown improvements in peak oxygen consumption on CPET, but there is no specific comparison of the efficacy of moderate vs HIIT based exercise interventions on improving functional capacity and surgical outcomes. It is also important to consider the individual variation between patients of both: compliance to any exercise programme; and the physiological response to exercise. Although hospital supervised HIIT regimes have a higher compliance, not all patients respond physiologically to the same degree to this regime.[208,210] Therefore, future studies will also need to look at the factors behind variability in physiological response to the same exercise prescription.

5.7.4 Process of activity monitoring with remote feedback

Augmenting exercise prehabilitation programs with activity monitoring has been suggested in a recent RCT and systematic review, as well as having been integrated into current trials in progress which are using commercially available accelerometer based activity monitors.[85,176,185,211] The feasibility prehabilitation study presented in this thesis has shown it is feasible to run a semi-supervised, personalised exercise program with remote monitoring of activity and with online and telephone feedback. The patient feedback in the exit interviews have demonstrated several issues which can be lessons learnt in designing future studies.

Firstly, although the chest location was chosen for sensitivity and accuracy of heart rate monitoring, this was felt to be uncomfortable for patients. As heart rate monitoring using wrist-based devices improves with the use of optical instead of ECG based heart rate detection, future studies are likely to use wrist-based devices for compliance of wear and patient comfort. The two RCTs that have been registered but not yet completed are using the Fitbit wrist device and the Sensewear arm band.[85,211] However, neither of these trials appear to offer regular feedback given to patients to guide their exercise program. The number of steps and sleep efficacy is recorded as part of trial outcomes, but no detailed feedback is offered to patients. The second learning point from the patient feedback for this study was that, although there was value in displaying visually the amount of time spent being sedentary, the understanding of other categories of activity intensity, including moderate intensity periods and activity score was not well established. The data produced from the activity reports was well received by the research physiotherapists to guide advice during the weekly telephone calls but may have been too much data for the patients.

Cardiac rehabilitation and weight loss interventions have overwhelmingly used step counts with pedometers to provide patients with real time feedback. This is an inexpensive and easy to understand metric for patients, with proven efficacy to increase physical activity levels.[84] A recent development to this is use of step rate or ‘cadence’, to give an indication of activity intensity, which has been strongly correlated with metabolic equivalents estimated by indirect calorimetry.[212] A rate of >100 steps / min has been shown to be associated with moderate intensity activity.

My study has shown that daily activity monitoring with regular feedback is feasible but relies heavily on the equipment being usable and reliable. More detailed data may be of research interest but may not offer additional benefits to patient understanding and motivation for prehabilitation. Technology cannot be used in isolation to drive behaviour change and may even promote complacency in patients. This is discussed further as part of the qualitative data analysis in Section 5.7.6. Two randomised controlled trials which aimed to increase physical activity with use of activity trackers failed to show lasting benefit in terms of weight loss and other health outcomes.[213,214] The benefit of personal supervision and peer-support or group-based exercise has been shown to be an important motivator to achieving exercise intervention.[185] Within a trial context and in clinical use, it may be more pragmatic to use step count or step rate, but research should continue on using more detailed data analysis from wearable activity trackers, including heart rate data, to guide exercise prescription in prehabilitation.

5.7.5 Classifying movement data by activity intensity

A major gap in the knowledge regarding using remote activity monitoring to aid exercise interventions is how to use the raw accelerometry movement data to classify activity. As discussed for the previous study in Chapter 4, some personalisation of the algorithms used to classify activity for each person wearing the same activity monitor is likely to be needed to be able to evaluate the relative intensity of an activity. This is important because the exact same activity intensity will require different degrees of effort by different people, and therefore energy consumption and work done cannot be assumed to be the same even if the activity can be correctly classified. This study has tried to address this issue to some degree by collecting data on minutes spent in different ranges of heart rate as well as using the generic classification scheme derived from our preliminary work as described in Section 5.5.4. However, without further validation work it is hard to know the accuracy of the classification scheme that MAT have derived.

For activity monitoring to be used widely and reliably in this context, further validation work will need to be done to understand how to threshold activity score and heart rate for different groups of individuals to create a more personalised activity classification system. This could use information based on patient BMI, age, resting heart rate and activity questionnaires to gauge how to adjust certain parameters of the activity classification system to make it more accurate in being able to threshold for moderate and vigorous intensity exercise for a particular patient.

5.7.6 Discussion of the qualitative data

The qualitative data collected from the four patient interviews in this study have provided an insight into patient perceptions of exercise intervention. These perceptions have been developed into the themes of: self-identity, their previous experience of exercise and views on the purpose of exercise, their understanding of exercise in relation to their cancer diagnosis and operation (‘prehabilitation context’), and the potential barriers to exercise that they experienced. These themes have revealed influences on patient exercise behaviour will impact the delivery of interventions or BCTs targeting capability, opportunity and motivation as part of the COM-B model of behaviour change.

Although there is a body of literature on BCTs used in exercise interventions, few prehabilitation studies have collected qualitative data with the aim to explore how to improve BCTs. The qualitative data in this study has been collected with the aim of analysing factors relevant to using BCTs to improve adherence to prehabilitation. BCTs used in this study included education on prehabilitation, use of motivational interviewing to enhance individual tailoring of the exercise prescription, providing participants with timely and relevant feedback and the use of regular telephone supervision. This discussion will consider the effectiveness of these techniques based on the behaviour theory literature and the insights from the themes developed from the qualitative analysis of patient interviews in this study.

5.7.6.1 Evidence from reviews investigating the effectiveness of behavioural change techniques employed for physical activity interventions

Published reviews of studies where BCTs were used to increase physical activity in different populations, including patients diagnosed with cancer, do not reach a firm conclusion on which behavioural components are the most effective.[187,215–218] There are no reviews of studies investigating BCTs used in surgical prehabilitation and therefore the evidence from other studies of exercise intervention in cancer patients and the general population are considered here. Of note, most of the RCTs included in reviews of physical activity interventions in cancer patients are for breast cancer.[217,218]

A 2005 Cochrane review of RCTs investigating the effectiveness of strategies for increasing physical activity in the general population could not reach a conclusion on which components of interventions were more effective.[215] The types of interventions employed in the studies included in the Cochrane review were one of, or a combination of: one to one counselling or group counselling, self-directed or prescribed physical activity, supervised or unsupervised physical activity, home-based or a facility-based physical activity, ongoing face-to-face support, telephone support, written education or motivational support material and self-monitoring. The review did note that the heterogeneity in reported effects was reduced in higher-quality studies where the physical activity was self-directed with some professional guidance, and when there was on-going professional support.[215]

Another 2018 Cochrane review of exercise intervention in people living with cancer, showed that BCTs which involved 'setting of graded tasks', 'programme set goal' and 'instruction of how to perform behaviour' were most commonly included in interventions which resulted in a significant increase in physical activity levels.[219] A 2017 systematic review of physical activity and healthy eating intervention in overweight and obese adults concluded that increasing the number of BCTs included in an intervention, and using the 'goal-setting of outcome', 'feedback on the outcome of behaviour', 'graded tasks', 'adding objects to the environment (e.g. a step counter) significantly predicted intervention effectiveness.[220]

There are currently no agreed optimal methods for BCTs as part of exercise intervention in cancer patients, and little evidence for which BCTs are effective in the prehabilitation population. Macmillan Cancer Support have provided recommendations on how BCTs may be integrated into prehabilitation implementation but acknowledges that more research is needed on which BCTs are effective, and a need for studies of prehabilitation to accurately label their BCTs according to a recognised taxonomy.[26,187] Table 5.12 lists the recent RCTs of prehabilitation as discussed in Section 5.1.1 with further detail on the components of the intervention mentioned in the study methodology which could be labelled as BCTs. Although all studies employed a combination of BCTs, only one study details the behavioural concepts underlying the intervention, in this case, motivational interviewing.[176] The lack of clear labelling of BCTs used according to a recognised taxonomy also limits analysis of how many BCTs have been used and which aspect of behaviour they are targeting. However, it can be seen that the BCTs thought to be effective from the Cochrane review of exercise intervention in cancer patients are being employed in these prehabilitation RCTs. Three of the six studies described using all the BCTs mentioned as effective in the Cochrane review which were: ‘goal-setting of outcome’, ‘feedback on the outcome of behaviour’, ‘graded tasks’ and ‘adding objects to the environment’.[176,179,180] All of the 6 studies except for one used some degree of personalisation to the exercise prescription,[177] although only one of the personalised studies took into account the patient’s wider physical and social factors in addition to baseline exercise capacity.[176]

Although my study was not a behavioural science study, the results of the qualitative data analysis have provided insight into how BCTs may be implemented according to the COM-B model of behaviour change. The BCTs used in my study, and common to other prehabilitation studies as listed in Table 5.12, are discussed below with reference to the results of the qualitative analysis. These are broadly grouped into three themes: techniques based on patient education, individualised exercise prescription and supervision, and monitoring of progress to improve adherence.

Author	Year	Operation	Intervention(s)	Capability	Opportunity	Motivation
Carli et al.[205]	2010	Colorectal surgery	• Aerobic exercise 20-45 mins/day • Weight training 3x week • Home based • 4-week duration	• Exercise intensity based on baseline exercise test peak and resting heart rate	• Provision of exercise bike and weights • Home visit at least once • Weekly telephone call	• Control group 'encouraged' to walk daily
Gillis et al.[179]	2014	Colorectal cancer resection	• Aerobic and resistance exercises, 50 mins, 3 x a week • Home based • Moderate intensity • Relaxation exercises • 4-week duration	• Instructional booklet in simple language with pictures • 1 hour consultation with trained psychologist to teach relaxation techniques and enhance motivation for exercise • Training by kinesiologist, demonstration by participant and corrective feedback given • Aerobic exercise prescribed according to heart rate and perceived Borg exertion on 6MWT	• Aerobic exercise could be walking, jogging or swimming at patient discretion • Provided with resistance bands and heart rate monitor • Compact disc with relaxation exercises to perform at home	• Diary to record all activities related to the program • Weekly telephone call to encourage and measure adherence • Progression of training intensity
Jensen et al.[180]	2015	Radical Cystectomy	• Standardised aerobic and resistance exercise 15 mins twice a day • Home based • 2-week duration	• Information about goals and interaction between lifestyle nutritional status and physical activity • Written standardised exercise program instructed by physical therapist • Number of repetitions individualized with progression	• Provision of step trainer at home	• Discussion of mutual expectations and motivation • Encouraged to perform exercise twice a day • Telephone call after 1 week to ensure adherence to the program • Patient diary to document daily achievement
Barakat et al.[177]	2016	AAA surgery (open or endovascular)	• Aerobic and resistance exercise classes • 3 x 1 hour a week • Hospital supervised • 6-week duration		• Timetable to join hospital based exercise classes • Standard set of exercises in the class	
Dunne et al.[181]	2016	Liver resection for colorectal metastases	• 12 x 30-minute exercise sessions on a cycle ergometer • Moderate to vigorous intensity • Supervised • 4-week duration	• Exercise program personalised to patients based on CPET performance	• Supervised exercise	

Author	Year	Operation	Intervention(s)	Capability	Opportunity	Motivation
Barberan-Garcia et al.[176]	2018	Major abdominal surgery	• Unsupervised home personalised exercises and walking with use of motivational interviewing • Supervised high intensity cycle ergometer 1-2 sessions per week • 6-week duration	• Intervention tailored by specialized physiotherapist taking into account: primary disease and comorbidities, fitness, logistics, adherence profile	• Supervised high intensity endurance training with cycle ergometer tailored to subject's symptoms • Provision of pedometer	• Motivational interview to assess patient's adherence profile and codesign program • Interview rules were: avoid passive speech format, allow subject to expose fears barriers and doubts, generate summaries of interview, highlighting positive aspects, foster self-efficacy • Pedometer used to increase steps per day • Dairy to record unsupervised exercise • Use of Borg scale

Table 5.12 Recent randomised controlled trials of prehabilitation with description of the behavioural change techniques described in the methodology classified by the COM-B model components of capability, opportunity and motivation. AAA, abdominal aortic aneurysm; CPET, cardiopulmonary exercise testing; 6MWT, 6-minute walk test.

5.7.6.2 Patient education on prehabilitation and its limitations as a BCT

Education on the aims and benefits of prehabilitation and how to exercise effectively is usually included as part of prehabilitation.[185] Three of the six studies in Table 5.12 specifically describe provision of written or verbal education on preoperative exercise.[176,179,180] The interview responses from my study suggests that patients broadly understood the principles of prehabilitation, having been given this information as part of the study. But this understanding of the benefits of prehabilitation did not appear to be the main factor affecting attitudes to exercise and exercise behaviours.

This reflects the research in behaviour theory which emphasises that explaining the need to change behaviour based on rational common sense is usually not sufficient to motivate actual behaviour change.[221] By framing prehabilitation as common sense, this assumes that the purpose of prehabilitation and the necessary behavioural changes are obvious and no further explanation or intervention is necessary to support the patient.[221] This ignores the complex influences on behaviour as a result of the interactions between habit, automatic responses to the immediate and wider environment, conscious choice and calculation and the social and cultural context. Furthermore, patients are usually already aware of the benefits of positive lifestyle behaviours. A survey of patients before abdominal cancer surgery showed that although 53% of patients reported they were currently exercising, 69% stated they did not believe they were doing enough exercise.[222] Another survey of patient undertaking prehabilitation before cancer surgery showed that 75% perceived exercise as important.[223]

As for why patients may not be motivated by understanding the benefits of exercise intervention, the thematic analysis from my study interviews suggested that patient risk perception may be a factor in the effectiveness of education as a BCT.

Risk perception as a factor limiting the impact of education as a BCT

Patient risk perception is an important influence of health-related behaviour.[224] This is based on one's own understanding of the cost benefit utility of adopting or choosing not to adopt a certain behaviour, and contributes to the level of 'intent' as part of reflective motivation that exists at the beginning of prehabilitation.[221] The interview data revealed, that for the patients in this study who already felt fit and strong, they did not perceive their risk of adverse events as a motivator to exercise. However, for the patient who was motivated by weight loss, the risk was high as he was told the operation may not happen if he did not lose weight. The interview data showed how these risk perceptions shaped their understanding of the potential benefits of prehabilitation and ultimately level of 'intent' or reflective motivation for complying with exercise prescription.

Risk perception has been studied as an underlying factor for exercise behaviour change in different patient populations. In a study of orthopaedic patients undergoing exercise therapy, patients were asked about their perception of the level of risk of adverse outcomes of not undertaking the exercise therapy.[225] It was found that for those who had not already formed an intention to exercise, risk perception was an important factor in forming an intention, and the higher the risk perception the higher the probability of forming an intention. For those who already intended to exercise, risk perception was not an important factor.[225]

Potential areas for improvement of education as a BCT

The themes of 'self-identity', 'experience of exercise' and 'prehabilitation context' developed in this study provides a basis for considering how education and 'risk communication' as a BCT could be improved. The influences on behaviour related to these themes suggest that education should be individualised to take improve psychological capability in the areas that patients are lacking, and this in turn would enhance the initial 'intent' to do exercise. For example, the participants in my study that felt 'strong' already, or with few symptoms from their cancer, and therefore a relatively low level of risk perception, could receive targeted education on how their fitness could be improved or how symptoms of cancer do not relate to risk to an operation. This could further be supplemented by additional BCTs that do not rely solely on education given the limitations that have been discussed.

Additional BCTs described within the COM-B model that may be effective for prehabilitation include: the use of 'modelling' to provide an example for patients to aspire to or imitate; 'incentivisation' to create an expectation of reward along with 'coercion' to create an expectation of punishment or cost, and 'persuasion' which is using communication to induce a positive or negative feeling.[226] In the context of prehabilitation, this could mean employing BCTs on a patient with no intention of exercising, and low risk perception, using 'modelling' to aspire to be a patient case study who had improved outcomes after exercising, to be incentivised with an expectation of a reward of a shorter recovery time, to be 'coerced' with an expectation that the operation may not happen, and to be persuaded by describing positive experiences of people who exercise.[226] This can make use of qualitative findings from prehabilitation studies that show patients have reported improvement in sleep and feeling a greater sense of confidence and readiness of the operation, as positive motivators with more immediate benefits.[227]

5.7.6.3 Individually tailored exercise prescription

Exercise prescription - in terms of the quantity, frequency, intensity and mode of exercise performed -is a key component of preoperative exercise intervention. All 6 studies listed in Table 5.12 except for one used some degree of personalisation to the exercise prescription, with use of baseline physiological testing to establish individual physical capability.[177] These studies mentioned a combination of BCTs related to personalised exercise prescription including ‘action planning’, ‘graded tasks’, ‘goal setting’, ‘barrier identification/problem solving’, and ‘proving information on where and when to perform behaviour’.[226]

Individualised exercise prescription would benefit from understanding of previous exercise history. This is known to influence patients’ attitudes to the importance of exercise and their self-efficacy to be able to initiate and self-regulate their exercise behaviour.[228] Two studies of patient views of prehabilitation linked previous exercise experience to their current motivation to participate in exercise.[223,227] The ‘regulatory fit theory’ of behaviour hypothesises that individuals engage more strongly in what they are doing if they feel right about it and it fits with their prior engagement, and this may include enjoyment of the behaviour and of the immediate outcomes of the behaviour.[228] A qualitative study of 52 patients undergoing cancer prehabilitation found that patient enjoyment in exercise prehabilitation was related to the fact that the majority of the patients surveyed were physically active prior to prehabilitation.[223] The importance of enjoyment of exercise was emphasised by three of the four participants in my study, whether this was from watching TV whilst at the gym, or enjoyment from competitive sports.

Personalised exercise prescription could be improved by not just matching exercise prescribed to baseline physical capability and opportunities, but also to focus on which aspects of exercise the patient may enjoy, which will be informed by their previous experience and be highly individualistic. Based on the participant responses in my study, patient enjoyment of exercise may stem from many different reasons and attempting to find a consensus through qualitative data on patient preference for a certain type of exercise regime is unlikely to be reliable. Conversely, patients with a lack of previous positive experience of exercise, may consequently lack the automatic motivation driven by a positive emotional association to exercise. These patients are often not represented in prehabilitation studies, which tend to recruit for the patients already motivated by exercise.[223] Exercise prescription could be improved by taking into consideration patients' prior engagement with exercise to personalise the exercise prescription to something they would likely enjoy. This makes use of 'incentivisation' as a BCT which anticipates reward of a particular exercise regime based on what the patient finds rewarding, be it competitive sports or being able to enjoy TV whilst exercising.

5.7.6.4 Supervision and monitoring of exercise to improve adherence

Ensuring compliance with home-based exercise

Supervision of exercise is preferred to maximise adherence but this has resource and logistical challenges, making home-based exercise with self-monitoring tools as an adjunct to supervision a more attractive option. Three of the six studies in Table 5.12 were home-based exercise intervention with two using remote telephone supervision,[179,180,205], two studies were hospital-based and supervised[177,181] and one study was a mixture of both.[176] Although the main purpose of self-monitoring tools is to facilitate exercise prescription, these tools can also be considered as BCTs which 'add objects to the environment' and aim to improve psychological capability, as well as reflective and automatic motivation. The participant interview data from my study provides insight into the patient perspective on activity monitoring as a BCT using an added object during prehabilitation.

Activity monitoring to increase motivation

Use of activity monitors with feedback is a method that can potentially measure patient adherence to achieve optimal treatment fidelity, as well as being a useful adjunct for a number of BCTs to increase physical activity. The participants in my study who viewed their activity data both remarked surprise at how inactive they were suggesting that activity monitoring could also help with forming an intent to exercise.

Activity monitors could theoretically assist in the BCTs shown to be effective in exercise intervention for cancer patients, namely 'goal setting of outcome', 'graded tasks', and 'feedback on outcome of behaviour'.[220] Patients have reported that objective progression measures help with motivation and maintaining adherence to exercise prescription.[227] Activity monitors can allow for a degree of 'self-monitoring of behavioural outcome' and providing cues and prompts which has been shown to be an effective BCT in promoting self-efficacy to increase physical activity in studies of obese patients.[229] The participants in my study were aware of their activity being monitored and that periods of exercise would be recorded. This act of being 'watched' in this way has been reported by cancer patients to be contribute to a feeling of needing to be accountable and a motivating factor for achieving their activity goals.[230,231] An interview study of breast cancer survivors suggested that receiving the prompt from remote monitoring was more important than the actual content of the feedback or prompt for motivation.[231] The motivating factor of feeling 'accountable' and receiving regular prompts, suggests that activity monitors may be assisting in the 'self-regulation' of behaviour.

According to behaviour theory, self-regulation is an important factor for behaviour maintenance.[228] Self-regulation includes the ongoing processes of self-monitoring, self-evaluation and self-reinforcement, based on a system of hierarchically organised goals.[228] Individuals monitor their behaviour against their goals and if behaviour meets goals then the patient is satisfied. If behaviour falls short of their goals, this will cause dissatisfaction which will either result in the individual spending more effort or disengaging from the goal. Therefore, although activity monitors are theoretically able to aid self-regulation by providing more information for self-monitoring, this is only a small of part of the self-regulation process required for behaviour change maintenance.

The participants in my study did not feel the continued feedback and activity reports were useful to increase their capability and motivation for exercise, and lost interest in the feedback after the first report. . Loss of interest and lack of adherence with wearing an activity monitor is a repeated theme across studies of activity monitoring and physical activity interventions.[214,230,232,233] In some patients, this is because they felt active enough already, or had established exercise habits and therefore likely already had good self-regulatory capacity.[232] Others stated reasons of the device being uncomfortable, inaccurate or a ‘waste of time’. Technological issues were rarely reported as a reason for discontinuation.[232]

Qualitative data from interviews of cancer survivors’ experience of activity monitors suggests that the satisfaction from using activity monitors appears to derive from patients achieving set goals. A focus group study of 14 breast cancer survivors showed that the patient felt the wearable devices made them more aware of their activity, and increased motivation and confidence, although the authors felt this was mainly due to having a clear achievable goal of number of steps per day.[230] This fits with the interview data from two studies showing that patients did not use, or largely only preferred to use the step count and distance walked on activity monitors, and ignored the other features such as calories and active minutes because the activity goal was related to step-count only.[230,232] In fact, patients disliked the feature on some monitors that adjusted goals based on previous activity levels, which made them feel less motivated compared with fixed goals used on other monitors.[230] Matching the use of a pedometer to clear step count goal was also a significant predictor of increased physical activity in trials of pedometer use in the outpatient adult population.[84]

The benefit of activity monitors to aid behaviour change maintenance is unclear. Although many different types of feedback and data and prompts can be offered through a remote monitoring device, the impact on reflective and automatic motivation may be more related to the nature of the goal and the accountability factor rather than the content of the feedback itself. The data from my interviews suggests offering more complex feedback is unlikely be helpful, and alignment of goals with the feedback given is the most important motivator. Furthermore, activity monitoring alone is unlikely to improve adherence to prehabilitation exercise intervention without human support as part of remove supervision.

Monitoring versus support

Although logistical barriers to attending supervised exercise classes have prompted trials of home prehabilitation, providing adequate patient support, in the form of remote supervision and activity monitoring, to target the components of the COM-B model is a challenge. The participants in my study reported feeling supported by the study staff but the effectiveness of the weekly telephone calls from the physiotherapists is questionable. These invoked fear in one participant who felt he was letting the study team down by forgetting to do his exercises, and for another participant these calls were not useful as he had a high level of self-efficacy already.

Telephone calls have been shown to be popular with patients as part of prehabilitation to offer support, but patient feedback from prehabilitation studies also emphasise the popularity of group exercise classes. Group exercise has been shown to have functional and psychological benefits, as well as improving adherence.[223,234,235] A systematic review of RCTs of distance-based physical activity interventions for cancer survivors was unable to conclude that a distance-based program was effective in facilitating physical activity.[217] In the prehabilitation population, the use of remote supervision with the aid of technology has the potential to act as a demotivator rather than a useful tool. A survey of 103 patient before major abdominal cancer surgery revealed that 41% of participants reported that the use of technology or telehealth would become a barrier to participation in prehabilitation, although the reason for this was not explored.[222] Therefore, implementation strategies to achieve uptake of technological solutions needs careful planning as well as consideration for how to support patients in excess of what technology can offer.[222]

The level of support and supervision patients may require for a home-based exercise program may be highly variable. A study of prehabilitation before cystectomy used a short intensive home-based exercise intervention but found that adherence (fulfilling at least 75% of the prehabilitation program) was only 59%.[180] The authors considered the impact of comorbidity in the bladder cancer patient program and that the comprehensive prehabilitation program may have been intimidating to patients with baseline poor physical status. More than a third of the patients lived alone and a possible lack of social support was thought to influence adherence.[180] However, no qualitative data was collected to explore the needs of patients in terms of social support and supervision. Interview data from another prehabilitation study of exercise intervention before cystectomy showed that patients felt the supervised exercise provided was key to adherence due to the support received and relationships built with the exercise instructors.[227]

Supervision is clearly an important component of exercise intervention, and suggested as an effective BCT from reviews of exercise intervention in non-prehabilitation populations.[215] Patients appear to prefer supervised exercise but the level of support will likely depend on patient baseline physical and psychological capability and availability of other social support. Resource and logistical barriers may be able to be overcome with a combination of supervised exercise in community settings as well as remote supervision and self-monitoring with the aid of activity monitors. The Prehab4Cancer initiative in Manchester used community gyms to bridge the problem of providing supervised exercise but in a local setting with peer support.[235] The feedback from patients enrolled in Prehab4Cancer suggested that the personal supervision and exercising with others was a motivating factor.[235] Further investigation is needed of how technology and remote monitoring can best facilitate behaviour change in a semi-supervised prehabilitation exercise intervention.

Future considerations for use of activity monitoring as a BCT in prehabilitation

Activity monitors and patient remote support using APPs and web-based self-management portals have been suggested by several prehabilitation groups as a way to support patients and improve adherence to prehabilitation intervention.[26,167,235] However, the goal of these devices and applications is often targeted at providing data for the research or clinical team, to ensure compliance to exercise prescription, or with the aim to improve the surgical pathway. There is little qualitative data to help understand how these can best support patients to improve their capability, opportunity and motivation for exercise.

The way patients engage with these digital solutions also requires further investigation. The participants in the intervention group in my study did not engage in the activity monitoring feedback on a weekly basis, and were not interested in the longitudinal feedback. This may have been due to a variety of reasons, including a lack of clear set gaols, not aligning the exercise prescription well enough to the feedback, providing too much feedback data which caused confusion and not making clear the purpose of the activity monitoring to the participants. These demotivating factors may have the potential to increase anxiety rather than support the patient, and may not be best solution for all patients.[160] The Macmillan Cancer Support recommendations for prehabilitation in cancer patients emphasise the importance of making better use of data and technology both for patient support and service improvement and quality assurance during prehabiliation.[160]

5.7.6.5 Limitations of the qualitative data analysis

The limitations of the study result from the small number of patients and being all male and Caucasian. This is partly reflective of the patient population requiring major urological surgery in the form of prostatectomy, cystectomy and nephrectomy but clearly does not include the views of women and a range of backgrounds and disease severity. The data from the interviews does still contribute to the literature, which for prehabilitation studies of cancer patients, is dominated by studies of breast cancer patients.

The themes raised in my study have included issues expressed by patients which have previously not been discussed in the surgical prehabilitation literature such as the influence of risk perception, the importance of self-identity related to work, previous exercise experience and relationships with healthcare staff, as well as the feedback on activity monitoring in this context. Thematic analysis using the Braun and Clarke method also does not stipulate that a certain number of responses are required, and can be used in 1 or 2 patient case studies or larger datasets, depending on the aim of the qualitative analysis.[204] In my study, the interviews aimed to provide point of discussion for how BCTs may be used in prehabilitation, rather than a survey study of the most common barriers or preferences of a group of patients. A smaller, homogenous sample may also result in easier identification of themes, although with reduced external validity.[204]

Interviewing patients who have agreed to take part in a prehabilitation study provides a limited viewpoint and is likely to include patients who are already motivated by exercise or by taking part in research to help others. This is not representative of the population of patients listed for major urological surgery. This is a source of bias prehabilitation studies, with one RCT of prehabilitation for radical prostatectomy patients reporting that 34% of eligible patients did not then consent to participate in the study due to lack of interest or unwillingness to travel.[127] Although my study aimed to include patients that were not already very fit, the usefulness of gaining viewpoints from patients who already have established exercise habits is questionable when considering how to employ BCTs to increase motivation for exercise. Less qualitative data exists for the viewpoints of patients with a large 'cost opportunity' to starting exercise due to a higher number of barriers in terms of physical capability and physical opportunity as well as reflective motivation. This is an important population of patients to recruit for qualitative studies investigating BCTs in prehabilitation exercise intervention.

Another limitation of the qualitative data analysis is reliance on behaviour theory to inform methodology in prehabilitation exercise intervention. Patient viewpoints expressed in the study interviews may have no bearing on how behaviour change techniques may be used in such a study. There is also conflicting evidence in the literature on whether behaviour theory approaches to increasing physical activity are effective.[187,220,236] Although recommendations from reviews of BCTs for increasing physical activity broadly agree that theory based approaches should be used, there is not enough evidence that this is an effective approach for prehabilitation of surgical patients. My study is also limited in that the design of the intervention was not specifically investigating BCTs and therefore conclusions on the BCTs used from the qualitative data is merely descriptive. However, the thematic analysis has provided an opportunity for hypothesis generation on which BCTs may be effective and may warrant further research in prehabilitation studies.

5.7.6.6 Summary of discussion of the qualitative data and implications for BCTs used in prehabilitation

The analysis of patient interviews in this study is one of the first to investigate BCTs using qualitative data for surgical prehabilitation. The themes developed in this study include 'self-identity' and 'experience of exercise' which contribute to an individual's degree of self-efficacy, and may impact on a patient's risk perception and how responsive they may be to education interventions in the preoperative period to increase exercise. The theme of 'experience of exercise' will also impact on reflective and automatic motivation, and should be considered when tailoring exercise prescription to the individual.

The interview data also suggested that the use of activity monitoring and feedback in my study was effective in some aspects, in terms of improving patients' understanding of their level of inactivity, but largely ineffective in increasing patient motivation and adherence to their exercise prescription. The barriers to use of activity monitoring as a BCT include technical difficulties, adherence to wearing the device on a daily basis, perception of the measurement of activity as unrepresentative or inaccurate and a misalignment of the goals of exercise to the feedback provided by the device. Patients require ongoing support and supervision during exercise intervention. The role of activity monitors to support behaviour change is currently unproven in studies of non-prehabilitation populations, and requires further research in the surgical prehabilitation context.

5.8 Conclusions

This feasibility study was designed to address some of the issues that have been raised from previous prehabilitation studies in the elective major abdominal surgery population. Although incomplete, several learning points have been gained from the study. Of crucial importance in prehabilitation interventions is the need to ensure that the intensity and quantity of exercise undertaken reaches adequate levels, which are moderate intensity and above, in bouts of 10 minutes or more. Activity monitoring in this study has achieved the ability to measure this and the format of the exercise intervention for the 2 patients in this study appear to show some effect of being able to achieve greater periods of moderate intensity activity is likely to be more accurately measured with a wearable accelerometer than a physical activity questionnaire. This format of prehabilitation has the potential to be feasible in clinical practice but improvements on reliability of equipment and usefulness of the patient feedback are needed. Further consideration of how behaviour change techniques can be incorporated into exercise intervention may also improve patient adherence. Remote monitoring can be used as an adjunct to increase patient motivation during prehabilitation but is unlikely to be effective as the main form of supervision and feedback.

6 Summary of thesis and future directions

This thesis aimed to improve understanding on how accelerometry data related to cardiorespiratory fitness or functional capacity and how this could be used in the perioperative setting for both preoperative assessment and as part of prehabilitation exercise intervention. The learning points from this thesis is the current lack of a good understanding of how raw accelerometry can, and should be used, to measure physical activity and how this is interpreted in terms of physical fitness.

6.1 Key findings and learning points.

The first study has shown how different summary measures of activity extrapolated from raw accelerometry data are related to patient performance in CPET. Some traditional measures of activity from accelerometry data such as *Magnitude of Acceleration* do not show a relationship to functional capacity measured by CPET, whereas the variance of magnitude and frequency of acceleration do appear to be related. Parameters measured by accelerometers show promise in this study to be able to discriminate for high risk patients, but this is likely not an additional benefit to commonly used tools such as the ASA status and Duke Activity Status Index. The benefit to collecting the accelerometer data in conjunction with CPET data, is to enable assessment of both baseline functional capacity and activity level. This will in turn enable meaningful prescription and monitoring of exercise interventions that aim to increase the patient's activity by a significant level that we know corresponds to better functional capacity and decreased risk from surgery.

The second study has shown promise for the utility of daily activity monitoring to be able to provide useful information to the medical team and the patient in implementing a prehabilitation exercise program. Few studies exercise intervention studies in surgical patients have collected qualitative information on the patient's perception of exercise prehabilitation.

Although the study is not able to draw conclusions on feasibility or utility of this type of exercise intervention, the feedback in the patient interviews has provided useful information to improve on this model for future studies. One would anticipate that the direction of exercise prehabilitation, as part of a multimodal program that also includes patient education, nutrition and psychological support, would be a semi-supervised, community-based exercise program that is tailored to the individual requirements of the patient. Instigating behaviour change is very difficult, especially for increasing exercise, and a successful prehabilitation program will need to use all the available tools, including peer support, expert physiotherapy input, useful feedback on progress using activity monitoring, and access to group-based and hospital-based exercise sessions.

As a research tool, accelerometer and heart rate-based activity monitoring can provide valuable insight into the adherence and efficacy of prehabilitation exercise interventions, but the validity of the way the data from these devices is interpreted to represent free-living physical activity levels is not yet proven.

The added value of the work in this thesis is from the bringing together of expertise in perioperative care from several specialties. These include an anaesthetic and surgical point of view, the expertise of the industry collaborators and their experience in analysing accelerometer data, and the advice of research physiotherapists who have expertise on exercise testing and prescription. This thesis contains novel data on the relationship between daily activity measured by an accelerometer and functional capacity assessed by CPET, and a novel study design incorporating remote monitoring and feedback into an exercise prehabilitation program for patients undergoing major urological surgery. The implications of the results in this thesis and other available evidence is that, preoperative fitness testing and prehabilitation are effective at identifying high risk patients and reducing their risk for adverse postoperative outcomes, and that preoperative exercise programs require optimisation of all elements to be effective, of which activity monitoring could play a useful role.

6.2 Areas for further research

The work in this thesis has highlighted several areas related to accelerometer use in this context which would need further investigation, before utility of activity monitoring can be fully realised in the surgical pathway. The groundwork for the relationship between accelerometers and energy expenditure has already been done, but there is lack of validated data in the free-living environment, especially in the more elderly and inactive populations.

Further work is needed on the validation of wrist-worn accelerometers with heart rate monitoring in this population for being able to classify and quantify the ‘amount’ of physical activity. Ideally, this would produce a method of activity classification that can easily be personalised to a particular individual. This would likely involve creation of a standard set of activities, that the patient undertakes in a controlled environment, which would provide essential baseline data on which to adapt algorithms that can estimate activity levels in the free-living environment. Although validation datasets exists for healthy individuals that help estimate activity intensity from accelerometer data, there is a need to find metabolically validated cut points for activity intensity classification specific to the older or perioperative population.

Initially, this would involve use of a wrist-based accelerometer to measure baseline activity in a larger population of perioperative patients to ensure good compliance for a larger dataset. This would generative normative values on which further information from CPET performance and other physiological tests could be compared to understand the relationship between changes in cardiorespiratory fitness and changes in accelerometery measured activity. For example, as we gather more data on changes in physiological test such as CPET and other submaximal exercise tests, we can map this to expected changes in accelerometry variables, such that exercise prescription as part of prehabilitation can be tailored to daily activity monitoring data rather than repeated physiological testing of cardiorespiratory fitness.

Detecting movement alone with one location of a wearable accelerometer is unlikely to be able to capture all episodes of relevant activity. Use of GPS (which can measure distance travelled) and heart rate information would be needed to be able to more accurately estimate amount of exercise performed. It is unlikely that a sophisticated system of feedback to the patient of their activity monitoring data is required for the purposes of exercise prehabilitation.

Going forwards, simple but effective methods of being able to summarise and present activity data to patients to help with compliance and motivation should be optimised. The role of activity monitors as part of a wide range of BCTs used to improve patient adherence to prehabilitation should be investigated further. The evidence from this thesis suggests that a device which is easy to use and reliable, having clearly set goals which are aligned precisely with the feedback from the monitor and the use of regular prompts along with in-person supervision is needed to support behaviour change if remote supervision and monitoring is used. Activity monitoring could also be used as part of a peer-support system to create a community of patients in prehabilitation who are able to see each other's results. Finally, the added value of this kind of system to prehabilitation and the surgical pathway needs to be evaluated using health economics analysis. Inclusion of activity monitoring in the perioperative pathway will only occur if it can be shown improve outcomes for patients and offer enhanced value for the healthcare system.

Appendices

A. Relevant documents for ‘Activity Monitoring Before and After Surgery’ study.

i. Patient Information Leaflet

Activity Monitoring Before and After Surgery

Patient Information Leaflet

Invitation to take part

We would like to invite you to take part in a research study relating to your activity levels before and after your upcoming operation. Before you decide if you would like to take part it is important for you to understand why the research is being done and what it will involve.

Please take time to read the following information carefully. If you are interested in taking part or would like to ask questions, you can contact the researcher using the contact details at the end of this leaflet, or you can speak to the researcher when you come in for your hospital appointment.

Background

Every operation has a degree of risk for the patient. It is important to be able to assess this risk accurately as it can help us plan how to reduce the risk of the operation and improve the postoperative recovery. This is currently done through asking questions about a patient's health in the preoperative clinic and requesting additional tests if necessary. However, we currently do not know what the best method of assessment is.

What is the purpose of the study?

We aim to collect information on a person's usual activity level at home before and after their operation using a small, wearable, activity monitoring device. A person's level of physical activity is known to be an important measure of a patient's general health and can help predict how well a patient will recover from their operation. Activity levels after an operation can also help us determine how the operation has affected a person's daily function and quality of life. We will compare this new method to existing methods of assessment to see if it is feasible and effective for future use. By better understanding the preoperative risk and what a patient can expect after their operation, we can give more accurate information to patients about their operation.

Why have I been invited to take part?

You are due to have an elective operation and have been referred for a cardiopulmonary exercise test (CPET) at the hospital before your operation.

Do I have to take part?

No. It is entirely up to you whether or not to take part. Please take as much time as you feel you need to make this decision. You can read this information sheet as many times as you wish and ask your doctor and/or the researcher when you arrive for your hospital appointment any questions. If you decide not to take part this will not affect your care surrounding your operation. If you do decide to take part after talking to the researcher, you will be asked to sign a consent form confirming your agreement. However, even after you have signed this form, you are still free to withdraw at any time and without giving a reason. A decision to withdraw from the study will not affect the standard of care you receive.

What will happen if I take part?

If you agree to participate, you will have your CPET test as planned. For the study, we will give you a small activity monitoring device and show you how it can be worn securely and discreetly. We would like you to wear the activity monitoring device during your CPET test. After the CPET test we will ask you to complete 3 questionnaires, taking approximately 10 minutes. You will then take the activity monitor home and we would like you to wear this for 3 continuous days including during sleep. However, you can choose to remove the device at certain times or wear on separate days for comfort and privacy reasons. We will give you a prepaid envelope to post the device back to us once the 3 days of monitoring have been completed. You will also have a brief questionnaire asking how acceptable you have found wearing the device to post back to us with the device.

You will have your operation as planned. We will review your notes once you have been discharged from hospital to collect information on how your operation went and how you recovered in hospital afterwards.

At the 3-month period after your operation, we will give you a telephone call to ask how you have been since the operation. If you agree to continue participating in the study, we will send you another activity monitor to wear at home for 3 days and the same set of questionnaires you completed before your operation to complete now you have had your operation. As before, you can post these back to us in a prepaid envelope. The anonymous activity data from the monitors will be sent to a commercial partner with expertise in movement data analysis.

What are the possible risks or disadvantages of taking part?

There are no anticipated risks or disadvantages in participating in this study. The activity monitoring device is CE licensed and approved for medical use. You may find it an inconvenience to wear the device and post it back to us and this can be discussed with the researcher at any point in the study to make it as little trouble for you as possible.

What are the possible benefits of taking part?

You will receive the same health care from your doctors whether or not you choose to take part. You may not benefit personally from taking part in this study. By taking part in this study, you will help us inform the care of future patients undergoing an operation in finding more effective methods of assessing patients before and after their operation.

What if there is a problem?

The University of Oxford, as Sponsor, has appropriate insurance in place in the unlikely event that you suffer any harm as a direct consequence of your participation in this trial. NHS indemnity will operate in respect of the clinical treatment which is provided.

If you have a concern or wish to complain about any aspect of the study or the way in which you have been approached or treated, you should ask to speak to the researchers who will answer your questions.

If you become unable or unwilling to continue in this study, we would withdraw you from the study. If this happens, we will keep the relevant information already collected about you for the study results. This information will remain confidential and will not be used for any other purpose.

Who will know I am taking part in the study?

All information that is collected about you during the course of the study will be kept strictly confidential and will be held securely in accordance with the Data Protection Act. Only certain members of the research team will have access to your information in order, for instance, to send you the questionnaires. If you participate in the study, we will tell your GP you are taking part, but only with your permission. Responsible members of the University of Oxford or the Oxford University Hospitals NHS Trust may be given access to data for monitoring and/or audit of the study to ensure we are complying with regulations.

Anonymised data collected during the study may be passed on to other organisations which may include commercial organisations.

What will happen if I don't want to carry on with the study?

You can withdraw from the study at any point. This will not affect your routine clinical care. The data from any questionnaires or activity monitoring you have provided will contribute to the analysis of the results from the study unless you would like us not to do so.

What will happen to the results of the study?

The results of the study will be used to evaluate activity monitoring as a tool for patient assessment. The main results of this study, which may take 2 years to be become available, will be published in scientific journals and presented at scientific meetings. You will not be identified in any publication of results of the study. We are very happy to provide you with a summary of the results.

Who is organising and funding the research?

The research has been organised by surgical and anaesthetic doctors within the Oxford University Hospitals. The study is led by Chief Investigator, Mr Benjamin Turney who is a consultant urological surgeon and Senior Clinical Researcher at the Nuffield Department of Sciences, University of Oxford. It is funded by the Allison Hanson Charity and McLaren Applied Technologies.

Who has reviewed the study?

All research in the NHS is looked at by an independent group of people, called a Research Ethics Committee, to protect your safety, rights, wellbeing and dignity. This study has been reviewed and given a favourable opinion by the East of England, Norfolk, Research Ethics Committee (reference number 14/EE/1192). Approval does not guarantee that you will not come to any harm if you take part. However, approval means that the Committee is satisfied that your rights will be respected, that any risks have been reduced to a minimum and balanced against possible benefits, and that you have been given sufficient information on which to make an informed decision to take part or not.

Expenses and Payments

We do not anticipate extra expense for the participants of this study outside of expenses encountered for routine clinical care. Therefore, there is no provision for participant payments. Postage costs will be prepaid.

Further information and contact details?

If you would like further information or have any questions, please contact:

Helen Cui

Principle Investigator

Nuffield Department of Surgical Sciences

ii. Acceptability Questionnaire

Study of Activity Monitoring Before and After Surgery

Acceptability of wearing an activity monitoring device questionnaire

If possible, please list all the dates on which the activity monitor was worn:

Please tick one box for each question:

1. How many days in total did you wear the device for?	☐ 1 day or less ☐ 2 days or less ☐ 3 days or less ☐ More than 3 days
2. How did you wear the device?	☐ Attached to back ☐ Attached to chest ☐ Other method (please specify):

3. How acceptable did you find wearing the device?	☐ No problems with wearing the device ☐ Device caused slight discomfort or inconvenience ☐ Device caused significant discomfort or inconvenience ☐ Could not wear device due to (please specify reason):
4. What problems, if any, did you experience when wearing the device?	
5. Would you find it acceptable to wear the device again for future activity monitoring?	☐ Yes ☐ No

End of questionnaire. Thank you.

iii. EQ-5D Questionnaire

Under each heading, please tick the ONE box that best describes your health TODAY

MOBILITY

I have no problems in walking about ❑

I have slight problems in walking about ❑

I have moderate problems in walking about ❑

I have severe problems in walking about ❑

I am unable to walk about ❑

SELF-CARE

I have no problems washing or dressing myself ❑

I have slight problems washing or dressing myself ❑

I have moderate problems washing or dressing myself ❑

I have severe problems washing or dressing myself ❑

I am unable to wash or dress myself ❑

USUAL ACTIVITIES *(e.g. work, study, housework, family or leisure activities)*

I have no problems doing my usual activities ❑

I have slight problems doing my usual activities ❑

I have moderate problems doing my usual activities ❑

I have severe problems doing my usual activities ❑

I am unable to do my usual activities ❑

PAIN / DISCOMFORT

I have no pain or discomfort ❑

I have slight pain or discomfort ❑

I have moderate pain or discomfort ❑

I have severe pain or discomfort ❑

I have extreme pain or discomfort ❑

ANXIETY / DEPRESSION

I am not anxious or depressed ❑

I am slightly anxious or depressed ❑

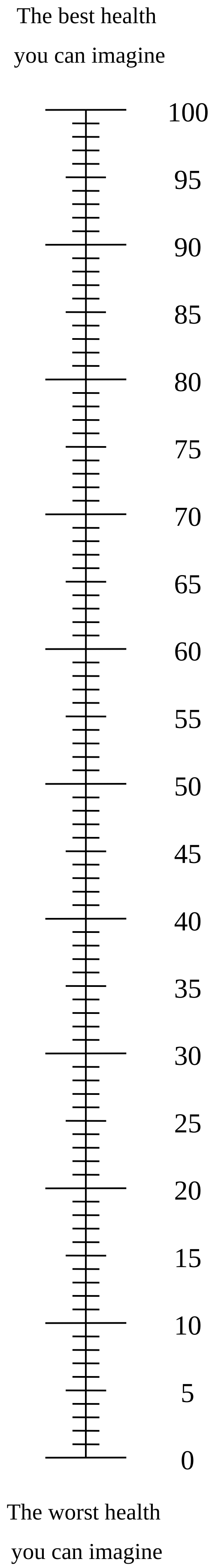
I am moderately anxious or depressed ❑

I am severely anxious or depressed ❑

I am extremely anxious or depressed ❑

We would like to know how good or bad your health is TODAY.

- This scale is numbered from 0 to 100.
- 100 means the best health you can imagine.
  0 means the worst health you can imagine.
- Mark an X on the scale to indicate how your health is TODAY.
- Now, please write the number you marked on the scale in the box below.



iv. SF-12 Questionnaire

Your Health and Well-Being

This survey asks for your views about your health. This information will help keep track of how you feel and how well you are able to do your usual activities. ***Thank you for completing this survey!***

For each of the following questions, please tick the one box that best describes your answer.

1. In general, would you say your health is:

Excellent	Very good	Good	Fair	Poor
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

2. The following questions are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much?

		Yes, limited a lot	Yes, limited a little	No, not limited at all
a	Moderate activities, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf	☐ 1	☐ 2	☐ 3
b	Climbing several flights of stairs	☐ 1	☐ 2	☐ 3

3. During the <u>past 4 weeks</u>, how much of the time have you had any of the following problems with your work or other regular daily activities <u>as a result of your physical health</u>?

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
a Accomplished less than you would like	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
b Were limited in the kind of work or other activities	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

4. During the <u>past 4 weeks</u>, how much of the time have you had any of the following problems with your work or other regular daily activities <u>as a result of any emotional problems</u> (such as feeling depressed or anxious)?

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
a Accomplished less than you would like	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
b Did work or other activities less carefully than usual	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

5. During the <u>past 4 weeks</u>, how much did pain interfere with your normal work (including both work outside the home and housework)?

Not at all	A little bit	Moderately	Quite a bit	Extremely
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

6. These questions are about how you feel and how things have been with you <u>during the past 4 weeks</u>. For each question, please give the one answer that comes closest to the way you have been feeling. How much of the time during the <u>past 4 weeks</u>…

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
a Have you felt calm and peaceful?	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
b Did you have a lot of energy?	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
c Have you felt downhearted and low?	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

7. During the <u>past 4 weeks</u>, how much of the time has your <u>physical health or emotional problems</u> interfered with your social activities (like visiting with friends, relatives, etc.)?

All of the time	Most of the time	Some of the time	A little of the time	None of the time
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

Thank you for completing these questions!

B. Relevant documents for 'Monitored Home Exercise before Major Urological Surgery' study.

v. Patient Information Leaflet

Principal Investigator: Ms Helen Cui
Email: helen.cui@ouh.nhs.uk, Address: Nuffield Department of Surgical Sciences, Level 6, John Radcliffe Hospital, Oxford, OX39DU

PARTICIPANT INFORMATION SHEET

Study Title: Monitored Home Exercise Intervention before Urological Surgery

We'd like to invite you to take part in our research study. Before you decide, it is important that you understand why the research is being done and what it would involve for you. Please take time to read this information, and discuss it with others if you wish. If there is anything that is not clear, or if you would like more information, please ask us.

What is the purpose of the study?

This is a feasibility study to help design a future, larger study on how to improve exercise intervention before major urological surgery. Exercise intervention before surgery aims to get patients fitter before their operation, which is thought to reduce the rate of complications and improve recovery after surgery. We would like to use a system of remote activity monitoring using a small, activity sensor worn on the chest to help patients undertake a home exercise program. As this is a relatively new method of exercise intervention and monitoring, we will use the information from this study to help us determine whether this method is acceptable to patients and can be used as part of a larger study to test the effectiveness of this exercise intervention in improving physical activity levels before surgery. This study will allocate participants to either a control or an intervention group randomly. The control group will undergo activity monitoring for 8 days in total only and attend 2 study visits. The intervention group will undergo activity monitoring for up to 6 weeks, during which time they will undertake a personalised exercise program and attend a total of 3 study visits.

Why have I been invited?

You have been invited to take part because you have been referred to the urology department, and are being investigated for suspected urological cancer, which may require surgery in the future.

This study intends to involve 36 patients who under the care of the urology outpatient department and being investigated and treated for possible urological cancer, which may require urological surgery in the future.

Do I have to take part?

No. It is entirely up to you whether to take part. You may take up to seven days to make this decision. You can read this information sheet as many times as you wish and ask your doctor and/or the researcher when you arrive for your hospital appointment any questions.

If you decide not to take part this will not affect your care. Due to the nature of this study, we may ask to discuss with you your reasons for not participating, so we can take this into account in future design.

If you do decide to take part after talking to the researcher, you will be asked to sign a consent form confirming your agreement.

However, even after you have signed this form, you are still free to withdraw at any time and without giving a reason. A decision to withdraw from the study will not affect the standard of care you receive.

What will happen to me if I decide to take part?

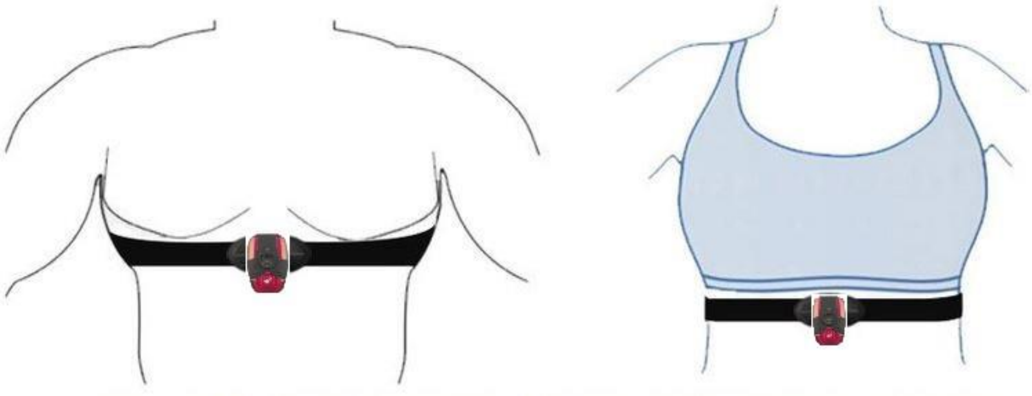
If you consent to take part in the study, all your usual appointments, tests and treatments, including any planned surgery, will occur as planned without any delays. The whole study lasts 6 weeks and you will need to attend a maximum of two extra research sessions in the Churchill hospital lasting 45 minutes to 1 hour each.

On the first visit, which may coincide with your scheduled outpatient appointment, you will fill in five questionnaires and do a walking test, all of which will take approximately 30 minutes. These baseline assessments collect information about your usual activity levels, physical and mental health and your fitness level as tested by walking.

After this, you will be provided with a small activity sensor (see picture below) to take home which will tell us what your usual activity levels are at home.

This records your direction and degree of movement, and heart rate only. This does not record your location. You will be asked to wear this using a chest strap (see picture below) during the hours of the day you are awake, with the aim to wear it for at least 10 hours a day, for 4 days in a row.

You will also be asked to record how many minutes of moderate intensity activity you do each day in an activity diary.



You do not need to make any changes to your usual routine. You do not need to do anything else with the sensor other than remembering to turn it on and off, to charge it overnight, and to wear it during the day. You will receive a text message each morning to remind you to wear the sensor.

After 4 days, you will receive a telephone call to let you know whether you will be in the control group or the intervention group of the study. This is randomly allocated using a computer. This means the researcher has no way of influencing or knowing in advance which group you will be in. Details of each group are given below:

Control Group

If you are in the control group, you will post the sensor, chest strap and activity diary back to us in a pre-provided stamped addressed envelope. You will not receive any further contact from us for the next 4 weeks. You do not need to do anything additional to your usual routine. If you happen to do extra physical activity that is not normal for you, we will ask you to record this on paper.

After the 4 weeks, we will telephone to check you would like to continue with the study, and if you agree, you will repeat another 4 days of activity monitoring, using the same sensor and chest strap, which will be posted to you.

After these last 4 days of activity monitoring, you will be asked to return to the hospital for one final visit lasting approximately one hour. At this visit, you will return the activity monitoring equipment to us and repeat the questionnaires and the walking test you completed at the beginning of the study and have a short interview with a researcher on your experience of the study. This interview will be audio recorded with your consent. After this visit the study will be finished, and no further visits or information will be required from you.

Intervention Group

If you are in the intervention group of the study, you will need to attend for two further visits.

After the first visit and initial 4 days of activity monitoring, you will return to the hospital for a second visit lasting approximately 45 minutes with a physiotherapist and the researcher. We will discuss together and agree on a personalised exercise plan for you to do at home.

This exercise plan will last 4 weeks and aim to increase the number of minutes of moderate intensity exercise you do per day. This will help you reach nationally recommended targets of aiming for 150 minutes of moderate intensity activity a week. This will be guided by your fitness level and exercises you would be happy to do. The exercise plan will aim to increase your activity level by 2.5% per day gradually over the 4 weeks.

You will also be provided with the information and equipment which allows your daily activity levels to be recorded. You will be using the same activity sensor with the chest strap, as well as a hub device that allows the data to be transmitted back to the research team for analysis. You will also use an online website to receive feedback on your exercise plan progress three times a week, based on what the activity sensor has recorded over the last few days. You will have your own username and password to access the feedback on your daily activity levels on the website. The feedback will also be emailed to you 3 times a week.

Once a week, you will receive a call from the study researcher which will last approximately 15 minutes. They will ask you about how you are getting on with the exercise plan and activity sensor, and ask you a short questionnaire about how much activity you think you have done in the past week. They will also give guidance on how to progress with the exercise plan.

At the end of the 4 weeks of doing your exercise plan, you will continue to wear the sensor during waking hours for another 4 days. We will compare these last 4 days with your activity levels recorded at the start of the study. You do not need to do anything differently during these last 4 days.

After these 4 days of activity monitoring have been completed, you will be asked to return to the hospital for a third and final visit. At this visit, you will return the activity monitoring equipment to us, repeat the questionnaires and the walking test and have a short interview with a researcher on your experience of the study. This interview will be audio recorded with your consent, so your responses can help us improve the study. After this visit the study will be finished, and no further visits or information will be required from you.

What should I consider?

You may not be able to participate in the trial if any of the following apply:

- If you have a scheduled urological operation in less than 6 weeks from recruitment into the study
- If you are already very fit, which will be assessed using an activity questionnaire
- You have other medical problems that are severe enough to interfere significantly with participating in the study

- If you do not have 3G phone signal at home
- If you do not have access to internet or email
- If you have a heart pacemaker or Implantable Cardioverter Defibrillator (ICD) as this will interfere with the activity sensor.
- If you are involved with other research studies which may interfere with this study, or require the permission of the researchers in the other study.

Are there any possible disadvantages or risks from taking part?

You will need to wear the activity sensor on your chest using the chest strap. This may cause some discomfort during the day.

If you are allocated to the control arm of the study, there is a disadvantage in that you will not be receiving feedback on your activity levels and you will not be receiving a personalised exercise plan to try and improve your activity levels. However, you will receive a report at the end of the study which gives feedback on your activity levels during the time you have undertaken activity monitoring.

If you are allocated to the intervention arm of the study, there may be a slight risk to you having to undertake more physical activity. However, we try and minimise this by setting realistic targets for your ability level, and different types of exercises for you to choose.

What are the possible benefits of taking part?

We would like to use this study to help us design a future study that will test if this type of exercise intervention is effective. We think that improving exercise intervention will lead to better outcomes for future patients due to have urological surgery.

This study may encourage participants to increase their daily physical activity levels and we know that any increases in physical activity level are beneficial to overall health.

Will my General Practitioner/family doctor (GP) be informed of my participation?

We will not be informing your GP of your participation in the study.

Will my taking part in the study be kept confidential?

We will keep all your study information strictly confidential and stored securely in accordance with the Data Protection Act on password protected hospital computers. Only certain members of the research team will have access to your personal information in order, for instance, to call you on the telephone. This will be stored in a locked filing cabinet at the Nuffield Department of Surgical Sciences, University of Oxford.

Responsible members of the University of Oxford and the Oxford University Hospitals NHS Foundation Trust may be given access to data for monitoring and/or audit of the study to ensure that the research is complying with applicable regulations.

The audio recordings of your interview at the final visit with the researcher, will be used to analyse the experience of the participants in the study. This audio recording will be transcribed into text and then the original recording will be destroyed. Both the audio recording and the transcribed text will be labelled with your participant ID number and have no information that can allow someone else, other than the researchers, to identify who you are.

Will I be reimbursed for taking part?

You will be reimbursed for your travel expenses.

In addition, you will also be reimbursed for your time and effort in taking part in this study. This reimbursement will be a total of £100 paid at the end of the study. If you decide to withdraw at any point before the end of the study, you will be reimbursed £50.

You will be reimbursed the same amount if you have been allocated to the control or intervention group.

What will happen to my data?

If you consent to participate in the study, your contact details used for the researchers to contact you about the study will be stored on paper in a locked filing cabinet at the John Radcliffe Hospital which will only be accessible to the study researchers.

All other data related to you will be anonymised using a Participant ID, including any electronic data, and be stored securely at the hospital or on a hospital or university computer.

The activity monitoring data collected by your sensor will be stored on a secure cloud server, hosted by Amazon Web Services. This is password protected and only accessible to the researchers. No information that can identify you is stored on the cloud server. Once the activity data has been analysed, the data on the cloud server will be deleted.

With your consent, the anonymised data from this study may be used for future ethically approved research studies.

Personal data on NHS computers will be deleted as soon as it has been used and will be restricted access. However, if you consent to us contacting you about participation in future research studies, your personal contact details will be retained and stored in a password protected file on an Oxford University computer for 5 years.

What will happen if I don't want to carry on with the study?

You can withdraw from the study at any point. This will not affect your routine clinical care. The data from any questionnaires, interviews or activity monitoring you have provided will contribute to the analysis of the results from the study unless you would like us not to do so.

If you withdraw from the study, we will plan for you to return any equipment we have provided.

If you withdraw from the study, we will ask you to take part in a qualitative interview to examine any barriers to participating in the study, including the uptake of exercise intervention and activity monitoring. This would compromise a short face to face discussion or telephone call (approximately 15 minutes) on one occasion only. You are under no obligation to take part in this, but it will help us with the development of a future larger study.

What happens at the end of the study?

We will use the results from this study to design a future, larger study. We will present the main results of this study (which may take 2 years to be available) in scientific journals and meetings. You will not be identifiable in any publication of the results, and you will not be identifiable from any quotes used from interviews you have participated in. We are very happy to provide you with a summary of the results if requested.

Some of the research being undertaken will also contribute to the fulfilment of a doctoral thesis.

What if we find something unexpected?

If we find something unexpected during the study which may be significant to your clinical care, we will consult about this with you. Your usual clinical team may then investigate further if necessary.

What if there is a problem?

If you are experiencing difficulties in participating in the study, including using the monitoring equipment or doing the exercise recommendations, please contact the researcher Ms Helen Cui.

The University of Oxford, as Sponsor, has appropriate insurance in place in the unlikely event that you suffer any harm as a direct consequence of your participation in this study. NHS indemnity operates in respect of the clinical treatment which is provided.

If you wish to complain about any aspect of the way in which you have been approached or treated during the course of this study, you should contact Mr Benjamin Turney.

The Patient Advisory Liaison Service (PALS) is a confidential NHS service that can provide you with support for any complaints or queries you may have regarding the care you receive as an NHS patient. PALS is unable to provide information about this research study.

How have patients and the public been involved in this study?

We have used feedback on activity monitoring from a previous study to provide information to help design this study.

The links below can give more general information about taking part in research:

www.crn.nihr.ac.uk/can-help/patients-carers-public/how-to-take-part-in-a-study/

www.nhs.uk/Conditions/Clinical-trials/Pages/Introduction.aspx

Who is organising and funding the study?

Surgical and anaesthetic doctors within the Oxford University Hospitals NHS Foundation Trust organised the study. The study is led by Chief Investigator, Mr Benjamin Turney, who is a consultant urological surgeon and Senior Clinical Researcher at the Nuffield Department of Sciences, University of Oxford.

The study is sponsored by the University of Oxford and funded by McLaren Applied Technologies.

Who has reviewed the study?

All research in the NHS is looked at by an independent group of people, called a Research Ethics Committee, to protect participants' interests. The London-Bloomsbury Research Ethics Committee has approved this study.

Participation in future research:

If you would like to participate in future research after this study, we will ask for your consent to keep your contact details for 5 years on a password protected file on a university computer. This does not mean you have to take part in future research if you do not want to.

For further information please contact Ms Helen Cui

Thank you for considering taking part.

vi. International Physical Activity Questionnaire (IPAQ)

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** and **moderate** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal.

PART 1: JOB-RELATED PHYSICAL ACTIVITY

The first section is about your work. This includes paid jobs, farming, volunteer work, course work, and any other unpaid work that you did outside your home. Do not include unpaid work you might do around your home, like housework, yard work, general maintenance, and caring for your family. These are asked in Part 3.

1. Do you currently have a job or do any unpaid work outside your home?

☐ Yes

☐ No → ***Skip to PART 2: TRANSPORTATION***

The next questions are about all the physical activity you did in the **last 7 days** as part of your paid or unpaid work. This does not include traveling to and from work.

2. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, heavy construction, or climbing up stairs **as part of your work**? Think about only those physical activities that you did for at least 10 minutes at a time.

_____ **days per week**

☐ No vigorous job-related physical activity → ***Skip to question 4***

3. How much time did you usually spend on one of those days doing **vigorous** physical activities as part of your work?

_____ **hours per day**
_____ **minutes per day**

4. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads **as part of your work**? Please do not include walking.

_____ **days per week**

☐ No moderate job-related physical activity → ***Skip to question 6***

5. How much time did you usually spend on one of those days doing **moderate** physical activities as part of your work?

_____ **hours per day**
_____ **minutes per day**

6. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **as part of your work**? Please do not count any walking you did to travel to or from work.

_____ **days per week**

☐ No job-related walking → ***Skip to PART 2: TRANSPORTATION***

7. How much time did you usually spend on one of those days **walking** as part of your work?

_____ **hours per day**
_____ **minutes per day**

PART 2: TRANSPORTATION PHYSICAL ACTIVITY

These questions are about how you traveled from place to place, including to places like work, stores, movies, and so on.

8. During the **last 7 days**, on how many days did you **travel in a motor vehicle** like a train, bus, car, or tram?

_____ **days per week**

☐ No traveling in a motor vehicle → ***Skip to question 10***

9. How much time did you usually spend on one of those days **traveling** in a train, bus, car, tram, or other kind of motor vehicle?

_____ **hours per day**
_____ **minutes per day**

Now think only about the **bicycling** and **walking** you might have done to travel to and from work, to do errands, or to go from place to place.

10. During the **last 7 days**, on how many days did you **bicycle** for at least 10 minutes at a time to go **from place to place**?

_____ **days per week**

☐ No bicycling from place to place → ***Skip to question 12***

11. How much time did you usually spend on one of those days to **bicycle** from place to place?

_____ **hours per day**
_____ **minutes per day**

12. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time to go **from place to place**?

_____ **days per week**

☐ No walking from place to place → ***Skip to PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY***

13. How much time did you usually spend on one of those days **walking** from place to place?

_____ **hours per day**
_____ **minutes per day**

PART 3: HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY

This section is about some of the physical activities you might have done in the **last 7 days** in and around your home, like housework, gardening, yard work, general maintenance work, and caring for your family.

14. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, chopping wood, shoveling snow, or digging **in the garden or yard**?

_____ **days per week**

☐ No vigorous activity in garden or yard → ***Skip to question 16***

15. How much time did you usually spend on one of those days doing **vigorous** physical activities in the garden or yard?

_____ **hours per day**
_____ **minutes per day**

16. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, sweeping, washing windows, and raking **in the garden or yard**?

_____ **days per week**

☐ No moderate activity in garden or yard → ***Skip to question 18***

17. How much time did you usually spend on one of those days doing **moderate** physical activities in the garden or yard?

_____ **hours per day**
_____ **minutes per day**

18. Once again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** activities like carrying light loads, washing windows, scrubbing floors and sweeping **inside your home**?

_____ **days per week**

☐ No moderate activity inside home → ***Skip to PART 4: RECREATION, SPORT AND LEISURE-TIME PHYSICAL ACTIVITY***

19. How much time did you usually spend on one of those days doing **moderate** physical activities inside your home?

_____ **hours per day**
_____ **minutes per day**

PART 4: RECREATION, SPORT, AND LEISURE-TIME PHYSICAL ACTIVITY

This section is about all the physical activities that you did in the **last 7 days** solely for recreation, sport, exercise or leisure. Please do not include any activities you have already mentioned.

20. Not counting any walking you have already mentioned, during the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time **in your leisure time**?

_____ **days per week**

☐ No walking in leisure time → ***Skip to question 22***

21. How much time did you usually spend on one of those days **walking** in your leisure time?

_____ **hours per day**
_____ **minutes per day**

22. Think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **vigorous** physical activities like aerobics, running, fast bicycling, or fast swimming **in your leisure time**?

_____ **days per week**

☐ No vigorous activity in leisure time → ***Skip to question 24***

23. How much time did you usually spend on one of those days doing **vigorous** physical activities in your leisure time?

_____ **hours per day**
_____ **minutes per day**

24. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the **last 7 days**, on how many days did you do **moderate** physical activities like bicycling at a regular pace, swimming at a regular pace, and doubles tennis **in your leisure time**?

_____ **days per week**

☐ No moderate activity in leisure time → ***Skip to PART 5: TIME SPENT SITTING***

25. How much time did you usually spend on one of those days doing **moderate** physical activities in your leisure time?
_____ **hours per day**
_____ **minutes per day**

PART 5: TIME SPENT SITTING

The last questions are about the time you spend sitting while at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading or sitting or lying down to watch television. Do not include any time spent sitting in a motor vehicle that you have already told me about.

26. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekday**?

_____ **hours per day**
_____ **minutes per day**

27. During the **last 7 days**, how much time did you usually spend **sitting** on a **weekend day**?

_____ **hours per day**
_____ **minutes per day**

This is the end of the questionnaire, thank you for participating.

vii. PHQ9 Questionnaire for Depression

PHQ-9 Depression

Over the last 2 weeks, how often have you been bothered by any of the following problems? *(Use "✔" to indicate your answer")*	**Not at all**	**Several days**	**More than half the days**	**Nearly every day**
1. Little interest or pleasure in doing things................	0	1	2	3
2. Feeling down, depressed, or hopeless..................	0	1	2	3
3. Trouble falling or staying asleep, or sleeping too much...	0	1	2	3
4. Feeling tired or having little energy........................	0	1	2	3
5. Poor appetite or overeating..................................	0	1	2	3
6. Feeling bad about yourself — or that you are a failure or have let yourself or your family down......................	0	1	2	3
7. Trouble concentrating on things, such as reading the newspaper or watching television............................	0	1	2	3
8. Moving or speaking so slowly that other people could have noticed? Or the opposite — being so fidgety or restless that you have been moving .around a lot more than usual..	0	1	2	3
9. Thoughts that you would be better off dead or of hurting yourself in some way...	0	1	2	3
Column totals	___ +	___ +	____ +	___

= ***Total Score*** _____

- ***PHQ-9 Depression Severity***

Scores represent: **0-5 = mild 6-10 = moderate 11-15 = moderately severe 16-20 = severe depression** *viii. General Anxiety and Depression Questionnaire (GAD7)*

GAD-7 Anxiety

Over the last 2 weeks, how often have you been bothered by the following problems? *(Use "✔" to indicate your answer")*	Not at all	Several days	More than half the days	Nearly every day
1. Feeling nervous, anxious or on edge	0	1	2	3
2. Not being able to stop or control worrying	0	1	2	3
3. Worrying too much about different things	0	1	2	3
4. Trouble relaxing	0	1	2	3
5. Being so restless that it is hard to sit still	0	1	2	3
6. Becoming easily annoyed or irritable	0	1	2	3
7. Feeling afraid as if something awful might happen	0	1	2	3

Column totals: ___ + ___ + ___ + ___

= ***Total Score*** _____

If you checked off any problems, how difficult have these problems made it for you to do your work, take care of things at home, or get along with other people?

Not difficult at all	**Somewhat difficult**	**Very difficult**	**Extremely difficult**
☐	☐	☐	☐

- ***GAD-7 Anxiety Severity.***

This is calculated by assigning scores of 0, 1, 2, and 3, to the response categories of "not at all," "several days," "more than half the days," and "nearly every day," respectively. GAD-7 total score for the seven items ranges from 0 to 21.

Scores represent: **0-5 mild 6-10 moderate 11-15 moderately severe anxiety 15-21 severe anxiety.**

ix. End of study interview question guide

Control Group

- Please tell me about your motivation for taking part in this study.

- How would you describe your current level of fitness?

- What normally motivates you to stay fit and healthy?
    - Or
    - What do you think prevents you from doing more?

- Please tell me about your experience of using the monitoring equipment during this study.

Intervention Group only

- Please tell me about your motivation for taking part in this study.

- How would you describe your level of fitness before taking part in this study?

- I’d like to talk about your initial consultation with the physiotherapist. Please tell me how you felt about your initial activity goals that were agreed?

- Did you feel there were any obstacles to achieving your (activity) goals?

- Please tell me about any changes you’ve noticed in your daily life as a result of the increased exercise during the study.

- Please tell me about your experience of using the monitoring equipment during the study.

- Please tell me about your experience of the online feedback system that was used.

- In an ideal world, could you describe to me what the best method for increasing and monitoring your activity levels would look like, before your operation.

C. Accelerometer data analysis to estimate intensity of activity level

Activity Type	Activity Score Mean	95% CI for Mean of Activity Score	Activity Score SD	Activity Score Range	Heart Rate Mean	95% CI for Mean Heart Rate	Heart Rate SD	Heart Rate Range
Sitting Still	1.5	0.78-2.16	1.3	1-5	61.6	58.2-64.9	6.33	49.6-69.8
Sitting Naturally	1.8	0.65-2.85	2.2	1-10	63.0	59.1-66.9	7.89	48.3-76.6
Walking 1.7mph	228	182-273	95	96-394	81.3	76.2-86.3	10.5	60.1-92.5
Walking 3.4mph	2780	2468-3092	586	1826-3472	91.9	84.7-99.0	13.5	68.3-106.8
Cycling	55.2	31.2-79.2	48.3	15-220	117	111-122	11.7	106-139
Jogging 5mph	16891	15194-18588	3185	12067-22549	136	129-143	13.3	117-164

Table 0.1 Activity score and heart rate results whilst undertaking different intensity activities in 4 volunteer subjects in their 20s. Each activity was undertaken for 4-5 minutes whilst wearing a Faros 180 accelerometer on a chest strap with heart rate monitoring.

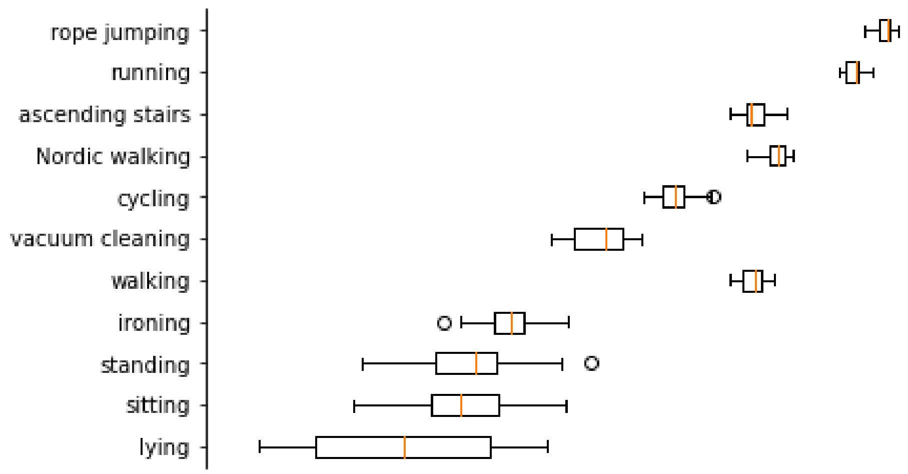


Figure 0.1 Boxplots of log activity score for each activity across 9 different subjects recorded with an accelerometer using data from the UCI PAMAP2 physical activity monitoring dataset.

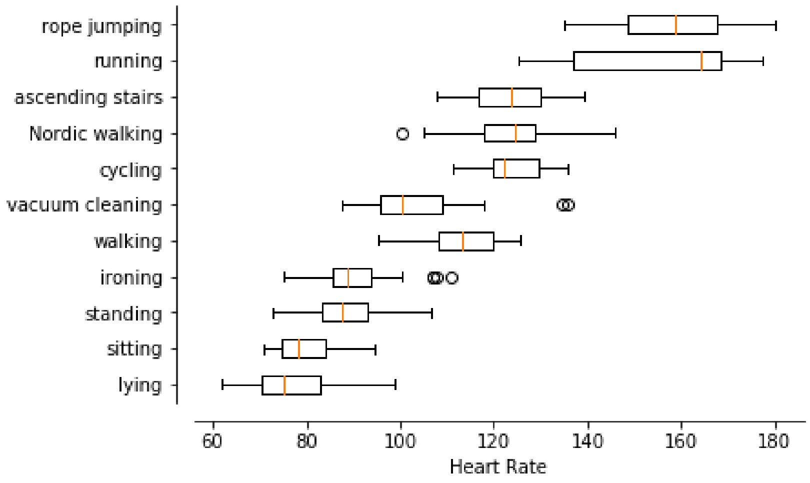


Figure 0.2 Boxplots of heart rate for each activity across 9 different subjects recorded with heart rate monitor using data from the UCI PAMAP2 physical activity monitoring dataset.

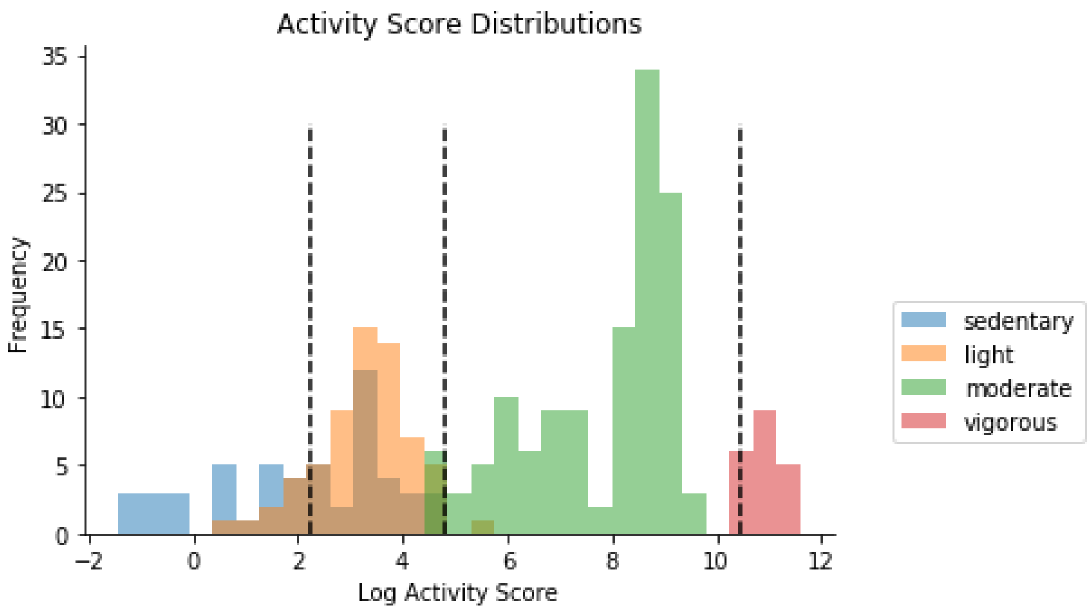


Figure 0.3 Histogram of log activity score distributions with colour coding to indicate whether the original activity from which the activity score was measured would have been classified as sedentary, light, moderate or vigorous. Dashed vertical lines represent suggested thresholds to classify activity intensity based on activity score.

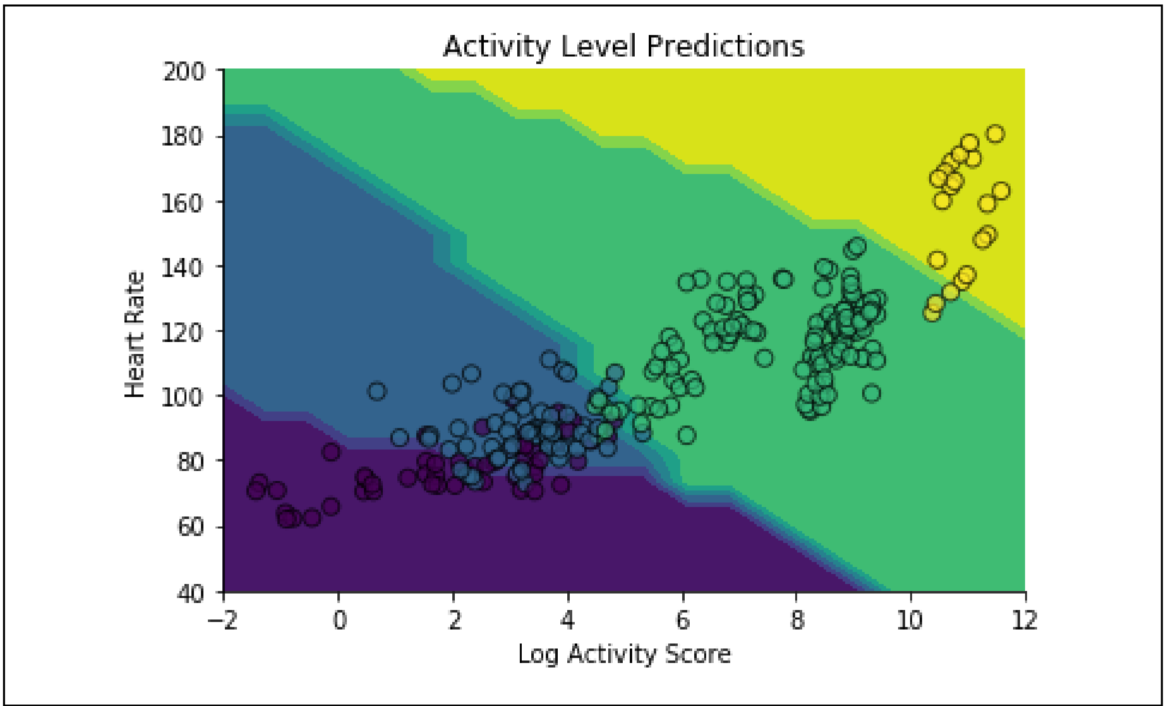


Figure 0.4 Scatter plot of different activities performed across 9 subjects and their respective heart rate and activity score recordings. Each scatter point is shaded with a colour representing intensity of original activity (purple =sedentary, blue = light activity, green = moderate intensity activity, yellow = vigorous intensity activity). Colour shading in the chart represents how an algorithm using heart rate and activity score would classify these activities into intensity categories of sedentary, light, moderate and vigorous.

D. Patient end of study interviews: initial coding process

Coding reference	Data (participant number: C = control group, I = intervention group)	Initial Codes
	I1 Interview 1	
	So, the first question I'm going to ask is about your motivation for taking part in the study, with Dr X?	
1	Well... I'm, I'm overweight. I've been trying to do something about it.	Reflective motivation related to being overweight Previous attempt at behaviour change Linking exercise to weight control
2	I've been hit with the shock of a, of um...prostate cancer, and um, I thought well, anything I can do a) to get me a little bit fitter, and b) to help in the future is worth doing, so...so I said yes.	Shock of cancer diagnosis Changes in life circumstances Understanding of benefits of being fitter given cancer diagnosis Future long-term benefits Self-preservation Taking advantage of opportunity Teachable moment Self-efficacy to change own health prospects
	And, do you think that the aims of the study were made clear to you?	
3	I think so. Yeah, yeah I think so, I mean it, it depended on I s'pose your lifestyle. It's sometimes a bit difficult to do the things they want you to do...but yeah the aims were made perfectly clear to me.	Understanding of goal of intervention Difficulty to do intervention as prescribed by health professional Concept of 'they' the health professionals (social network driver) vs the patient Relationship between health professional and patient Lifestyle as a potential barrier – physical environment, physical capability and opportunity
	Okay, and I'd like to just, you've touched on a little bit...could you tell me about your exercise history and your attitude or experience towards physical activity.	
4	Well, I mean, all my life, I've been very physically active. Umm, I took an apprenticeship down at the Press Steele. You know, I worked in a tool room, which was a physically active job, you know, up and down the surface tables, and um, you know, um...I used to build full size models of cars...but that's besides the point, it was heavy lifting and all this sort of thing besides the technical aspect of it.	Self-perception as very active Activity level linked to type of job Purpose filled activity when being active during work that wasn't just exercise
5	I used to bike to work, do a full day's work, hard work, bike back again...all my life, you know. Play a bit of sport, and, and do that sort of thing. So, I've been physically active all my life. I stopped being physically active really when I retired, and um, so you know...I didn't have a daily bike ride, I didn't have my job, so you know, and then I thought, ahhh, I'll get a little job...so I became a courier which is	Impact of retirement on physical activity – in this case reduction Major life circumstance changes i.e. retirement Transport to work as part of physical activity

	sitting down all day driving all over the flipping place, and so really, I mean, that's when...I was always as, you know, as skinny as a rake all my life, and it was only when I retired I started putting weight on. So...all my life, up until the last, (boom boom), about 13 years...13 years, I have been physically active...up till when I was about 60.	Awareness of different intensity levels of activity Linking physical activity to weight control
	And, do you think other people might feel similar to that, do you think you change what you do when you retire?... Do you think there's something in that?	
6	Oh, yeah. Yeah, you know, I mean, I've always loved working in wood. I still work in wood, coz that was what I was trained to work in, so, you know, I've still got a workshop and this sort of thing...ummm, but I've heard so many stories of people retiring, and more or less going to seed, you know, so I didn't want to do that, so, you know, I kept a job going, and this that and the other...and of course when [my wife] got MS, that changed things a hell of a lot.	Self-efficacy Sense of purpose Fear of loss of self-purpose and control Enjoyment of hobbies in retirement Life circumstances due to caring responsibilities
7	I mean, you know she wasn't walking very well before we went and then she went in for the operation in hospital and came out 2 days later, and this sort of thing, and then, you know, my daughter said to me, "Dad, look at mum walking", and she was walking like she always did. I mean, she could, she could out walk me any day, (laughs), you know, I mean, after, if we went for a walk, after 10 minutes, we didn't look like a married couple, you know, she was way ahead, and I was sort of, trying to keep up. But, um, yeah, that really worked for her, her walking was fine for about 4 months until she had a cancer scare, a breast cancer scare, and that, seemed to knock it back and flip the switch again, and she just started to deteriorate again. We're funny creatures....I tell ya. We really are.	Impact of medical treatment on spouse Importance of the physical effects of illness on wife Role of husband in caring for wife Unexpected and sudden changes in life circumstances Fear of deterioration of health
	So could you tell me about your experience of using the equipment, during the study?	
8	Well, no problem at all. You know, once you've got it on, the thing, and then you put your shirt on and you forget it's on. You literally forget it's on there. And then, just at night, you know, you, you put the little monitor here, near the...near the bigger thing, and then plug the little monitor in, coz the big one's been plugged in all day, and that was it. So it... it was easy. I didn't notice it at all.	Ease of use of monitoring equipment Non-intrusive monitoring equipment Comfort of monitoring equipment
	And um did you, did you look at the data?	
9	Oh yeah, yeah, I looked at it and I mean, I was surprised how little I did. I thought, God, I'm sure I've done more than that, but, you know I had peaks when I went into moderate activity, and then, but most of my thing was um sort of light activity, you know, but I, I did the walks and all this sort of thing, but um, I was surprised just how inactive I was really. (laughs).	Surprise at lack of activity Understanding of activity intensities represented on feedback Automatic motivator when understand own activity levels. Potential teachable moment when understand baseline level of activity Potential mistrust of data if feels inaccurate or not aligned with self perception of activity
	Okay, um so we're going to think now about the start of the study, so when you came and you did your initial consultation with the physio. Could you tell me what you	

	got from that, could you tell me what you understood by, what it was about?	
10	Yeah, well, I understood that I should, I should do more um, um...physical exercise, as in, you know...press ups and um, leg bends, and this that and the other. Um, yeah, they impressed that on me, and I must say, I wasn't very good at it, in so much as... I'd forget to do it. I really would, you know, I'd just forget to do it. Um... I don't know why, possibly because, I sort of feel fine. You know what I mean? I thought...um, I'm strong enough, you know or subconsciously thought... I'm strong enough, I don't need to do that. It just went out of my head and these poor physios, you know I thought, oh God...I can't lie to them.	Capability – physical and psychological. Knowledge and understanding there but lack of confidence and skills Self-confidence – reflective motivation Forgetting to do activity due to lack of motivation due to lack of physical symptoms Reasons for lack of compliance Feel strong enough already Fear and guilt at lying to healthcare professional, not reaching expectations Quality of life unaffected so lack of motivation to change behaviour
	So did you think the goals they set for you were realistic?	
11	Oh yeah, they were realistic, if I had the sort of nonce and will power to do them. Oh yeah, the goals were easy. Realistic. Yeah.	Realistic goal setting Lack of willpower perceived by patient
	Okay, so, so you had the data monitoring which we talked a little bit about and you had, did they follow up by phone? Did you have a phonecall?	
12	No, no, I mean um...(blows nose, excuse me), Dr X emailed me and this sort of thing, yeah, which was good but and I knew that if I had an issue I could get in touch with her and she would come back with the answer, so.....um	Felt supported by study staff Reluctance to use emailed feedback Feeling that follow up was for technical issues rather than emotional support
13	No, no, not really. Once. Yeah, once when the, this monitor, oh no, the large monitor seemed to have a peculiar thing flashing on and off. It was 2 arrows going up and down and a cross by it, sort of thing (okay) and I phoned Dr X up, and she said, oh, it's, it's run out of um credit	Issues with monitoring equipment
	So, so they had to put more credit on, and then that stopped.	
14	Yeah, and that's the only thing that happened that I had to get in touch. The rest of the time, you know, I mean, I just sort of flew along on my own, quite happily.	Self efficacy Positive emotion associated with intervention
	Okay, and did the weekly phone calls, what, did they help?	
15	Yeah, they tended to refocus me a little bit yeah, certainly tended to refocus me. Ummmm, like a say, it's a bit embarrassing talking to the physios, because, I'd done quite a few of Dr X's walks, but I know, I had done the press ups and this sort of thing and they wanted me to get up every now and again when I'm in my sedentary period, you know, when I'm usually watching youtube at night sat on the sofa and this sort of thing and they said, "Well, you need to get up a bit more"... and all that, but, you know, I didn't really do that. I mean, I'd get up to make [my wife] cups of tea and get up to see...you know, let the dog out, and all this sort of thing, but, but it wasn't as structured, you know, it's half past 8 and I better get up and walk	Phone calls from physiotherapist helped to refocus Feeling of embarrassment / shame when talking to physiotherapist linked to not meeting expectations Understands aims but finds hard to do in practice Hard to change habits Self as an obstacle Unable to self-motivate

21	around like this, (laughs) you know, it came as it came (ah ha) and that's it so…	
	Okay, um, so have you noticed any changes in your life, um in your daily life as a result of this study, of the exercise you've done in this study?	
16	Well, I've gone for walks which I wouldn't have gone on if I wasn't on this study. I've definitely gone for walks, and you know I must admit, you know, they were quite pleasant. Um yeah, I've gone for walks...um….and at times I've been conscious, and you know and I've thought, yeah well this will show up on the monitor (laughs) but, but, but, you know and that's it really, yeah, that's it. You know, I don't tend to go out for really long periods, because of [wife], you know because at home, if she gets up out of the wheelchair to do something sort of thing, she's really unsteady and I don't want her falling over.	Change in behaviour to increase physical activity Enjoyment of walks Awareness of activity monitor possibly as an incentive to adherence Caring responsibilities limiting time available for exercise Fear associated with time spent exercising and leaving other responsibilities
	No	
17	...so I'm usually there, but, yeah, yeah you know, the walks have been very pleasant.	
	And is that something that you think that you would continue to do?	
18	Yeah, yeah, why not? Why not. Yeah definitely. Definitely.	Positive attitude to continuing exercise -? the influence of my role as a physio and possibly the patient wanting to meet my expectations?
	So, in an ideal world, what do you think the best way of increasing and monitoring exercise would be before an operation, for you?	
19	Uhhhhh, ummmm, in an ideal world what would be the best? I don't really know. I mean, you know, I think it's down, it's just down to the individual isn't it? You know, if you're like that and you're going to go for an operation, and you know, I think you owe it to the poor surgeon and everyone to get a lot, set a lot of that off, so it's just down to the individual. I can talk to people like you and Dr X and the other physios until the cows come home, unless an individual has got the motivation to do it themselves, you know, you know, it's the old "lead a horse to water, you can't make it drink".	Individual preferences Feeling of obligation to meet expectations of surgeon before operation Respects the role of health professionals but ultimately comes down to the choice of the individual
	No, you can't, so do you think there's anything that would help with that motivation. Is there anything else that we could do, in general?	
20	I don't really know. I don't really know. I haven't thought about it, I mean. You see, I come from a generation where, you know, you were told. You're too fat. You know, these days, ahh(gasp) that's um, I don't know some ist (laughs), racist, or, you know some ist…. Or um, you've offended me… but I come from a generation where, you know, the answer was, well tough. You're too fat. You know, these days you've got to tiptoe around these subjects…umm	No preconceptions or plans on what would help with motivation Weight loss as a motivator Would not feel offended to be told to lose weight
	So thinking about, you know, your exercise. You've gone for walks and stuff at home. Do you think that individual exercise is the way to go?	
21	Yes	Preference for individual exercise

	Do you think it would be better to come in to the hospital, or to go to a gym perhaps? Or	
	Do you think being with other people would have helped you?	
22	Maybe, maybe, you know. But it still comes down to you. You know, I mean, oh, I'm being philosophical here now.	Feeling that external factors such as peer support and gym facilities are not as important as self-motivation
23	You know, but my dad had a wonderful expression, he said, if you want to see the person who's responsible for most of the things that go wrong in your life, look in the mirror. Simple as that. And that's it - it's down to the individual. It's down to the individual. You know, I've got this prostate cancer, and you know, the, you know, I'm fine, I've never had any symptoms. I watched a video, and it was Stephen Fry, and he had it and he was saying, you know, if you're of a certain age, you ought to go and get your PSA checked and I thought, last time I got it checked it was alright. I might as well go again. You know, and sure enough I went, high PSA, went for all the various things, yeah, you know, "You've got a fairly aggressive cancer, it hasn't spread, luckily, so we'll have it out tout suite, and that's it". But you know, I mean, that was my individual decision. My friend said, "I'm not gonna go for them". And I said, "Well, why not?"..."Ah, Nah! - I don't want to bloody know"...you know, and once again you can't, if he gets prostate cancer in a couple of years and it spreads, then he's got no-one to blame but himself. It's not good blaming other people.	Individual responsibility and individual decision Self-efficacy to get cancer screening Does not want to blame other people Focus is on treating cancer and feels has done well by not missing cancer diagnosis (other priorities)
	Well I think it's a good one and I think it would benefit a lot of people.	
24	Well it would do, wouldn't it, yeah, it would do. It might save a lot of lives, you know. As I say, if I hadn't of seen that video, I'd have carried on my own sweet way, and the, the surgeon said to me, if you'd left this another 12-18 months, it would have spread. So, you know, I mean, there's now that whole thing, I dodged a bullet there, and it was only because of that video, you know no-one called me in to say, you need your prostate checked. So, I think that's a bit of an omission in the GPs sort of practice.	Prefers to be educated and informed to manage own health Fear of missing a diagnosis Wary of over reliance on healthcare professionals due to process of cancer diagnosis
	And, is there anything else that you want to tell me about the study, about exercise, about the surgery?	
25	No, I'm quite happy he explained the surgery to me. I'm quite happy with the study I've done, and the support that I've been given, and the goals I've been given and once again it comes down to me as an individual to either fulfil them or not..those goals, but I was clearly told the goals, and the surgery, yeah, I mean, the, the surgeon explained what's going to happen, it's going to be keyhole, done by a robot, and um, you know, I should just be in for a night and if everything goes well I will be home the next day, and let's hope, you know touch wood, everything's alright.	Happy with being given goals Individual responsibility to fulfil goals related to surgery Feels had good information regarding treatment plan Positive feeling about receiving cancer treatment, feels reassured – may be related to minimally invasive surgery
	Back to normal?	
26	Yeah, I'm surprised how unconcerned I am about having cancer, maybe it's because the bloke said, well it hasn't spread, so, you know you're in time, maybe it's that. Maybe, you know, if he started mentioning chemotherapy	Feeling of lack of worry over having cancer due to being localised

	and all that, I'd have a different attitude, but at the moment, you know, I don't even think about it. I'm going in next Monday and hopefully after it that will be okay.	Focus on advice and reassurance of surgeon with regards to disease
	That's okay. No problem. It's lovely to meet you.	
	Really, really nice, I've enjoyed it.	
Patient	I2 Interview 4	
	So, the first question I've got is about your motivation, so tell me about your motivation for taking part in this particular study? Why did you say yes?	
27	Um, because, I like research.	Previous life experience informs motivation
28	Let me explain that. In my mid 40s, I went to University and did a Masters.	
	Ah ha	
	And, got to the research bit, and just loved it so much, I could have done research for the rest of my life.	
	Ah, that's phenomenal, okay.	
29	And, I was just fascinated with it.	Curiosity with research
	And, what did you research?	
30	Um, it was called kinship responsibilities and sick absence. I'm an HR specialist.	Sees themselves as an active participant and contributor to research
31	The answer, um, and this was going to blow my masters apart, because all the research at the time, said, yes, people with kinship responsibilities, do take more time off. My research showed that, um, they didn't, and the research that, that, that told me it was going to be like that was quite old, when everybody worked 39 hours a week, and since then, employment patterns have changed drastically, um and, I mean, we call it the work life balance now.	Good understanding of purpose of research and enjoyment of finding new things
	And, and that has changed it entirely. Um, so, um that upset my, um thesis if you like (laughs), but in a good way.	
	And, were the aims of the study made clear to you? Did you understand what the study was about?	
32	Um, I have a vague notion	Possibly sarcastic tone, actually implying good understanding
	……….that it was to measure pre-operative motivations and fitness, and so forth.	
33	Um, I get the impression, though, that this is the first part of a much larger piece of research that you are going to have to do compared to post-op.	Good understanding of study aims and procedures
	So this is the bit that tests whether it works, whether this bit works or not.	
	Okay, just now, a little bit about your thoughts about exercise, and your experience of physical activity and sport in the last few years, leading up to this.	
34	Um, I am not, in that respect, I am not my father's son (laughs).	Using another person as a reference point for baseline fitness and motivation level for exercise
	He was, he was a person who just loved sport, and lived for it.	
35	And up, he'd go for a 10 mile run in the morning and then referee a game of football in the afternoon, and you know,	Reluctance to exercise, not motivated by enjoyment

	just, it's not me, I'm a lazy exerciser, I exercise coz I have to.	Awareness of health benefits of exercise
36	And I probably do the minimum that I have to to remain mobile. I'm not that enthusiastic about it.	Lack of confidence in own ability to do more exercise Realistic expectations of own motivation
	And, what do you think the difference between him and you is?	
	Um, I don't know really. Wouldn't it be nice to be able to put your finger on that? …………….Ummm I dont know.	
37	It's an attitudinal thing, maybe.	Motivation for exercise associated with attitude
38	Maybe. He comes, he came from a very different background to myself.	Love of exercise related to background and life experience
38	He was was um,,,,,,,he knew the um, the food queues after the first world war, and everything, you know, he knew really poverty. And, um got out of that by joining the army, and then he grabbed life by the throat. Whereas I'm a different generation, I have never known war, I've never been conscripted on how to go to war, I've been so lucky. One of the baby boomers.	
	Coz you say, you do the bare minimum to keep mobile do you have an idea of what that bare minimum entails?	
39	Hmmm, probably, basically because I know how I feel.	Evaluates exercise done based on individual feelings (not using objective measures)
40	When I was working, I used to go most nights to um, a gym and swim, straight after work. It was just around the corner,….so convenient.	Exercise as part of daily routine Importance of convenience
41	And then, um, when I stopped working, I joined the gym that my wife went to. So, we saved on going together to that, and...we went 3 times a week.	Exercising with wife Self motivation to join gym Regular habit of going to gym three times a week
	Together?	
42	Yeah, and we did a variety of things, we went to classes.	Did a variety of exercise
43	Swam, and generally enjoyed it (laughs) coz that's the thing, it's gotta be enjoyable.	Has been finding exercise enjoyable
44	And there's a good thing on the cross trainer, you see they've got a television, so I can watch Star Trek whilst I'm cross training (laughs).	Enjoyment from doing exercise with television
	And so, going to the gym. What made you go the gym? So, was it the fact that you were going with your wife?	
45	Um, well simply because I used to go at work. And, at work I used to sit in front of a computer screen most of the time.	Awareness of consequences of being sedentary
46	And um, I needed to go and loosen up, so when I retired, I thought, there wasn't enough in the garden to um, to give me the full exercise that I needed, so I went off and saw the instructor and got a series of exercises to do, and went through the whole cross training then, then and then went for a swim afterwards.	Retirement as opportunity and motivation to exercise Self motivated to find instructor to gain skills in exercise Found new facilities and opportunities to exercise when own garden not enough
	Um okay, and so can you tell me about your experience of using the monitoring equipment in this study. So, your chest strap?	
	Oh yes, um…………	

	What did you think of that?	
	It took a couple of days to get used to it,	
47	I got some irritation to start with.	Discomfort with wearing activity monitor
48	But that soon wore off and the hub thing stopped working after a while, so [Dr X] had to come out to me and collect the thing and give me a new uh, monitor.	
49	So, she couldn't get the hub to work. We live in the middle of nowhere (laughs)	
49	The reception is very bad in our village.	Problems with connectivity of monitoring device
50	Um, so that was the reason. Um yeah it was okay. I did forget to put it on once, so, there's a 3 hour gap this week, when I thought I had it on, but I didn't.	Burden on patient to remember to wear device
51	But, for the most part, I got into a habit of taking it off and charging it at night. And getting dressed in the morning and put it on.	
	Yes, so making it part of your routine?	
51	Yes, that is the trick, to make it part of your routine.	Already good at forming habits and incorporating new things into routine
	I think so. Yeah. Okay. Alright. So, um we are going to now just think about the exercise stuff that you've done. So, could you tell me about your initial consultation with the physio or the physios, I know there are 2 of them. Did you feel that they set goals that were appropriate for you?	
52	Um, well……. Oh yes, for sure. I was fairly active anyway and there wasn't much they could recommend.	Conflicting viewpoints in same interview about patient's own perception of amount of exercise they do
53	Apart from doing a brisk 10 minute walk, um, as often as I could. Um, and I kind of…… (laughs) I decided not to do that, and didn't tell them…….but took up cycling instead, because I prefer that.	Failure of individual tailoring to patient as patient decided on own exercise plan Patient using own autonomy to make own exercise decision in a positive way
54	Um, I should say that about 7 or 8 years ago, I fell off a ladder and injured my back, which makes walking awkward or painful sometimes, but cycling is a doddle.	Pre-existing physical condition limiting exercise Patient managing own physical symptoms in positive way to find alternate ways to exercise
55	I still get the aerobic workout but it doesn't hurt my back.	Patient managing own physical symptoms in positive way to find alternate ways to exercise
	So, you started doing cycling and did you talk about that with the physios? Did you tell them about the cycling?	
56	I did yes, when there was a phone interview with [Dr X] and the 2 physios, and I told them there, that I was taking up cycling. They were very pleased about that.	Collaborative decision making with study team for preference of exercise
57	But yes it was, it was entirely appropriate, because I wasn't doing any walking type exercises but I took up cycling instead.	Patient using own autonomy to make own exercise decision in a positive way
	Um and so tell me a little bit about the telephone conversations. Did you think they were helpful?	
	Ummm	

	So the follow up.	
58	I don't know if they were helpful. They might have been helpful to the physios. I've no idea. Um I don't know that they were particularly helpful to me in any way, other than to say, I'm not doing a lot of walking, but I've taken up cycling.	Supervision using telephone calls from study physiotherapists not that useful, no meaningful advice
	Yeah. Okay. Did you use the monitoring equipment? Did you have a look at your data?	
	I did.	
59	Um, the first week, [Dr X] sent me the results which were quite interesting. I was staggered to see how much time I spent sitting around.	Feedback from activity monitor interesting, new information for patient on sedentary time
59	That was really quite a shock. How much time I'm slumped in a chair, or not doing anything especially vigorous.	
60	But conversely on 2 days in a weekend, were sort of, really hot and I thought, (whispers) I'm not gonna do anything, and I really didn't do very much for those 2 days, but it came up as quite active on the charts.	Trying to match real life activity to data and finding potential inconsistencies
60	And um, the physios thought that was my heart coping with the heat. Maybe temperature is a big variable.	
	It's nice and cool up here. So, so you think that the information that you got from the data monitoring, do you think that was useful?	
61	Yes, because um, they spoke about doing 10 mins every now and again, whereas I was spending a lot of time slumped in a chair. When I wasn't, um I was lumping the exercise together, when I should have been spacing it out.	Feels data from activity monitor was useful, increasing regularity of exercise
62	And that, that was very apparent in the graphs that I saw, and that was useful.	Found graphs in feedback from activity monitoring useful initially but not for comparison over time
62	Um, I printed out the first lot. I had a look at, I don't know, the second, the third week and didn't do a lot of comparison.	This patient was unsure if the graphs were for him or the health professionals.
62	I thought, okay, they're going to do that, so I didn't do a lot of looking at that.	Question of who the data is for and who is responsible for using the data
	And thinking, the next question is about obstacles, so could you tell me if you perceived any obstacles to achieving your activity goals?	
	Um, so I think is where it would be appropriate to talk a little bit about cycling. Because, you found that walking…	
63	Yeah, um, I suppose the uh, well I've always had this back thing for about 8 years, um, and surprisingly, errr, it changed me physically.	Realisation of physical limitations, identification with new status of physicality as an obstacle to exercise
	And then I realised that I physically I had changed shape.	
64	And, I don't walk as well as I used to. Although I've er gotten round it um slightly, I got myself some walking poles which I decided to try out.	Impetus to get new equipment and try new exercise
65	And, er, I'm now a pole walker.	Identification as a 'pole walker'
66	So that's, that's an obstacle I suppose. The other obstacle is, somedays you just get up and you think "ahhh I canne be bothered". Sorry, that was my Scottishness just coming in (laughs).	Self-motivation as an obstacle depending on mood that day
	What's the difference between those days and the days where you think, actually, I can do it today?	

66	Umm, I've no idea, just your demeanor on the day, I suppose.	
67	And, perhaps if I've um slept, or not. And that's a big thing for me, because I have an enlarged prostate which means I sometimes get up a lot, and don't sleep as well as I could do.	Sleep quality as a factor for capability to do exercise
68	And for the extent of this um research, I've been taking um Lendormin	Patient dealing with making multiple decisions and interaction with different health professionals in managing symptoms and cancer
69	Which, has side effects which are not good for me. But they work to a certain extent. I've been to see my GP. I'm kind of balancing whether or not it's, whether the side effects are worth the fewer visits to the bathroom at night, so um….the er….the jury's out on that for the moment.	Physical symptoms from medication for urinary complaints affecting sleep
70	Umm, Yes, this morning we got up at 8 o'clock and and cycled for 10kms which is something we've never done before. We kind of just lie in bed and watch the news or get up slowly. But I tell you what, the coffee afterwards is just….ahhh, to die for. (laughs).	New exercise habits Exercising with wife Enjoyment from feeling of having exercised
	Yes. Ahh, good. Okay. And so, kind of just the final question and I want to spend some time of this because you've got a lot to say. So, um in an ideal world, what do you think would be the best method of increasing or monitoring exercise, before an operation?	
71	Ummmm, targets. Without a doubt. Knowing that you've got to reach the target, or, the operation is in……. in jeopardy. It's got to be as tough as that I think.	Having a target helps with increasing exercise Jeopardy of the operation, some element of fear
	And do you think that's what has worked for you?	
	Ummm, no. (laughs….) because my BMI is such that it's not a problem.	
71	But that wasn't a motivator for me. It was an option right at the start, surgery, or radiology. It wasn't a case of surgery if you can get to this level of fitness.	Patient understood there was no limit to choice of treatment based on fitness, self motivated to do more exercise without jeopardy of not being eligible for a certain treatment
71	And ummm, maybe more connection there is the thing. I mean a lot of people don't really realise the level of fitness that you have to have, you know to have um surgery.	Education about the benefits of exercise in terms of operation outcomes.
71	And, I was speaking to Mr Y (surgeon) and he was going through my sheets. Oh, you've got a heart murmur. I said no I haven't. He said, it says here you have. He said, give me your wrist, so he said, look at that, no you're right you haven't. And, it's knowing that just little things like that cumulatively can affect whether or not you go for surgery, and I don't think the general public grasp that.	Repeat theme - motivated by threat to the operation if goal not met.
72	Those risks, which is what Mr Y (surgeon) was doing. But, your average person comes along, gets the bad news they've got prostate cancer, isn't perhaps that concerned about it, and more worried about the big C, than how fit they're gonna be to get cured, and it is……I don't quite know how you turn that round in people's minds because,	Competing 'worries' of cancer diagnosis versus level of fitness

	um, when we first came to see [J], my assigned nurse….ummmm…..she, she had, um a piece of uh paper with - You've got cancer written on the top and err tick boxes of the uh surgery, and I thought, why, why would you need to do that. Why do you need to….I worked it out afterwards, clearly, some people don't take it in, and they don't grasp it, until 2….weeks or 2 years later.	
73	Ummm, or whatever, and that, that brought it home. And in...when it's brought home like that, that grabs your attention. There's no escaping that.	Teachable moment, impactful cancer diagnosis
74	And, maybe that is the time, you know when you are looking at the surgery option, to say, provided you can maintain this level of fitness, or you can do this, you can get your cholesterol down, or you can... or whatever.	Believes cancer diagnosis can be teachable moment
	Yeah, absolutely. So I think, I think you're right. I think the surgery has to be a motivator. What about after the surgery. So, thinking about now, you're obviously really fit, you've been to the gym, you do a lot, you've added in cycling, will you continue to do that do you think?	
75	Oh most certainly yes, um, because I've been retired now how many years, 5 years and I've been to the gym every week.	Also had long history of exercising, mostly impacted by change in life due to retirement
76	Um, oh I've been doing that, and I will certainly be doing my best to rehabilitate myself after the uh surgery. I'm seeing um, someone on Thursday to talk about the start of that. Um, so presumably there will be appointments with physios after that about how I rehabilitate my bladder or whatever it is you do.	
76	So I don't see that as a problem, because I am reasonably fit beforehand and I want to maintain that, but I can see some situations where a person is not particularly fit beforehand, um, has the operation and sees no reason to be fitter than that, um afterwards, and I don't know how you get to motivate those sorts of people. I guess people have different motivations.	Wishes to maintain fitness, do his best a rehabilitation Feeling of own responsibility for maintaining fitness
	So just then, thinking about the difference between supervised and non-supervised exercise, do you think there's something in that, do you think going to classes would be helpful? Do you think other people would be helpful?	
77	Um…….I don't know. I tend to exercise on my own. And when we used to go to classes to do things like yoga and pilates and stuff, which I quite enjoyed, um, I'm really a lone exerciser, I think. I go out with my wife cycling, she's very good at it, and she's my pacemaker, left to my own devices I just (laughs).	Tends to exercise on their own But also does exercise with spouse, benefits of being 'pacemaker'
	So, do you think there's something in that. Do you think having your wife, in your life has made a difference to how you exercise?	
78	Ah to me it has, yes. Um, for sure. She's, she's a born again cyclist as well.	Benefit of exercising with wife
	So yes, perhaps, um a partner, an exercise partner might be the er, not necessarily your spouse, might be a, might be a way forward, or a person who is in a similar situation.	

	I don't know whether that would be possible given how the area, you know oxfordshire, that might be difficult.	
79	Um, I don't know if you could, you see, I am not a particularly technically savvy person, it's one of the things that irritates me beyond belief. I have never tweeted in my life. I don't have a facebook or anything like that, and um, but I can see where that might be useful to people who are looking for a buddy or a partner to touch base with and uh, sympathize with and get encouragement from. But that wouldn't work for me.	Does not feel confident with social media but can see its usefulness
	I can't, I just don't understand why people want to spend saying oh I'm just having a coffee on facebook and I just seem so uncertain	
	(laughs)	
	(whispers) Why, why do people do it?	
	Yes, I'm with you. Ah ha.	
80	I think it's my age, I'm just a grumpy old git, aren't I?	Perception of social media as not for his age group
	(Laughs). Okay. So, is there anything else that you want to tell me about exercise, or about the study? Have you enjoyed doing it?	
81	Um, yes, it made me think about it.	Study made him think about exercise and lifestyle
82	And that's the important thing. It made me, and that was um...ahhh…. a motivator for sure. And, maybe everyone should be encouraged to take part in it, you know, as a motivator to get going. I tell you one thing that I don't know who to tell this to, but there was a part of the ummm, the consultation with the surgeon um, [Mr Y], and I only realised it, when he sent me the copy of my letter to my GP. Um and we never discussed it but it was there in black and white, what it was. I know we didn't discuss it. But, it in he said that my prostate had enlarged to a volume of 50ccs, which is nothing to do with the cancer, it had just enlarged. So, it had gone from being um a walnut to a small peach or something like that. And, when I went to see the radiologist, she said, ummmm this is vastly interesting if you don't know this, she said the radiotherapy kills the cancer, but it is hormone treatment that reduces the size of the prostate, and she said, but i can't guarantee that your prostate is going to return to its former size of a walnut, and I thought, well that's good, that means, I'm gonna be forever up and down at night taking the bloody Lendormin stuff and it's side effects and that kind of leaned, lent me towards going down the surgical route. But, it was the er, the actual volume of the er, er, the prostate. But I had to work that out, that didn't form part of the discussions with anyone.	Feels that taking part in the study motivated him to get going. Feels everyone should get that encouragement. Highlights importance of patient centred care, choice and truly understanding the condition to make an informed choice.
	Whereas, actually maybe it should have formed part of the discussion, is that what you think?	
83	Yes, because, the operation and everything is all about cancer. And I was taking a wider view, about my life and my sleep patterns, and the medication that I might have had to take if…..the er prostate hadn't returned to it's formal size. I was taking a wider view.	Taking a holistic approach to patient needs

	Yeah, well all of these things are really interesting because they will be fed back, so you know, taking part in research is about setting up the future, helping other people as well, and so, you know, all of that's really valuable.	
84	Yeah. The staff have been unbelievably helpful and sympathetic. Um, they really have been really really helpful. Um, and everything has happened really quickly.	Supportive study staff
	END	
	C1 Interview 2	
	I've just got a few questions about the study. And so, the first one is…….if you could tell me about your motivation for taking part in the study to begin with.	
85	Well it was when [Dr X] asked me, or whoever it was who first asked me. I think by nature, I'm co-operative, and if I can help, I'll help. You know, I've seen other people treated and if it can make it easier or more efficient for them…. okay….fine.	Wants to help with research to help others as motivation
	Great, and do you think that that aims of the study were made clear to you? Do you know what the study was about?	
86	Yes, yes, well I think, I mean from what [Dr X] said, I did yes. You know you can physically prepare people without um, necessarily medication.	Good understanding of prehabilitation as physical (non-medical) preparation for surgery
	Yes, okay, great. And so, and did you have any feelings about the random selection process?	
	No, no. I just wondered, why me (laughs), but not really.	
	Would you have preferred to be in the other group, do you think?	
	What's the other group?	
	So, the exercise intervention group.	
87	I have no idea. I just went along with it. I did another one with, the blunt chest testing thing, I did that. So, I mean, I thought it might just be interesting to see what happens.	Curiosity for research Deference to research team
	Yes. Okay, so could you tell me a little bit about your exercise history and your attitude, umm towards physical activity.	
88	Ummmm…. I've always been physically active but umm……in sport.	
88	I find...ummm sort of…. independent activity by itself a little bit pointless. So, I find it very difficult to go for a walk for no purpose. Whereas, you know, I'd play cricket all day or tennis or whatever. So um…..	Feels independent activity by himself is not purposeful Previous history of playing competitive sport
	And do you still do those things?	
	No……no.	
89	My main game, I mean, I played...ummm….cricket until the latest…..but my main game is lacrosse, which is for young men, (laughs) or young people ….umm, and so I gave that up. But at school I did everything. Absolutely everything. Ummm, everything, athletics and so on, and at university, I played tennis, and then lacrosse, and since then, with my children I've played tennis, cricket, so on.	Identified with a sport as his 'main game'
	Fantastic, so you've said that you find going for a walk for no purpose quite difficult, so what do you think it is about the games, lacrosse, cricket that you like?	
90	Well, there's a point in it. I mean, you're trying to win. The whole point of sport is to win, whatever the game is.	Purpose to sport and exercise, to win

91	In walking, I mean, obviously I …..ummmm….when you go for a walk in some lovely scenery or when you go on holiday in the Lake District for example, I mean that's, that's different, but at home, just to walk around, you know 5 minutes, 10 minutes a day I find just boring. I'd rather watch an interesting television programme or read a book (laughs), or something. Gardening's alright.	Boredom associated with walking at home, would rather watch television
	Ah, ha. Okay so tell me a little bit more about your gardening.	
92	Yes, well my daughter's come to live with me now and so, she's very active and pushes me to do much more in the garden.	Daughter encouraging patient to be more active
93	And, so, it's interesting, my mother and my father were both very keen and I've inherited a little bit from them I think, but when I was working and when you're an academic, I can remember my friend saying, you're always pushed to do more, you know, particularly in a competitive field of publishing books or giving lectures, or writing papers, there's always a competition, particularly you know in a college, where, you know, all your fellows are your competitors and (laughs) rivals as well.	Identifies himself as a competitive person from career and parents
94	**Um…….so you, you feel you can't waste time, and so, you tend to do your exercise by sitting down and reading.**	Prioritising time for other pursuits
	Yeah, and it's more brain exercise, isn't it (laughs)?	
95	Oh, I don't really think…….you can do it. I mean, you, you can't persuade someone to do something if they're not interested and don't really want to.	Individual decision making based on own interests
96	I mean, I went to a gym for a while, you know I quite enjoyed it, um, but then lost interest, and um, I've never regained it, so, I mean, in theory, yes. But there's quite a few people here in reception who are very obese, I'm mean they're really….I was quite disappointed to see them so they're not following their own rules. But, you know, as long as I don't become grossly overweight and so on, I'm…..and, I can do the things that I enjoy, I mean, I enjoy cooking for example which can be quite exhausting	Lost interest in going to gym Importance of not being overweight Feeling that they are different in a good way to others in a similar situation
97	Standing in the kitchen, for 2 or 3 hours or what not, ummm, well that's okay. Well I'm very old now, so it doesn't really matter all that much.	Self identifies as very old, as a demotivator to make changes possibly
	And um, so I just want to talk a little bit about…..you know, you said you went to the gym and you enjoyed it for a bit and then you lost interest. What do you think it was…. that, that made you lose interest?	
98	Just the repetition ….umm, you know, I just find that, you know ro ro ro ro ro for hours on end, just utterly soul destroying, and, what's the point? I mean, yes you know you develop your muscles, and then, so what? If you stop for a week (laugh) all your hard work is undone. But that's why I like sport, because you have the satisfaction, I mean, either of losing or winning, but you had the satisfaction of pitting yourself against somebody and some point, you know. I mean standing in the cricket field all day was absolutely lovely….really nice (laugh).	Boredom with repetition at the gym Feels going to gym is not productive versus satisfaction of winning at sport
	And do you think, how important do you think the "somebody" is within the sport bit? So you said you were playing against somebody.	

99	Yes, yes, oh, absolutely essential. That's what I find. I, I played golf until quite recently, with my son mainly. Ummm, and, I very much enjoyed that, but that is not quite so competitive collectively, it's individually, you're just playing against yourself.	Lack of purpose if competing with yourself. Social element not for encouragement but for purpose of competition
100	You know with tennis, you have to beat somebody, or lose to them. With, um, most games, you have with a team you're playing against another team. But with golf, it's just you. And um, that I found a bit frustrating because I wanted the competitive aspect um, to be more than it is.	Motivation through competitive sport
	And so the last question is about the equipment, and so could you tell me about your experience of using the equipment?	
101	Yup. Well, It's just fiddly. A bit boring. I mean I didn't really know what the point of it was. I just did what [Dr X] told me. And um, there was no problem. But, um, I'm glad it was only 4 days (laughs).	Boring process of using monitoring equipment Fiddly to use equipment Glad only had to go it for 4 days in control group Followed instructions because he had to
	Was it comfortable to wear?	
102	Not really, no. No, A bit tight.	Monitoring equipment not comfortable
	And did you notice that it was on.	
	Yes, yes, not all the time, but suddenly you know, you feel something.....and it was that.	
	Restrictive?	
102	Yes. And I think it was a bit too tight, the one that I had on. But, it's okay.	
	Okay, um, and anything else that you'd like to tell me, about exercise, about the equipment, about....	
103	Ummmm, Yeah. Not really, I mean I feel that what I'm doing with you is more for other people in the future than myself, but that's, that's okay.	Patient in control group motivation contribute to research
	C2: Interview 3	
	I've got about 3 questions to ask you. And the first question is.....could you tell me a bit about your motivation for taking part in the study?	
104	Well, mainly, it was because of the operation, and then......i've always.....I mean, I've got mild IBS and years ago, it's a funny story, they asked me when i had the um the colonoscopy, for the camera, would you mind a few students. I said no, I said yeah, they've got to learn and (laughs) when they wheeled me in there (laughs), there were about 10 of them (laughs).	Motivation to contribute to knowledge in research Motivation related to having operation
104	Yeah, coz it's slightly errr embarrassing when you've got that many watching on, but.......I think these sort of programmes and that, will help, and if it helps teach them, then why not? You know. That was my main motivation.	Motivation to contribute to knowledge in research
104	If the research helps others, to better things, in a sense, I think that's a good thing.	
	And so, do you think that the aims of the study were made clear to you?	
105	I'm not quite sure if I read it properly. I did read through the information she gave, [Dr X] gave me, but, I think...I	Not confident understands aims of the study

	don't know if it's basically for the pre-op thing or whether it's mainly afterwards. I don't know. I'm not quite one hundred percent sure about that.	
	Okay, um and did you have any feelings about the random selection?	
106	No, not really. No. They asked, I said, yeah go on then (laughs). And I was going up the JR anyway, so we met up there.	
106	I was going for my pre-op that day...and in fact, I got approached by another doctor to do another research thing, and I thought, all I could think about was getting the appointment done and getting out of there before I hit the traffic, but unfortunately that didn't work. (Laughs).	Managing multiple things during an appointment Lots of things going on in one appointment
107	10 past 4 I left and it took me 20 minutes just to get to the Heading roundabout. I chose the wrong route anyway and it took me and hour and 40 minutes to get home.	Difficulty with appointments at the hospital due to traffic
108	But, I would have taken part in it….. I think he might still approach me before the operation yet, anyway.	Willingness to help with research
108	But I'm not fussed one way or the other really. I was quite happy to do this.	Willingness to help with research
	Oh, well, that's really nice. Okay, so the next question is about um, your exercise history, over the last few years, and your thoughts about physical activity and exercise.	
109	It's pretty poor really, I'll be honest, until I got diagnosed with cancer, then I asked to join the gym at work, and I probably, yeah probably a good year now, I've being doing...I started off with doing 2 sessions a night…..,a week, then 3, then I upped it to 4, roughly an hour, an hour and 10 minutes each time.	Joined gym after cancer diagnosis since 1 year ago, change in lifestyle due to diagnosis
	Okay, and so tell me why you decided to do that?	
110	Well it wasn't so much...I had to. I had to lose the weight for the operation. So I was, I think they weighed me in at 94 kilos.	Weight loss and operation as combined motivator for exercise
110	When I got diagnosed. My target weight was 83, and like I said, I didn't really change my diet, and I didn't do any other type of exercise, so, I decided to do the gym and keep at it, and eventually it's paid off.	Self-discipline to maintain exercise Goal driven change for weight loss Some fear in not being able to have operation if does not lose weight
111	But, I have cut back on the chocolate and cake, and a few other things. The wife does a few more salads, but working, eating at work, it's not the best of diets, you know, for the food wise, they don't do much. I'm not a vegetarian, so I do like my meat.	Behaviour change related to diet Role of work environment
	And where do you work?	
	I work at ASDA, at Didcot.	
112	It's a distribution warehouse. But I'm one of the fortunate ones, I'm lightly skilled, so I don't have to do a lot of picking. And, they've looked after me since my back operation, and um…..I don't do a lot of the heavy lifting, anyway.	Previous back operation, wary of injury with activity
	But would you describe your job as a fairly active job?	
113	Yes, I would say so, yes most days it's fairly active, yeah, no matter what you're doing. Even if you're on the forklift, you know you're tipping lorries and re-truck. You're set a certain number but officially by health and safety you	Has active job currently Reliance on work for activity

	shouldn't be set a figure, but they do have a figure they try and hit each time. But, it's not normally too bad.	
	Okay, and just going back to um joining the gym, so, you told me you joined the gym in order to lose weight.	
	For the operation. What sort of things did you do at the gym?	
114	I'd just do the um exercise bike for half an hour, err 28 minutes on the treadmill, and then 30 sit-ups, and then, I'd do, use the 5 kilo weights just for about a minute, that's about it, not even a minute really.	Routine made by patient at the gym
	And did you notice, apart from the weight loss which was obviously your goal, were there any other benefits? Did you feel any different?	
115	I'm not really sure. I used to think, if I was standing at the back, I don't feel so bloated. I feel like I've lost the weight, and I know I've lost the weight. I don't know if I felt fitter. I think I did. I know what afterward, when I've done the gym and I'm walking back to the, out to the car, you know, that's another good session, done. I feel better for doing it.	Feels better for having done exercise vs. no change in feeling from losing weight
116	But I'm not sure whether it affected me that much. It obviously has, and I know it's good for the cardiovascular bit, and I feel better for that, I must admit. And, I don't get breathless. You know I sweat a lot on the bike, but I don't feel breathless at the end of it, or anything like that.	Feedback on improvement from physical exercise – could be improved to educate patients how exercise is benefitting them
	And did you when you first started?	
117	I did when I first, it was hard to work to start with. Because I'm not, like I said, over the years I haven't done much exercise, I just rely on my work. Because when I first moved back to Carteron I did quarry work which was quite physical, a really physical job, and that kept my weight down to a certain degree. Then I took another job, in the same quarry, but I wasn't quite as physical, even though there were certain times of the day it would be quite physical. I was lifting steel pallets onto a runway for it, like, it was on a turntable press.	Reliance on job for exercise Linking need to exercise to weight control Exercise with purpose
118	Then, at the end of the night, you had to clean out the mixer, so that was quite physical (laughs), I used to sweat like hell doing that. It's a big drum mixer and you had to chip all the hard stuff off and every night to clean that out.	Previous experience of exercise and how it made him feel as barometer to the intensity of exercise he should be doing
119	And when you changed jobs did you notice any difference?	Identity linked with job and impact of experience of work
120	You have to work for so long for the Royal Family before you get the crest, and um yes, so that was quite an interesting job. The only thing I didn't like was the 2 days a week you had to go to London, so you had to be at the yard for 5 o'clock in the morning. That was a little bit too much, so I. But that was physical, you know some heavy stuff to move about. Some really heavy stuff.	Pride in being able to do heavy manual labour
121	You know, big oak tables. Yeah, I've been pretty physical all through my life (coughs), work-wise anyway. And then I went back to the quarry because they said, oh you can get your forklift licence, but I've since found out that there is no such thing as a licence, it's a certificate, you don't get an	Reliance on work for physical activity Replacement of physical work with more skilled work

	actual licence. And err, I went there, back for about 18 months, and then I got a job at ASDA, which the physical side is the picking side. But as I said, over the years I've got me skills so I don't need, I don't have to, I get taken off the pick occasionally to do a skill rather than picking.	
	Okay. I'm really interested in umm how you got yourself to go to the gym 2 days a week and then 4 days a week.	
122	Because I wanted to lose the weight. I was desperate to lose the weight.	Main motivation is to lose weight for going to gym
123	So, how did you change your lifestyle to incorporate that?	Own problem solving on how to lose weight Understanding of diet of exercise in weight loss
	Okay and so did you go on set days at set times.	
124	It was the same time every night I went and as I said I usually about 20 past 11 by the time i finished it sort of quarter past, 20 past 11, so I spent an hour, an hour and 10 minutes. I don't get started until about 10 past 10 and then do a good hour or hour and 10, but I increased it because I thought if I can't change my diet, or to a big extent, increase the exercise and see how that goes. I mean it was a long process. Longer than it should have been maybe.	Own ramping of exercise Previous experience of long process of weight loss through exercise-could have benefitted from more education to set realistic goals? Patient own goal setting and responding to progress of own achievements
125	But I was worried that if, because the previous appointment he said that if I didn't haven't lost the weight by then, they might think about doing another MRI, another biopsy and I don't want to go through all that again. I'm not worried about the MRI, but the biopsy is uncomfortable, and you have to rely on somebody to take you home.	Fear of delaying treatment if did not lose weight, source from 'he' the surgeon. Influence of medical decisions and treatment on short term behaviour change. Role of surgeons as motivator and ? importance of collaborative team approach.
126	So, the motivation was obviously to lose the weight, and I eventually got there, but now I'm annoyed because I am still waiting to get the operation.	? can't see beyond the short-term aspect. Lose the weight to have the operation and then the problem goes away? Demotivator when purpose of exercise is not clear or delayed reward
	Okay, and so now that you've lost the weight and you're in this waiting phase do you think you still have the motivation to exercise?	
127	Oh yeah, definitely, because I don't want to put the weight back on, so I haven't done as much, but there again, I had a week off, and the following week I went back to work and I didn't pick at all so I did, I think I got 4 nights in that week, 4 sessions in that week.	Background motivation to lose weight still exists
128	So, if I'm not picking tomorrow, I will do the gym again tomorrow. If I'm picking I will do the gym Saturday and Sunday and whatever.	Ease of having access to gym at work and scheduling gym sessions around work, good for adherence Patient judgement of how much extra exercise needed on top of work – understanding of changing physical activity day to day for patients and how to

		prescribe exercise to supplement.
	And, do you think that if you didn't have the motivation to lose weight that you would still go to the gym.	
129	No probably not. I probably wouldn't have done, If there was no motivation there, I probably wouldn't have done the gym. I'll be honest.	Weight loss as main motivator
	Okay, but now when the motivation goes away, once you've had your operation….	
	I am still gonna try and do at least 2 nights a week if I can, just to keep the weight to a, you know.	Motivation was cancer diagnosis and surgery to cure it.
	Okay, and so your motivation is maintaining weight?	
	Yeah, well, obviously it's helped the physical,	
130	And if it's good for my cardiovascular then that's what I shall do. But I shall cut it back down to 2 nights a week I expect. Because it can be a bit of a pain getting home at gone midnight all the time, rather than being home at 20 to 11.	Short term goals mean will cut down on exercise after surgery
131	So, I will probably try, I will try and keep up 2 nights a week at least.	Uncertainty if can maintain current level of exercise
	Okay, so do you think, why do you think that you need to lose weight for the operation why do you think that the role of physical exercise is?	
132	Well he obviously explained to me that is obviously cuts the, it can um, improve the er recovery time.	Understanding of benefit of prehabilitation to improve recovery time
133	And obviously there's less of the chance of heart attack and stroke.	Aim to reduce risk factors for perioperative complications
	And do you think it's just about the weight?	
134	I don't know. Oh um no, because of the procedure they are going to use, the robotic arms, and he said they're only so long, or something, so he said obviously less (laughs) trying to be, less fat to get through the better. Really.	Focus on weight as main factor to being able to have surgery Influence of what surgeons says on patient perception of aims
	Okay, and so um the last question is about your experience of using the monitoring equipment, so the monitoring equipment that Helen gave you. How did you find it?	
135	Well not a problem really. No. None at all. Apart from the second time I tried it, I think I damaged it at work, because the work I was doing, like um, I was on a reacher doing let downs what we call you have to get a pallet to put into a pick slot, and I have the tendency to squash the shrink wrap down, and I think I may have (laughs) may have squashed the monitor. Coz, it worked the first day, but I was doing something else, I wasn't picking, and then I got home and I thought, err the lights not flashing and I went to put it on charge and nothing happened, no blue came on and I thought, oooh, so I had to ring up [Dr X] and get her, she came round with another one. So um yeah I think I got one days worth of data out of that, but then I obviously damaged it, I think. But I didn't have a problem wearing it.	Need for monitoring device to be more robust for when patient is doing activities Not bothered by process of using monitoring equipment
	And was it comfortable?	
136	I wouldn't say it was comfortable. It irritated a bit because of the plastic strap, you know, where the monitor fits, that irritated a little bit.	
	And so, did you feel like you were noticing it all the time or were there periods of time where you forgot about it?	

136	The first day or so, yeah, but I just, well I didn't forget about it obviously because I didn't want to damage it, but obviously I did the second time, but (laughs), It didn't restrict me in any way.	Strap not comfortable but did not find it restrictive
	And do you know what it was monitoring?	
137	I think, well as far as I know it was just heart rate, but I think it may have been a few other things as well. But I can't remember what she said. (laughs)	Control group patient did not have access to the data
	Yeah, well I wore it several times when I did the gym,	
138	So she obviously got a bit more information off that one.	Wearing of monitor for information of researcher only, no impact on behaviour of patient
	Okay, great. And is there anything else that you would like to tell me about your operation, or physical activity or anything else?	
139	No, I'm worried about the after effects of the operation maybe. Coz, I mean, since I've the diagnosis and that, the urgency to pee is quite…. it can be close to embarrassing at work coz I can have a slight little dribble before you get to the toilet, and I explored the radiation, the bracket therapy I think it was where they inject the radioactive seeds and the consultant said, speaking honestly, you're quite relatively, you're still relatively young for somebody to have the condition and it won't get rid of the urgency and it could cause further cancers later on in life and I thought well it's bad enough getting older without having to deal with cancer as well so I thought, well that's not for me, I'll stick to the er surgical side and the only worry I have is the, you know coz you read the information sheet, you could be wearing pads up to 12 weeks. Well I don't really want to take 12 weeks, I'm definitely taking the 6 weeks off and anything else, no heaving lifting for 6 weeks and the nurse that was there, in first when I got the diagnosis was like, yeah, given the nature of your job, I'd take the 6 weeks.	Worried about side effects of surgery and impact on coping at work Patient dignity with side effects and symptoms Financial worries and possible loss of income
	But as we get full pay, I may try and sneak a few extra weeks off (laughs) on top of that.	
139	But I'd rather not go back to work you know if I'm still having trouble weeing and things like that. I don't really want to stand there wetting myself or anything.	Dignity, worries of side effects
140	Even though you're wearing pads, and what have you. I'd just, I'd rather be a bit more comfortable at work. But I think that's the main thing. I'm hoping, obviously, they caught it in time and err, I don't know. It's just that bit really. I know there's one in so many that have problems with the peeing and that later on and obviously there's a sexual side to it as well, but thats, that changed when I had my discectomy, coz they warned me then as well, that you might lose a bit of your sex drive and all that, and it does seem to have happened anyway, I'm not using that as an excuse. But err yeah, that does worry me slightly. But I'm not unduly worried, at least I've removed one cancer from me body at least, that's the main thing.	Worry balanced by reassurance of treatment
141	Yeah, coz I had a friend, died a few years back. He was younger than me and he died of testicular cancer. He obviously didn't get diagnosed soon enough.	Worry about spread of cancer and death

141	And I was quite shocked when he died. Even though we weren't that close, it was still a bit of a shock to find out he died of it, especially at his age, which was a shame really. But I thought, I don't want to go through that, and I'd rather it not spread, coz in my opinion...I know there's treatments about and everything, there's lots and people go in remission and that, but the thought of it spreading from the prostate here is just frightening, I just want to get it done and out of the way, really.	
142	I'm not really, I'm worried about the after effects, but other people have coped, so I think I can do it and I feel a bit more determined now, especially with doing the gym and that, I think that's given me more motivation than anything.	Motivation to mitigate side effects of surgery, self efficacy and self management
143	I had a few lads that said…..hmmm come on, never seen anyone do that long on cardio, but it was there, it had to be done, even though I kept looking in the mirror and thinking, doh, my stomach's not going down, but I obviously have lost the weight, and I do feel slightly better for it.	Importance of understanding effect of exercise, expected outcomes and getting feedback – role for monitoring here
	And did you set the programme yourself? Did you set the amount of time yourself?	
144	Yeah, yeah. Well I started off at 20 minutes on the, coz obviously I haven't done a lot of exercise. I mean I've got a physical, fairly physical job. But it's not constant.	Able to set realistic exercise goals for himself, improves adherence
144	But I thought if you're gonna do something, you got to set yourself a target, so I started off with 20 minutes on the bike and maybe 10 minutes on the treadmill, no sit ups, and then after a couple of weeks I upped it, I upped it a minute each time, you know every other week or so, I upped it by another minute and up to half an hour on the bike, 28 minutes on the treadmill and I'm at me 30 sit ups now, coz I started off with about 10 and I increased it by 2 each other week or so, and now I'm up to 30. That's quite hard. I must admit. (laughs)	Able to ramp up own exercise routine, specific timings
	And again, you know….	
145	Well I was worried about my back as well, coz I still have a niggling pain there occasionally, you know, depending on what I do, and my right leg is slightly weaker than it was before.	Physical symptoms, back pain as a barrier
	And so, do you think, do you think you would have benefitted from having somebody advise you and help you with the exercise?	
146	Possibly, but no-body…..I just got shown, and I think, well one of the lads, he's one of the Polish lads there…	
	In the gym?	
146	He did give me like a diet thing.	Getting advice and information from others outside of health professionals
	Do you think that if you were offered some physio support or dietary support that actually that would….	
147	I don't know, coz I went to the GP several times, you know for me blood test and they had a book, I can't remember what it's called now but it's a calorie, like a, you can get it online apparently. We never did round to getting it, coz the wife said oh it likes like you can have curries, and obviously what you do, is just cut your portion size down mainly, and	Some support from GP on diet

	she did try doing that for a while (laughs).....and I just went hmmmmf on a diet am I? (laughs)	
147	But yeah, yeah, it's not been to bad. We eat quite a few veg, we even eat asparagus now, and I always thought that was for rich people (laughs), we had that Sunday funnily enough. And, yeah, I tend, I tend to steer away from too much greasy food, I don't have chips very often, and I've cut back on me chocolate, and yeah, I think it's basically it's more self discipline that anything.	Made changes to diet with help from GP and wife
148	Rather than anything. I find it boring with diets to be quite honest.	Finds diets boring
149	And then he said, well in 31 days, but this is the annoying part because I feel like I'm in limbo now. I've reached the weight target, and now I'm still waiting for the operation. But I know the NHS is under pressure, I know it is, but it just... a lot of people say ooooh I'd be on the phone everyday, well there's no point in ringing every day, and I just want it done as soon as really.	Demotivating to not receive the incentive of losing weight with delay of operation Impact of NHS pressures and waiting times
150	But I don't want it too late, well in the most because I've got Fairford tickets and I don't want to miss that.	Life events and booked activities as other priorities for patients
150	I've spent too much money on that to miss that.	
151	I mean, the physio that helped me out after my discectomy, like I said, my balance was all over the place, and we had the grandchildren, and the kids living with us, and if I'd stepped on a toy, you know, I'd be falling over in the house, and I thought, I can't go back to work like this, so I was off for about 5 months in the end and obviously like I said, I still get the odd pain in the back, and I must admit, i did neglect the exercises that they showed me to do, but I know roughly what I've got to do to do it, and then the occupational health at work showed me these exercises and they were quite difficult and then when I mentioned the problem with peeing he said, oh get it checked out, which i did, it was mainly him that nagged me rather than the wife and that, and she kept on about it, I just thought it was some like residual nerve damage from the operation, but as it turned out, it wasn't.	Previous operation and physical symptoms Previous experience with recommendation of doing exercises after discectomy operation – exercises difficult and competing concerns with urinary symptoms
	Well it's a good thing you checked it. Isn't it.	
	Yes it is. Coz I must have had it for a while before I went.	
152	But, yeah, I was a bit, when he, when they rang back and said do you want to come in and discuss your results, you know you've got it, because they don't bother otherwise, they just say, oh you're clear….la, la, la. But nah, so the wife came with me, it was a little bit of shock but it wasn't totally a surprise because obviously I had to go back in to discuss it. But this, as I say, the main motivation for losing the weight, I mean, I feel better for the exercise, but I wouldn't say I was the sort of person who lives for doing a bit of exercise, and I do, I mean, I know it's a bit of a stupid thing to do. When I go out for a drink, I will walk, so it's a good half hour walk there and back, so it's a little bit of exercise.	Motivation to lose weight spurred by cancer diagnosis and shock
	Absolutely. And I've seen your walking pace, it's a good pace. (laughs)	
153	Oh yeah, that is roughly my normal pace anyway. Like I said, some days it's a bit quicker, other days, if that pain's there,	Some days better than other days with limiting physical symptoms

	it does slow me down a little bit, but I always manage to, I walk through it. I mean there was, for the odd occasion, I thought, I'm going back home, this is too much. And like I said, the odd day, it does really hurt, and when I first started back at work, well before I went back to work, and after the physio at Witney, even then, walking down there, the first time I walked, it took me, whereas it used to take me about 20 minutes, it was taking me 45 minutes, and gradually I got it down, but I'd be glad to get there because the pain was quite, quite bad. And, I did try, the physio said to me at work, ah, he said, well he wasn't an actual, he did more sports injuries rather than actual physiotherapy, and he said, well I think you could try doing the picking, which we call level 1 and level 2. The level 2 is the lighter stuff, of what we call the flow racking.	Relationship with physio and goal setting important for recovery from previous back operation
154	And the level 1 is the stuff like beers and wines, flour, you know all the heavier stuff.	Importance of relationship between health and work. Back injury and recovery impacted on type of work he could do
155	So I came off them. But I must admit, there are some days when I think I could do with them. But, I don't think they like you on long term use of painkillers anyway. But, it did do the trick, certainly did. But I usually just sort of, go through the, you know, it's bearable, most days it's bearable, some days I think, ugggh I don't want to be doing this.	Some good days and bad days depending on physical symptoms Self-managing back pain
	Well, at least you are listening to your body, that's, you know...a good thing.	
156	So, they haven't put me on one since. They did try me on, as I said, previous to that they did try a couple of shifts where I did 4 hours of that, and then 4 hours of the other picking, and that was okay, but just about. But, 8 hours, I don't think I can do that again.	
157	I'm not quite sure what causes it. Well I went for a...she did sent me for another x-ray when I had those few days off and she's just said it's just wear and tear, which is what the consultant told me afterwards, he said…………..I think it was 6 weeks or so after the operation, he said…..I've looked at your scan, he said and there's a lot of wear and tear. I said, that's what you get for about 40 years manual work (laughs).	Need ongoing input from healthcare system to manage symptoms and process, ongoing interaction and demands, evolving advice on condition
	For talking to me.	
	It's okay.	
	And good luck with your operation and I hope you enjoy Fairford.	
	Yeah, so do I.	
	End	

E. Qualitative analysis of patient interviews: theme development

Theme	COM-B	Coding reference	Patient	Quotation
CAPABILITY	Capability is an attribute of a person together with opportunity that makes a behaviour possible or facilitates it			
PHYSICAL CAPABILITY	Physical capability is capability that involves a person's physique and musculoskeletal functioning e.g., balance and dexterity			
Baseline exercise behaviour and capability				
Exercise already part of daily routine Using gym	Physical capability Physical opportunity	40	E2	When I was working, I used to go most nights to um, a gym and swim, straight after work. It was just around the corner,....so convenient.
		41	E2	And then, um, when I stopped working, I joined the gym that my wife went to. So, we saved on going together to that, and...we went 3 times a week.
		75	E2	Oh most certainly yes, um, because I've been retired now how many years, 5 years and I've been to the gym every week.
		109	C2	**Oh, well, that's really nice. Okay, so the next question is about um, your exercise history, over the last few years, and your thoughts about physical activity and exercise.** It's pretty poor really, I'll be honest, until I got diagnosed with cancer, then I asked to join the gym at work, and I probably, yeah probably a good year now, I've being doing...I started off with doing 2 sessions a night.....,a week, then 3, then I upped it to 4, roughly an hour, an hour and 10 minutes each time.
Made own routine at the gym	Physical capability Physical opportunity	114	C2	I'd just do the um exercise bike for half an hour, err 28 minutes on the treadmill, and then 30 sit-ups, and then, I'd do, use the 5 kilo weights just for about a minute, that's about it, not even a minute really.
		124	C2	I increased it because I thought if I can't change my diet, or to a

				big extent, increase the exercise and see how that goes. I mean it was a long process. Longer than it should have been maybe.
		144	C2	**And did you set the programme yourself? Did you set the amount of time yourself?** Yeah, yeah. Well I started off at 20 minutes on the, coz obviously I haven't done a lot of exercise. I mean I've got a physical, fairly physical job. But it's not constant.
Enjoys exercise at gym and with wife	Physical capability Physical opportunity Social opportunity	43	E2	And then, um, when I stopped working, I joined the gym that my wife went to. So, we saved on going together to that, and...we went 3 times a week. **Together?** Yeah, and we did a variety of things, we went to classes. Swam, and generally enjoyed it (laughs) coz that's the thing, it's gotta be enjoyable.
Fear of loss of capability on retirement Using work to stay active and stay thin	Physical capability Physical opportunity Social opportunity Reflective motivation	6	E1	**And, do you think other people might feel similar to that, do you think you change what you do when you retire?... Do you think there's something in that?** Oh, yeah. Yeah, you know, I mean I've still got a workshop and this sort of thing...ummm, but I've heard so many stories of people retiring, and more or less going to seed, you know, so I didn't want to do that, so, you know, I kept a job going
Change in capability and outlook with previous back injury	Physical capability	63	E2	Yeah, um, I suppose the uh, well I've always had this back thing for about 8 years, um, and surprisingly, errr, it changed me physically. And then I realised that I physically I had changed shape.
Realisation of physical limitations, identification with new status of	Physical capability Self-identity	65	E2	And, I don't walk as well as I used to. Although I've er gotten round it um slightly, I got myself some walking poles which I decided to try out.

physicality as an obstacle to exercise				And, er, I'm now a pole walker.
Physical symptoms				
Pre-existing physical condition limiting exercise	Physical capability	54	E2	Um, I should say that about 7 or 8 years ago, I fell off a ladder and injured my back, which makes walking awkward or painful sometimes, but cycling is a doddle.
	Reflective motivation	53	E2	I decided not to do that, and didn't tell them…….but took up cycling instead, because I prefer that.
		55	E2	I still get the aerobic workout but it doesn't hurt my back.
		63	E2	Yeah, um, I suppose the uh, well I've always had this back thing for about 8 years, um, and surprisingly, errr, it changed me physically.
		112	C2	And, they've looked after me since my back operation, and um…..I don't do a lot of the heavy lifting, anyway.
		145	C2	Well I was worried about my back as well, coz I still have a niggling pain there occasionally, you know, depending on what I do, and my right leg is slightly weaker than it was before.
		151	C2	mean, the physio that helped me out after my discectomy, like I said, my balance was all over the place,
Some days better than other days in terms of ability to exercise with physical symptoms	Physical capability Automatic motivation	153	C2	Oh yeah, that is roughly my normal pace anyway. Like I said, some days it's a bit quicker, other days, if that pain's there, it does slow me down a little bit, but I always manage to, I walk through it.
Importance of relationship between health and work. Back injury and recovery impacted on type of work he could do	Physical capability Reflective motivation	153	C2	And, I did try, the physio said to me at work, ah, he said, well he wasn't an actual, he did more sports injuries rather than actual physiotherapy, and he said, well I think you could try doing the picking, which we call level 1 and level 2. The level 2 is the

				lighter stuff, of what we call the flow racking
Back pain limiting exercise requiring pain killers	Physical capability	155	C2	So I came off them. But I must admit, there are some days when I think I could do with them. But, I don't think they like you on long term use of painkillers anyway. But, it did do the trick, certainly did. But I usually just sort of, go through the, you know, it's bearable, most days it's bearable, some days I think, ugggh I don't want to be doing this.
Sleep quality as a factor for capability to do exercise, linked to urinary symptoms	Physical capability Physical opportunity	67	E2	And, perhaps if I've um slept, or not. And that's a big thing for me, because I have an enlarged prostate which means I sometimes get up a lot, and don't sleep as well as I could do.
Managing side effects of medications for physical symptoms	Physical capability	69	E2	Which, has side effects which are not good for me. But they work to a certain extent. I've been to see my GP. I'm kind of balancing whether or not it's, whether the side effects are worth the fewer visits to the bathroom at night, so um….the er….the jury's out on that for the moment.
		83	E2	Yes, because, the operation and everything is all about cancer. And I was taking a wider view, about my life and my sleep patterns, and the medication that I might have had to take if…..the er prostate hadn't returned to it's formal size. I was taking a wider view.
Feeling of lack of purpose of exercise as lack of physical symptoms, already feels strong	Automatic motivation	10	E1	I'd just forget to do it. Um... I don't know why, possibly because, I sort of feel fine. You know what I mean? I thought...um, I'm strong enough, you know or subconsciously thought... I'm strong enough, I don't need to do that. It just went out of my head and these poor physios, you know I thought, oh God...I can't lie to them.

Patient managing own physical symptoms in positive way to find alternate ways to exercise	Physical capability Self-efficacy	54	E1	Um, I should say that about 7 or 8 years ago, I fell off a ladder and injured my back, which makes walking awkward or painful sometimes, but cycling is a doddle.
		153	C2	Oh yeah, that is roughly my normal pace anyway. Like I said, some days it's a bit quicker, other days, if that pain's there, it does slow me down a little bit, but I always manage to, I walk through it
Other health conditions				
Previous procedure and residual disability	Physical capability	145	C2	Well I was worried about my back as well, coz I still have a niggling pain there occasionally, you know, depending on what I do, and my right leg is slightly weaker than it was before.
Not able to follow exercise regime if difficult or competing symptoms and worries	Physical capability Automatic motivation	155		So I came off them. But I must admit, there are some days when I think I could do with them. But, I don't think they like you on long term use of painkillers anyway. But, it did do the trick, certainly did. But I usually just sort of, go through the, you know, it's bearable, most days it's bearable, some days I think, ugggh I don't want to be doing this.
	Physical capability	151	C2	I mean, the physio that helped me out after my discectomy, like I said, my balance was all over the place, and we had the grandchildren, and the kids living with us, and if I'd stepped on a toy, you know, I'd be falling over in the house, and I thought, I can't go back to work like this, so I was off for about 5 months in the end and obviously like I said, I still get the odd pain in the back
Competing concerns of other health conditions	Physical and psychological capability	83	E2	And I was taking a wider view, about my life and my sleep patterns, and the medication that I might have had to take

				if…..the er prostate hadn't returned to it's formal size. I was taking a wider view.
Patient dealing with making multiple decisions and interaction with different health professionals in managing symptoms and cancer	Physical and psychological capability	68	E2	And for the extent of this um research, I've been taking um Lendormin
Trying to get advice from healthcare professionals	Physical and psychological capability	69	E2	Which, has side effects which are not good for me. But they work to a certain extent. I've been to see my GP. I'm kind of balancing whether or not it's, whether the side effects are worth the fewer visits to the bathroom at night, so um….the er….the jury's out on that for the moment.
		151	C2	I mentioned the problem with peeing he said, oh get it checked out, which i did, it was mainly him that nagged me rather than the wife and that, and she kept on about it, I just thought it was some like residual nerve damage from the operation, but as it turned out, it wasn't
PSYCHOLOGICAL CAPABILITY	Psychological capability is capability that involves a person's mental functioning (e.g., understanding and memory)			
Felt study goals were achievable Individual responsibility to achieve goals	Psychological capability Self-efficacy	25	E1	I'm quite happy with the study I've done, and the support that I've been given, and the goals I've been given and once again it comes down to me as an individual to either fulfil them or not..those goals, but I was clearly told the goals, and the surgery,
Prefers to be educated and informed to manage own health Not getting the full information from clinicians	Psychological capability Reflective motivation Self-efficacy	82	E1	As I say, if I hadn't of seen that video, I'd have carried on my own sweet way, and the, the surgeon said to me, if you'd left this another 12-18 months, it would have spread. So, you know, I mean, there's now that whole thing, I dodged a bullet there, and it was only because of that video, you know no-one

				called me in to say, you need your prostate checked. So, I think that's a bit of an omission in the GPs sort of practice.
Understanding / information about benefits of exercise, and what feedback expected from exercise to know it is effective	Psychological capability Self-efficacy	115	C2	I'm not really sure. I used to think, if I was standing at the back, I don't feel so bloated. I feel like I've lost the weight, and I know I've lost the weight. I don't know if I felt fitter. I think I did. I know what afterward, when I've done the gym and I'm walking back to the, out to the car, you know, that's another good session, done. I feel better for doing it.
		116	C2	But I'm not sure whether it affected me that much. It obviously has, and I know it's good for the cardiovascular bit, and I feel better for that, I must admit. And, I don't get breathless. You know I sweat a lot on the bike, but I don't feel breathless at the end of it, or anything like that.
Awareness of consequences of being sedentary	Psychological capability Reflective motivation	9	E1	I was surprised just how inactive I was really. (laughs).
		45	E2	Um, well simply because I used to go at work. And, at work I used to sit in front of a computer screen most of the time
		59	E2	Um, the first week, [Dr X] sent me the results which were quite interesting. I was staggered to see how much time I spent sitting around. That was really quite a shock. How much time I'm slumped in a chair, or not doing anything especially vigorous
		96	C1	But there's quite a few people here in reception who are very obese, I'm mean they're really….I was quite disappointed to see them so they're not following their own rules. But, you know, as long as I don't

				become grossly overweight and so on, I'm…..and, I can do the things that I enjoy, I mean, I enjoy cooking for example which can be quite exhausting
		117	C2	I did when I first, it was hard to work to start with. Because I'm not, like I said, over the years I haven't done much exercise, I just rely on my work
Evaluates exercise done based on individual feelings (not using objective measures)	Psychological capability Automatic motivation	39	E2	**Coz you say, you do the bare minimum to keep mobile do you have an idea of what that bare minimum entails?** Hmmm, probably, basically because I know how I feel.
Using measures of breathless and sweating as indicators of exercise		116	C2	But I'm not sure whether it affected me that much. It obviously has, and I know it's good for the cardiovascular bit, and I feel better for that, I must admit. And, I don't get breathless. You know I sweat a lot on the bike, but I don't feel breathless at the end of it, or anything like that.
		118	C2	Then, at the end of the night, you had to clean out the mixer, so that was quite physical (laughs), I used to sweat like hell doing that. It's a big drum mixer and you had to chip all the hard stuff off and every night to clean that out.
Unrealistic expectations of time taken to lose weight and visible effects may be a demotivator	Psychological capability Reflective motivation	144	C2	I had a few lads that said…..hmmm come on, never seen anyone do that long on cardio, but it was there, it had to be done, even though I kept looking in the mirror and thinking, doh, my stomach's not going down, but I obviously have lost the weight, and I do feel slightly better for it.
		124	C2	I increased it because I thought if I can't change my diet, or to a big extent, increase the exercise and see how that goes. I mean it was a long process. Longer than it should have been maybe.

Insight into own exercise behaviour				
Understanding of fitness related to weight control and work	Psychological capability Physical opportunity	1	E1	Well... I'm, I'm overweight. I've been trying to do something about it.
		5	E1	I've been physically active all my life. I stopped being physically active really when I retired, and um, so you know...I didn't have a daily bike ride, I didn't have my job, so you know, and then I thought, ahhh, I'll get a little job...so I became a courier which is sitting down all day driving all over the flipping place, and so really, I mean, that's when...I was always as, you know, as skinny as a rake all my life, and it was only when I retired I started putting weight on. So...all my life, up until the last, (boom boom), about 13 years...13 years, I have been physically active...up till when I was about 60
Insight into change in circumstances with retirement and need to start new exercise	Psychological capability Physical opportunity	46	E2	Um, well simply because I used to go at work. And, at work I used to sit in front of a computer screen most of the time And um, I needed to go and loosen up, so when I retired, I thought, there wasn't enough in the garden to um, to give me the full exercise that I needed, so I went off and saw the instructor and got a series of exercises to do, and went through the whole cross training then, then and then went for a swim afterwards.
Insight into how fitness relates to what he wants to do, to continue cooking and not be overweight	Psychological capability Reflective motivation	96	C1	I went to a gym for a while, you know I quite enjoyed it, um, but then lost interest, and um, I've never regained it, so, I mean, in theory, yes. But there's quite a few people here in reception who are very obese, I'm mean they're really....I was quite

				disappointed to see them so they're not following their own rules. But, you know, as long as I don't become grossly overweight and so on, I'm.....and, I can do the things that I enjoy, I mean, I enjoy cooking for example which can be quite exhausting
		97	C1	Standing in the kitchen, for 2 or 3 hours or what not, ummm, well that's okay. Well I'm very old now, so it doesn't really matter all that much.
Insight into strategy of diet vs. exercise to lose weight	Psychological capability	124	C2	I increased it because I thought if I can't change my diet, or to a big extent, increase the exercise and see how that goes. I mean it was a long process. Longer than it should have been maybe.
		127	C2	Oh yeah, definitely, because I don't want to put the weight back on, so I haven't done as much, but there again, I had a week off, and the following week I went back to work and I didn't pick at all so I did, I think I got 4 nights in that week, 4 sessions in that week.
Conflicting viewpoints in same interview about patient's own perception of amount of exercise they do		36 52	E2	And I probably do the minimum that I have to to remain mobile. I'm not that enthusiastic about it. Um, well……. Oh yes, for sure. I was fairly active anyway and there wasn't much they could recommend.
OPPORTUNITY	Opportunity is an attribute of an environmental system together with capability that makes a behaviour possible or facilitates it			
SOCIAL OPPORTUNITY	Social opportunity is opportunity that involves other peoples and organisations (e.g., culture and social norms)			
Impact of retirement				
Reliance on work for physical activity	Reflective Motivation Social Opportunity	4	E1	Well, I mean, all my life, I've been very physically active. Umm, I took an apprenticeship down at the Press Steele. You

				know, I worked in a tool room, which was a physically active job
		5	E1	I used to bike to work, do a full day's work, hard work, bike back again...all my life,
		113	C2	Yes, I would say so, yes most days it's fairly active, yeah, no matter what you're doing. Even if you're on the forklift, you know you're tipping lorries and re-truck.
		117	C2	over the years I haven't done much exercise, I just rely on my work. Because when I first moved back to Carteron I did quarry work which was quite physical, a really physical job, and that kept my weight down to a certain degree
Identity linked to work	Reflective Motivation Physical Opportunity	120	C2	You have to work for so long for the Royal Family before you get the crest, and um yes, so that was quite an interesting job. The only thing I didn't like was the 2 days a week you had to go to London, so you had to be at the yard for 5 o'clock in the morning. That was a little bit too much, so I. But that was physical, you know some heavy stuff to move about. Some really heavy stuff.
	Physical capability	121	C2	Yeah, I've been pretty physical all through my life (coughs), work-wise anyway
Impact of surgery on work	Reflective motivation Physical capability	139	C2	But I'd rather not go back to work you know if I'm still having trouble weeing and things like that. I don't really want to stand there wetting myself or anything.
Being sedentary at work led to seeking exercise	Reflective motivation Physical opportunity	46	E2	Um, well simply because I used to go at work. And, at work I used to sit in front of a computer screen most of the time. And um, I needed to go and loosen up, so when I retired, I thought, there wasn't enough in the garden to um, to give me the full exercise that I needed,

				so I went off and saw the instructor and got a series of exercises to do, and went through the whole cross training then, then and then went for a swim afterwards.
	Reflective motivation Physical opportunity	75	E2	Oh most certainly yes, um, because I've been retired now how many years, 5 years and I've been to the gym every week.
Weight gain since retirement	Reflective motivation	5	E1	I was always as, you know, as skinny as a rake all my life, and it was only when I retired I started putting weight on
		117	C2	I did quarry work which was quite physical, a really physical job, and that kept my weight down to a certain degree
Importance of relationship between health and work. Back injury and recovery impacted on type of work he could do		156	C2	They did try me on, as I said, previous to that they did try a couple of shifts where I did 4 hours of that, and then 4 hours of the other picking, and that was okay, but just about. But, 8 hours, I don't think I can do that again.
Exercising with others				
Exercising with wife	Social opportunity Automatic motivation	41	E2	And then, um, when I stopped working, I joined the gym that my wife went to. So, we saved on going together to that, and...we went 3 times a week.
Wife as pacemaker when cycling	Social opportunity Physical opportunity	77	E2	. I go out with my wife cycling, she's very good at it, and she's my pacemaker, left to my own devices I just (laughs). **So, do you think there's something in that. Do you think having your wife, in your life has made a difference to how you exercise?** Ah to me it has, yes. Um, for sure. She's, she's a born again cyclist as well
Daughter pushing him to exercise	Social opportunity Reflective motivation	92	C1	my daughter's come to live with me now and so, she's very active and pushes me to do much more in the garden.

Playing golf with son but still not competitive enough	Social opportunity Automatic motivation	99	C1	I played golf until quite recently, with my son mainly. Ummm, and, I very much enjoyed that, but that is not quite so competitive collectively, it's individually, you're just playing against yourself.
Role of wife with diet	Social opportunity	111	C2	I have cut back on the chocolate and cake, and a few other things. The wife does a few more salads, but working, eating at work, it's not the best of diets, you know, for the food wise, they don't do much. I'm not a vegetarian, so I do like my meat.
Interaction with healthcare staff				
Phone calls from physiotherapist helped to refocus	Social opportunity Reflective motivation Psychological capability	15	E1	**Okay, and did the weekly phone calls, what, did they help?** Yeah, they tended to refocus me a little bit yeah, certainly tended to refocus me.
Getting advice and information from others outside of health professionals – person at gym, physio at work	Psychological capability Social opportunity	146	C2	**And so, do you think, do you think you would have benefitted from having somebody advise you and help you with the exercise?** Possibly, but no-body…..I just got shown, and I think, well one of the lads, he's one of the Polish lads there… He did give me like a diet thing.
Relationship with physio and goal setting important for recovery from previous back operation	Psychological capability Social opportunity	153	C2	And, I did try, the physio said to me at work, ah, he said, well he wasn't an actual, he did more sports injuries rather than actual physiotherapy, and he said, well I think you could try doing the picking, which we call level 1 and level 2. The level 2 is the lighter stuff, of what we call the flow racking.
Patient wished for more holistic consideration of his urinary symptoms in discussion of cancer treatment with surgeon	Psychological capability	82	E2	But I had to work that out, that didn't form part of the discussions with anyone.
		83	E2	Yes, because, the operation and everything is all about cancer. And I was taking a wider view, about my life and my sleep

				patterns, and the medication that I might have had to take if…..the er prostate hadn't returned to it's formal size. I was taking a wider view.
Social barriers				
Preference for individual exercise	Automatic motivation	21	E1	**So thinking about, you know, your exercise. You've gone for walks and stuff at home. Do you think that individual exercise is the way to go?** Yes
		77	E2	I tend to exercise on my own. And when we used to go to classes to do things like yoga and pilates and stuff, which I quite enjoyed, um, I'm really a lone exerciser, I think. I go out with my wife cycling, she's very good at it, and she's my pacemaker, left to my own devices I just (laughs).
Wary of over reliance on healthcare professionals due to process of cancer diagnosis		24	E1	I dodged a bullet there, and it was only because of that video, you know no-one called me in to say, you need your prostate checked. So, I think that's a bit of an omission in the GPs sort of practice.
Previous experience of health service, surgery, struggling to get symptoms diagnosed	Social opportunity	151	C2	it was mainly him that nagged me rather than the wife and that, and she kept on about it, I just thought it was some like residual nerve damage from the operation, but as it turned out, it wasn't.
		69	E1	. I've been to see my GP. I'm kind of balancing whether or not it's, whether the side effects are worth the fewer visits to the bathroom at night, so um….the er….the jury's out on that for the moment.
		83	E2	Yes, because, the operation and everything is all about cancer. And I was taking a wider view, about my life and my sleep patterns, and the medication that I might have had to take if…..the er prostate hadn't

				returned to it's formal size. I was taking a wider view.
Ineffective intervention on diet from GP	Psychological capability Social opportunity	147	C2	I went to the GP several times, you know for me blood test and they had a book, I can't remember what it's called now but it's a calorie, like a, you can get it online apparently. We never did round to getting it
Supervision using telephone calls from study physiotherapists not that useful, no meaningful advice	Psychological capability Social opportunity	58	E2	I don't know if they were helpful. They might have been helpful to the physios. I've no idea. Um I don't know that they were particularly helpful to me in any way, other than to say, I'm not doing a lot of walking, but I've taken up cycling.
Relationship to healthcare professional – fear of lying Feeing obligation to follow healthcare advice	Social opportunity Automatic motivation	10	E1	. It just went out of my head and these poor physios, you know I thought, oh God...I can't lie to them.
		19	E1	You know, if you're like that and you're going to go for an operation, and you know, I think you owe it to the poor surgeon and everyone to get a lot, set a lot of that off, so it's just down to the individual
Feeling of obligation to meet expectations of surgeon before operation	Social opportunity Automatic motivation	125	C2	But I was worried that if, because the previous appointment he said that if I didn't haven't lost the weight by then, they might think about doing another MRI, another biopsy and I don't want to go through all that again. I'm not worried about the MRI, but the biopsy is uncomfortable, and you have to rely on somebody to take you home
		134	C2	Oh um no, because of the procedure they are going to use, the robotic arms, and he said they're only so long, or something, so he said obviously less (laughs) trying to be, less fat to get through the better. Really.
Fear associated with time spent exercising and	Physical opportunity	16	E1	I don't tend to go out for really long periods, because of [wife], you know because at home, if

leaving other responsibilities	Automatic motivation			she gets up out of the wheelchair to do something sort of thing, she's really unsteady and I don't want her falling over.
PHYSICAL OPPORTUNITY	Physical opportunity is opportunity that involves inanimate parts of the environmental system and time (e.g., financial and material resources)			
Competing concerns of other roles and responsibilities				
Responsibility for dependents	Physical and social opportunity	151	C2	I mean, the physio that helped me out after my discectomy, like I said, my balance was all over the place, and we had the grandchildren, and the kids living with us, and if I'd stepped on a toy, you know, I'd be falling over in the house, and I thought, I can't go back to work like this,
Fear associated with time spent exercising and leaving other responsibilities	Physical opportunity	16	E1	I don't tend to go out for really long periods, because of [wife], you know because at home, if she gets up out of the wheelchair to do something sort of thing, she's really unsteady and I don't want her falling over.
Unexpected changes in life circumstances – health conditions of wife and back injury	Physical opportunity Physical capability	7	E1	her walking was fine for about 4 months until she had a cancer scare, a breast cancer scare, and that, seemed to knock it back and flip the switch again, and she just started to deteriorate again
		54	E2	Um, I should say that about 7 or 8 years ago, I fell off a ladder and injured my back, which makes walking awkward or painful sometimes, but cycling is a doddle.
Difficulty with time, doing exercise after work and getting home not too late	Physical opportunity	130	C2	But I shall cut it back down to 2 nights a week I expect. Because it can be a bit of a pain getting home at gone midnight all the time, rather than being home at 20 to 11.
Prioritisation of other pursuits – feeling that some exercises are a waste of time	Physical opportunity Reflective motivation	94	C1	**Um…….so you, you feel you can't waste time, and so, you tend to do your exercise by sitting down and reading.** Yeah, and it's more brain exercise, isn't it (laughs)?

MOTIVATION	Motivation is an aggregate of mental processes that energise and direct behaviour			
REFLECTIVE MOTIVATION	Reflective motivation is motivation that involves conscious thought processes (e.g., plans and evaluations)			
Cancer diagnosis as motivator				
Cancer diagnosis as self-motivator for change in lifestyle	Reflective motivation	109	C2	**Okay, so the next question is about um, your exercise history, over the last few years, and your thoughts about physical activity and exercise.**It's pretty poor really, I'll be honest, until I got diagnosed with cancer, then I asked to join the gym at work, and I probably, yeah probably a good year now, I've being doing...I started off with doing 2 sessions a night.....,a week, then 3, then I upped it to 4, roughly an hour, an hour and 10 minutes each time.
Concerns about recovery from surgery mitigated by positive feeling of self-efficacy to exercise Fighting cancer linked with determination to exercise and lose weight	Reflective motivation Automatic motivation-emotive factors Reflective motivation (Self-efficacy)	142	C2	I'm worried about the after effects, but other people have coped, so I think I can do it and I feel a bit more determined now, especially with doing the gym and that, I think that's given me more motivation than anything.
Cancer diagnosis as teachable moment	Reflective motivation Social opportunity	73	E2	that, that brought it home. And in...when it's brought home like that, that grabs your attention. There's no escaping that.
		74	E2	And, maybe that is the time, you know when you are looking at the surgery option, to say, provided you can maintain this level of fitness, or you can do this, you can get your cholesterol down, or you can... or whatever.
Preoccupation with cancer diagnosis and treatment				
Focus is on treating cancer and feels has	Reflective motivation	23	E1	"You've got a fairly aggressive cancer, it hasn't spread, luckily,

done well by not missing cancer diagnosis (other priorities)				so we'll have it out tout suite, and that's it". But you know, I mean, that was my individual decision
		24	E1	I dodged a bullet there, and it was only because of that video, you know no-one called me in to say, you need your prostate checked. So, I think that's a bit of an omission in the GPs sort of practice.
		141	C2	But I thought, I don't want to go through that, and I'd rather it not spread, coz in my opinion...I know there's treatments about and everything, there's lots and people go in remission and that, but the thought of it spreading from the prostate here is just frightening, I just want to get it done and out of the way, really.
	Psychological capability	141	C2	Yeah, coz I had a friend, died a few years back. He was younger than me and he died of testicular cancer. He obviously didn't get diagnosed soon enough.
Competing 'worries' of cancer diagnosis versus level of fitness	Reflective motivation	72	E2	But, your average person comes along, gets the bad news they've got prostate cancer, isn't perhaps that concerned about it, and more worried about the big C, than how fit they're gonna be to get cured
Jeopardy of the operation, some element of fear	Reflective and automatic motivation	71	E2	Ummmm, targets. Without a doubt. Knowing that you've got to reach the target, or, the operation is in……. in jeopardy. It's got to be as tough as that I think.
		122	C2	Because I wanted to lose the weight. I was desperate to lose the weight.
		132	C2	Well he obviously explained to me that is obviously cuts the, it can um, improve the er recovery time.
		125	C2	But I was worried that if, because the previous appointment he said that if I didn't haven't lost the weight by

				then, they might think about doing another MRI, another biopsy and I don't want to go through all that again. I'm not worried about the MRI, but the biopsy is uncomfortable, and you have to rely on somebody to take you home.
Worry about side effects of operation	Psychological capability	139	C2	I'm worried about the after effects of the operation
Concerns of symptoms of incontinence and sexual side effects Patient dignity	Physical and psychological capability	140	C2	obviously there's a sexual side to it as well, but thats, that changed when I had my discectomy, coz they warned me then as well, that you might lose a bit of your sex drive and all that, and it does seem to have happened anyway, I'm not using that as an excuse. But err yeah, that does worry me slightly
		139	C2	But I'd rather not go back to work you know if I'm still having trouble weeing and things like that. I don't really want to stand there wetting myself or anything.
Reassured that cancer is being treated Positive feeling to treatment	Automatic motivation	25	E1	No, I'm quite happy he explained the surgery to me. I'm quite happy with the study I've done, and the support that I've been given, and the goals I've been given and once again it comes down to me as an individual to either fulfil them or not..those goals, but I was clearly told the goals, and the surgery, yeah, I mean, the, the surgeon explained what's going to happen, it's going to be keyhole, done by a robot, and um, you know, I should just be in for a night and if everything goes well I will be home the next day, and let's hope, you know touch wood, everything's alright.
		140	C2	But I'm not unduly worried, at least I've removed one cancer from me body at least, that's the main thing.

Weight loss as motivator to exercise				
Importance of not being overweight	Reflective motivation Automatic motivation	1	E1	, I'm overweight. I've been trying to do something about it.
	Self-identity	5	E1	I was always as, you know, as skinny as a rake all my life, and it was only when I retired I started putting weight on
		96	C1	But there's quite a few people here in reception who are very obese, I'm mean they're really….I was quite disappointed to see them so they're not following their own rules.
		117	C2	I did quarry work which was quite physical, a really physical job, and that kept my weight down to a certain degree
		122	C2	Because I wanted to lose the weight. I was desperate to lose the weight. (when asked for motivation to go to gym regularly)
		129	C2	No probably not. I probably wouldn't have done, If there was no motivation there, I probably wouldn't have done the gym. I'll be honest. (when asked if he would go to gym without the motivation of weight loss)
Motivation to lose weight triggered by operation and cancer diagnosis	Reflective motivation	110	C2	I had to. I had to lose the weight for the operation
		122	C2	Because I wanted to lose the weight. I was desperate to lose the weight. (when asked for motivation to go to gym regularly)
		125	C2	But I was worried that if, because the previous appointment he said that if I didn't haven't lost the weight by then, they might think about doing another MRI, another biopsy and I don't want to go through all that again. I'm not worried about the MRI, but the biopsy is uncomfortable, and

				you have to rely on somebody to take you home.
		134	C2	Oh um no, because of the procedure they are going to use, the robotic arms, and he said they're only so long, or something, so he said obviously less (laughs) trying to be, less fat to get through the better. Really.
		152	C2	But this, as I say, the main motivation for losing the weight, I mean, I feel better for the exercise, but I wouldn't say I was the sort of person who lives for doing a bit of exercise,
Not losing weight may delay operation and lead to more uncomfortable tests	Reflective motivation Automatic motivation	125	C2	
Weight and operation not linked	Reflective motivation	71	E2	It wasn't a case of surgery if you can get to this level of fitness.
Healthy weight is important to enjoy hobbies. E.g. cooking	Reflective motivation	96	C1	But, you know, as long as I don't become grossly overweight and so on, I'm…..and, I can do the things that I enjoy, I mean, I enjoy cooking for example which can be quite exhausting
Would not feel offended to be told to lose weight, linked to being of a certain generation	Automatic Motivation	20	E1	You see, I come from a generation where, you know, you were told. You're too fat. You know, these days, ahh(gasp) that's um, I don't know some ist (laughs), racist, or, you know some ist…. Or um, you've offended me… but I come from a generation where, you know, the answer was, well tough. You're too fat. You know, these days you've got to tiptoe around these subjects
Motivation related to purpose and goal of exercise				
Purpose to sport and exercise, to win	Reflective motivation Automatic motivation	88	C1	I find...ummm sort of…. independent activity by itself a little bit pointless. So, I find it very difficult to go for a walk for no purpose. Whereas, you know, I'd play cricket all day or tennis or whatever

		90	C1	Well, there's a point in it. I mean, you're trying to win. The whole point of sport is to win, whatever the game is
	Reflective motivation	98	C1	I like sport, because you have the satisfaction, I mean, either of losing or winning, but you had the satisfaction of pitting yourself against somebody and some point, you know. I mean standing in the cricket field all day was absolutely lovely….really nice
Identified with a sport as his 'main game'	Self-identity	89	C1	My main game, I mean, I played...ummm….cricket until the latest…..but my main game is lacrosse, which is for young men, (laughs) or young people ….umm, and so I gave that up. But at school I did everything. Absolutely everything. Ummm, everything, athletics and so on, and at university, I played tennis, and then lacrosse, and since then, with my children I've played tennis, cricket, so on.
Social element of exercise as competition rather than enjoyment of company	Automatic motivation Reflective motivation Social opportunity	99	C1	Yes, yes, oh, absolutely essential. That's what I find. I, I played golf until quite recently, with my son mainly. Ummm, and, I very much enjoyed that, but that is not quite so competitive collectively, it's individually, you're just playing against yourself.
Different levels of enjoyment with different activities. Social vs. purpose of competition	Automatic motivation	100	C1	But with golf, it's just you. And um, that I found a bit frustrating because I wanted the competitive aspect um, to be more than it is.
Self-efficacy				
Self-efficacy with exercise improves confidence with managing operation and cancer	Reflective motivation	142	C2	I'm not really, I'm worried about the after effects, but other people have coped, so I think I can do it and I feel a bit more determined now, especially with doing the gym and that, I think that's given me more motivation than anything.
		110	C2	When I got diagnosed. My target weight was 83, and like I said, I

				didn't really change my diet, and I didn't do any other type of exercise, so, I decided to do the gym and keep at it, and eventually it's paid off.
Emphasis on individual responsibility and decision making	Reflective Motivation	53	E2	Apart from doing a brisk 10 minute walk, um, as often as I could. Um, and I kind of…… (laughs) I decided not to do that, and didn't tell them…….but took up cycling instead, because I prefer that.
		76	E2	I will certainly be doing my best to rehabilitate myself after the uh surgery
		110	C2	When I got diagnosed. My target weight was 83, and like I said, I didn't really change my diet, and I didn't do any other type of exercise, so, I decided to do the gym and keep at it, and eventually it's paid off.
		122	C2	Because I wanted to lose the weight. I was desperate to lose the weight.
Individually driven to adapt exercise plan to achieve weight loss goals, good insight into amount of exercise needed	Psychological capability Reflective motivation	124	C2	I increased it because I thought if I can't change my diet, or to a big extent, increase the exercise and see how that goes. I mean it was a long process. Longer than it should have been maybe.
		127	C2	because I don't want to put the weight back on, so I haven't done as much, but there again, I had a week off, and the following week I went back to work and I didn't pick at all so I did, I think I got 4 nights in that week, 4 sessions in that week.
		143	C2	**And did you set the programme yourself? Did you set the amount of time yourself?** Yeah, yeah. Well I started off at 20 minutes on the, coz obviously I haven't done a lot of exercise. I mean I've got a physical, fairly physical job. But it's not constant.
Setting own exercise plan with ramping	Psychological capability	144	C2	But I thought if you're gonna do something, you got to set

				yourself a target, so I started off with 20 minutes on the bike and maybe 10 minutes on the treadmill, no sit ups, and then after a couple of weeks I upped it, I upped it a minute each time, you know every other week or so, I upped it by another minute and up to half an hour on the bike
Setting own targets		144	C2	But I thought if you're gonna do something, you got to set yourself a target
Conscious planning of exercise regime		114	C2	**For the operation. What sort of things did you do at the gym?** I'd just do the um exercise bike for half an hour, err 28 minutes on the treadmill, and then 30 sit-ups, and then, I'd do, use the 5 kilo weights just for about a minute, that's about it, not even a minute really.
		128	C2	So, if I'm not picking tomorrow, I will do the gym again tomorrow. If I'm picking I will do the gym Saturday and Sunday and whatever.
Recognises has good self-efficacy	Psychological capability Reflective motivation	75,76	E2	Oh most certainly yes, um, because I've been retired now how many years, 5 years and I've been to the gym every week. I will certainly be doing my best to rehabilitate myself after the uh surgery I don't see that as a problem, because I am reasonably fit beforehand and I want to maintain tha
Self-motivated to find instructor to gain skills in exercise	Psychological capability Reflective motivation	46	E2	And um, I needed to go and loosen up, so when I retired, I thought, there wasn't enough in the garden to um, to give me the full exercise that I needed, so I went off and saw the instructor and got a series of exercises to do, and went through the whole cross training then, then and then went for a swim afterwards.

Exercising autonomy Chose own methods of increasing activity against physiotherapy advice	Reflective motivation	53 57	E2	I decided not to do that, and didn't tell them…….but took up cycling instead, because I prefer that. But yes it was, it was entirely appropriate, because I wasn't doing any walking type exercises but I took up cycling instead.
Self-reflection on success of exercise and weight loss	Psychological capability Reflective motivation	143	C2	I had a few lads that said…..hmmm come on, never seen anyone do that long on cardio, but it was there, it had to be done, even though I kept looking in the mirror and thinking, doh, my stomach's not going down, but I obviously have lost the weight, and I do feel slightly better for it.
Recognition of individual barriers to exercise and overcoming them	Psychological capability Reflective motivation	35	E2	I'm a lazy exerciser, I exercise coz I have to.
		41	E2	when I stopped working, I joined the gym that my wife went to
		54	E2	Um, I should say that about 7 or 8 years ago, I fell off a ladder and injured my back, which makes walking awkward or painful sometimes, but cycling is a doddle. I still get the aerobic workout but it doesn't hurt my back.
		64	E2	And, I don't walk as well as I used to. Although I've er gotten round it um slightly, I got myself some walking poles which I decided to try out.
Respects the role of health professionals but ultimately comes down to the choice of the individual	Reflective motivation	19	E1	, I think it's down, it's just down to the individual isn't it? You know, if you're like that and you're going to go for an operation, and you know, I think you owe it to the poor surgeon and everyone to get a lot, set a lot of that off, so it's just down to the individual. I can talk to people like you and Dr X and the other physios until the cows come home, unless an individual

				has got the motivation to do it themselves, you know, you know, it's the old "lead a horse to water, you can't make it drink".
		95	C1	you can't persuade someone to do something if they're not interested and don't really want to.
Feeling that external factors such as peer support and gym facilities are not as important as self-motivation	Reflective motivation	22	E1	**Do you think it would be better to come in to the hospital, or to go to a gym perhaps? Or Do you think being with other people would have helped you?** Maybe, maybe, you know. But it still comes down to you. You know, I mean, oh, I'm being philosophical here now.
		11	E1	Oh yeah, they were realistic, if I had the sort of nonce and will power to do them. Oh yeah, the goals were easy. Realistic. Yeah.
Felt study goals were achievable Individual responsibility to achieve goals		25	E1	I'm quite happy with the study I've done, and the support that I've been given, and the goals I've been given and once again it comes down to me as an individual to either fulfil them or not..those goals, but I was clearly told the goals, and the surgery,
Needs targets for motivation and for operation to be in jeopardy	Reflective motivation	71	E2	**And so, kind of just the final question and I want to spend some time of this because you've got a lot to say. So, um in an ideal world, what do you think would be the best method of increasing or monitoring exercise, before an operation?**Ummmm, targets. Without a doubt. Knowing that you've got to reach the target, or, the operation is in……. in jeopardy. It's got to be as tough as that I think.
Lack of self-efficacy				
Realistic i.e. low expectations of own motivation Positive insight	Reflective motivation	36	E2	And I probably do the minimum that I have to to remain mobile. I'm not that enthusiastic about it.

Lack of confidence in own ability to do more exercise Lack of willpower perceived by patient	Reflective motivation	11	E1	Oh yeah, they were realistic, if I had the sort of nonce and will power to do them. Oh yeah, the goals were easy. Realistic. Yeah.
Forgets to do exercises, lack of symptoms as demotivator to change behaviour Emphasis on satisfying needs of research team rather than own goals Study and personal goals not aligned	Psychological capability Automatic motivation	10	E1	, I wasn't very good at it, in so much as... I'd forget to do it. I really would, you know, I'd just forget to do it. Um... I don't know why, possibly because, I sort of feel fine. You know what I mean? I thought...um, I'm strong enough, you know or subconsciously thought... I'm strong enough, I don't need to do that. It just went out of my head and these poor physios, you know I thought, oh God...I can't lie to them
Self-efficacy with process of monitoring	Psychological capability	14	E1	Yeah, and that's the only thing that happened that I had to get in touch. The rest of the time, you know, I mean, I just sort of flew along on my own, quite happily.
		51	E2	But, for the most part, I got into a habit of taking it off and charging it at night. And getting dressed in the morning and put it on.
		59	E2	**Yeah. Okay. Did you use the monitoring equipment? Did you have a look at your data?** I did.
		62	E2	And that, that was very apparent in the graphs that I saw, and that was useful.
Deference to research procedures	87	87	C1	**Yes, okay, great. And so, and did you have any feelings about the random selection process?** I have no idea. I just went along with it. I did another one with, the blunt chest testing thing, I did that. So, I mean, I thought it might just be interesting to see what happens.
Other life priorities				
Incentives may come from over life events such as tickets to an event the patient does not	Reflective motivation	150	C2	But I don't want it too late, well in the most because I've got Fairford tickets and I don't want to miss that.

want to miss, and financial implications				I've spent too much money on that to miss that.
Financial worries and possible loss of income	Physical capability	139	C2	Well I don't really want to take 12 weeks, I'm definitely taking the 6 weeks off and anything else, no heaving lifting for 6 weeks and the nurse that was there, in first when I got the diagnosis was like, yeah, given the nature of your job, I'd take the 6 weeks
Incentive to be able to enjoy hobbies such as cooking by being active enough	Reflective motivation	96	C1	But, you know, as long as I don't become grossly overweight and so on, I'm…..and, I can do the things that I enjoy, I mean, I enjoy cooking for example which can be quite exhausting
Automatic motivation	Automatic motivation is motivation that involves habitual, instinctive, drive-related, and affective processes (e.g., desires and habits)			
Attitudes to exercise				
Preference for individual exercise	Automatic motivation	21	E1	**So thinking about, you know, your exercise. You've gone for walks and stuff at home. Do you think that individual exercise is the way to go?** Yes
		77	E2	I tend to exercise on my own. And when we used to go to classes to do things like yoga and pilates and stuff, which I quite enjoyed, um, I'm really a lone exerciser, I think. I go out with my wife cycling, she's very good at it, and she's my pacemaker, left to my own devices I just (laughs).
Lost interest in gym, finds it repetitive, purposeless	Automatic motivation Reflective motivation	96	C1	I mean, I went to a gym for a while, you know I quite enjoyed it, um, but then lost interest, and um, I've never regained it
		98	C1	Just the repetition ….umm, you know, I just find that, you know ro ro ro ro ro for hours on end, just utterly soul destroying, and, what's the point? I mean, yes you know you develop your muscles, and then, so what? If

				you stop for a week (laugh) all your hard work is undone
Emotive factors				
Shock of cancer diagnosis, new perspective, teachable moment	Automatic motivation Reflective motivation	2, 72, 73, 74, 152	E1	I've been hit with the shock of a, of um...prostate cancer, and um, I thought well, anything I can do a) to get me a little bit fitter, and b) to help in the future is worth doing, so...so I said yes.
		26	E1	Yeah, I'm surprised how unconcerned I am about having cancer, maybe it's because the bloke said, well it hasn't spread, so, you know you're in time, maybe it's that
		152	C2	, it was a little bit of shock but it wasn't totally a surprise because obviously I had to go back in to discuss it. But this, as I say, the main motivation for losing the weight
		73	E2	- You've got cancer written on the top and err tick boxes of the uh surgery, and I thought, why, why would you need to do that. Why do you need to….I worked it out afterwards, clearly, some people don't take it in, and they don't grasp it, until 2….weeks or 2 years later Ummm, or whatever, and that, that brought it home. And in...when it's brought home like that, that grabs your attention. There's no escaping that.
Fear of cancer spreading and death	Automatic motivation	141	C2	Yeah, coz I had a friend, died a few years back. He was younger than me and he died of testicular cancer. He obviously didn't get diagnosed soon enough.
Fear of not being able to have operation due to weight	Reflective motivation Automatic motivation	110	C2	Well it wasn't so much...I had to. I had to lose the weight for the operation. So I was, I think they weighed me in at 94 kilos.
		122		Because I wanted to lose the weight. I was desperate to lose the weight.
Worry of loss of dignity with	Reflective and automatic motivation	139	C2	No, I'm worried about the after effects of the operation maybe. Coz, I mean, since I've the

incontinence as a side effect				diagnosis and that, the urgency to pee is quite…. it can be close to embarrassing at work coz I can have a slight little dribble before you get to the toilet
Boredom associated with walking at home, would rather watch television	Automatic motivation	91	C1	In walking, I mean, obviously I …..ummmm….when you go for a walk in some lovely scenery or when you go on holiday in the Lake District for example, I mean that's, that's different, but at home, just to walk around, you know 5 minutes, 10 minutes a day I find just boring. I'd rather watch an interesting television programme or read a book (laughs), or something. Gardening's alright.
Boredom associated with diet	Automatic motivation	148	C2	Rather than anything. I find it boring with diets to be quite honest.
Reluctance to exercise, not motivated by enjoyment	Reflective motivation	35	E2	I'm a lazy exerciser, I exercise coz I have to.
		152	C2	But this, as I say, the main motivation for losing the weight, I mean, I feel better for the exercise, but I wouldn't say I was the sort of person who lives for doing a bit of exercise, and I do, I mean, I know it's a bit of a stupid thing to do. When I go out for a drink, I will walk, so it's a good half hour walk there and back, so it's a little bit of exercise
Importance of enjoyment of exercise	Automatic motivation	43	E2	Swam, and generally enjoyed it (laughs) coz that's the thing, it's gotta be enjoyable.
Enjoyment from doing exercise with television	Automatic motivation Physical opportunity	44	E2	And there's a good thing on the cross trainer, you see they've got a television, so I can watch Star Trek whilst I'm cross training (laughs).
Enjoyment from feeling of having exercised	Automatic motivation	152	C2	When I go out for a drink, I will walk, so it's a good half hour walk there and back, so it's a little bit of exercise.
		70	E2	Umm, Yes, this morning we got up at 8 o'clock and and cycled for 10kms which is something we've never done before. We

				kind of just lie in bed and watch the news or get up slowly. But I tell you what, the coffee afterwards is just….ahhh, to die for. (laughs).
Enjoyment from doing sports, standing on cricket pitch vs. gym or walking		98	C1	I like sport, because you have the satisfaction, I mean, either of losing or winning, but you had the satisfaction of pitting yourself against somebody and some point, you know. I mean standing in the cricket field all day was absolutely lovely….really nice
Feeling of exercise regime as ‘hard’	Automatic motivation	144	C2	That’s quite hard. I must admit. (laughs)
Swings in motivation depending on mood of the day	Automatic motivation	66	E2	So that’s, that’s an obstacle I suppose. The other obstacle is, somedays you just get up and you think “ahhh I canne be bothered”. Sorry, that was my Scottishness just coming in (laughs).
Guilt and shame at not meeting expectations of healthcare professionals Self blame for lack of self efficacy	Self-efficacy – lack of	10	E1	Yeah, well, I understood that I should, I should do more um, um...physical exercise, as in, you know...press ups and um, leg bends, and this that and the other. Um, yeah, they impressed that on me, and I must say, I wasn’t very good at it, in so much as... I’d forget to do it. I really would, you know, I’d just forget to do it. Um... I don’t know why, possibly because, I sort of feel fine. You know what I mean? I thought...um, I’m strong enough, you know or subconsciously thought... I’m strong enough, I don’t need to do that. It just went out of my head and these poor physios, you know I thought, oh God...I can’t lie to them.
IDENTITY				
Established identity related to weight	Automatic motivation	5	E1	I was always as, you know, as skinny as a rake all my life, and it was only when I retired I started putting weight on

Identified with a sport as his 'main game'	Reflective motivation Physical and psychological capability	89	C1	My main game, I mean, I played...ummm….cricket until the latest…..but my main game is lacrosse, which is for young men, (laughs) or young people ….umm, and so I gave that up. But at school I did everything. Absolutely everything. Ummm, everything, athletics and so on, and at university, I played tennis, and then lacrosse, and since then, with my children I've played tennis, cricket, so on.
Identity related to work	Physical capability	121	C2	You know, big oak tables. Yeah, I've been pretty physical all through my life (coughs), work-wise anyway
Pride at being able to do hard labour, heavy lifting	Physical capability Automatic motivation	120	C2	You have to work for so long for the Royal Family before you get the crest, and um yes, so that was quite an interesting job. The only thing I didn't like was the 2 days a week you had to go to London, so you had to be at the yard for 5 o'clock in the morning. That was a little bit too much, so I. But that was physical, you know some heavy stuff to move about. Some really heavy stuff.
Self-identifies as being older Age as a reason for behaviour and attitudes	Automatic motivation	79	E2	I think it's my age, I'm just a grumpy old git, aren't I?
		89	C1	My main game, I mean, I played...ummm….cricket until the latest…..but my main game is lacrosse, which is for young men, (laughs) or young people ….umm, and so I gave that up.
Being older as a demotivator for change in behaviour	Reflective motivation Physical capability	97	C1	Well I'm very old now, so it doesn't really matter all that much.
		139	C2	and I thought well it's bad enough getting older without having to deal with cancer as well so I thought, well that's not for me

Previous experience and role models for exercise	Reflective Motivation			
Existing habits of exercise and experience of physical activity	Physical capability Psychological capability	75	E2	Oh most certainly yes, um, because I've been retired now how many years, 5 years and I've been to the gym every week.
		88	C1	Ummmm…. I've always been physically active but umm……in sport.
		117	C2	over the years I haven't done much exercise, I just rely on my work
		121	C2	Yeah, I've been pretty physical all through my life (coughs), work-wise anyway
Using another person as a reference point for baseline	Reflective and automatic motivation Psychological capability	35	E2	Um, I am not, in that respect, I am not my father's son (laughs). He was, he was a person who just loved sport, and lived for it.
Comparison to father		36	E2	And up, he'd go for a 10 mile run in the morning and then referee a game of football in the afternoon, and you know, just, it's not me, I'm a lazy exerciser, I exercise coz I have to.
	Social context	38	E2	Maybe. He comes, he came from a very different background to myself.
Father as role model for individual responsibility	Automatic motivation	23	E1	You know, but my dad had a wonderful expression, he said, if you want to see the person who's responsible for most of the things that go wrong in your life, look in the mirror. Simple as that. And that's it - it's down to the individual
Comparison to daughter	Automatic motivation	92	C1	Yes, well my daughter's come to live with me now and so, she's very active and pushes me to do much more in the garden.
Comparison to those around him in hospital and societal expectations	Automatic motivation	96	C1	But there's quite a few people here in reception who are very obese, I'm mean they're really….I was quite disappointed to see them so they're not following their own rules. But, you know, as long as I don't become grossly overweight and

				so on, I'm.....and, I can do the things that I enjoy, I mean, I enjoy cooking for example which can be quite exhausting
Identifies himself as a competitive person from career and parents	Automatic motivation	93	C1	my mother and my father were both very keen and I've inherited a little bit from them
Themes related to the study				
Impact of study on exercise attitudes and behaviours	Automatic Motivation			
Good understanding of study aims and procedures	Psychological capability	32	E2	to measure pre-operative motivations and fitness, and so forth. Um, I get the impression, though, that this is the first part of a much larger piece of research that you are going to have to do compared to post-op.
		4	E1	**And, do you think that the aims of the study were made clear to you?** I think so. Yeah, yeah I think so, I mean it, it depended on I s'pose your lifestyle. It's sometimes a bit difficult to do the things they want you to do…but yeah the aims were made perfectly clear to me.
		86	C1	**Great, and do you think that that aims of the study were made clear to you? Do you know what the study was about?**
		86	C1	Yes, yes, well I think, I mean from what [Dr X] said, I did yes. You know you can physically prepare people without um, necessarily medication.
Not sure about how prehab works	Psychological capability	105	C2	**And so, do you think that the aims of the study were made clear to you?** I'm not quite sure if I read it properly. I did read through the information she gave, [Dr X]

				gave me, but, I think...I don't know if it's basically for the pre-op thing or whether it's mainly afterwards. I don't know. I'm not quite one hundred percent sure about that.
Not personally motivated by prehab in control group	Reflective motivation	87	C2	**Would you have preferred to be in the other group, do you think?** I have no idea. I just went along with it. I did another one with, the blunt chest testing thing, I did that. So, I mean, I thought it might just be interesting to see what happens
Understanding of the considerations for operative management	Psychological capability	71	E2	And, I was speaking to Mr Y (surgeon) and he was going through my sheets. Oh, you've got a heart murmur. I said no I haven't. He said, it says here you have. He said, give me your wrist, so he said, look at that, no you're right you haven't. And, it's knowing that just little things like that cumulatively can affect whether or not you go for surgery, and I don't think the general public grasp that.
Understanding of physical preparation for surgery without medication	Psychological capability	86	C1	**Great, and do you think that that aims of the study were made clear to you? Do you know what the study was about?** Yes, yes, well I think, I mean from what [Dr X] said, I did yes. You know you can physically prepare people without um, necessarily medication.
Study as a motivator to think about and do exercise	Reflective motivation Physical opportunity	82	E2	**So, is there anything else that you want to tell me about exercise, or about the study? Have you enjoyed doing it?** Um, yes, it made me think about it And that's the important thing. It made me, and that was um...ahhh…. a motivator for sure. And, maybe everyone should be encouraged to take part in it, you know, as a motivator to get going

Understanding of target of exercise intensities and interpretation the feedback	Reflective motivation Psychological capability	9	E1	Oh yeah, yeah, I looked at it and I mean, I was surprised how little I did. I thought, God, I'm sure I've done more than that, but, you know I had peaks when I went into moderate activity, and then, but most of my thing was um sort of light activity, you know, but I, I did the walks and all this sort of thing, but um, I was surprised just how inactive I was really. (laughs).
Changing frequency and intervals of exercise based on monitoring data	Psychological capability	61	E2	**So, so you think that the information that you got from the data monitoring, do you think that was useful?** Yes, because um, they spoke about doing 10 mins every now and again, whereas I was spending a lot of time slumped in a chair. When I wasn't, um I was lumping the exercise together, when I should have been spacing it out. And that, that was very apparent in the graphs that I saw, and that was useful.
New exercise habits Starting cycling	Reflective and automatic motivation	53	E2	Apart from doing a brisk 10 minute walk, um, as often as I could. Um, and I kind of…… (laughs) I decided not to do that, and didn't tell them…….but took up cycling instead, because I prefer that.
		70	E2	Umm, Yes, this morning we got up at 8 o'clock and and cycled for 10kms which is something we've never done before. We kind of just lie in bed and watch the news or get up slowly. But I tell you what, the coffee afterwards is just….ahhh, to die for. (laughs).
Positive attitude to continuing exercise beyond operative period	Reflective and automatic motivation	18	E1	the walks have been very pleasant. **And is that something that you think that you would continue to do?** Yeah, yeah, why not? Why not. Yeah definitely. Definitely.

		76	E2	**I think the surgery has to be a motivator. What about after the surgery. So, thinking about now, you're obviously really fit, you've been to the gym, you do a lot, you've added in cycling, will you continue to do that do you think?** Oh most certainly yes, um, because I've been retired now how many years, 5 years and I've been to the gym every week. , oh I've been doing that, and I will certainly be doing my best to rehabilitate myself after the uh surgery.
		127	C2	**Okay, and so now that you've lost the weight and you're in this waiting phase do you think you still have the motivation to exercise?** Oh yeah, definitely, because I don't want to put the weight back on, so I haven't done as much, but there again, I had a week off, and the following week I went back to work and I didn't pick at all so I did, I think I got 4 nights in that week, 4 sessions in that week.
Phone calls from physiotherapist helped to refocus	Social opportunity Reflective motivation	15	E1	**Okay, and did the weekly phone calls, what, did they help?** Yeah, they tended to refocus me a little bit yeah, certainly tended to refocus me.
Did not feel value in physiotherapist recommendations in the study as previously active	Psychological capability Individually tailored activity	52	E2	I was fairly active anyway and there wasn't much they could recommend.
Motivation to participate in study	Reflective Motivation			
Wants to help with research to help others as motivation	Reflective Motivation	2	E1	I've been hit with the shock of a, of um...prostate cancer, and um, I thought well, anything I can do a) to get me a little bit fitter, and b) to help in the future is worth doing, so...so I said yes.
		27	E2	because, I like research.

				just loved it so much, I could have done research for the rest of my life.
		84	E2	Yeah, well all of these things are really interesting because they will be fed back, so you know, taking part in research is about setting up the future, helping other people as well, and so, you know, all of that's really valuable.
Sees themselves as an active participant and contributor to research	Reflective motivation Social opportunity	85	C1	I think by nature, I'm co-operative, and if I can help, I'll help. You know, I've seen other people treated and if it can make it easier or more efficient for them….
Help others through research – control group	Reflective motivation Social opportunity	103	C1	I mean I feel that what I'm doing with you is more for other people in the future than myself, but that's, that's okay.
Education as a motivator, previous experience of having students involved in his care	Reflective motivation	104, 108	C2	…….I think these sort of programmes and that, will help, and if it helps teach them, then why not? You know. That was my main motivation. I was quite happy to do this.
Motivation related to diagnosis and operation	Reflective motivation	2	E1	I've been hit with the shock of a, of um...prostate cancer, and um, I thought well, anything I can do a) to get me a little bit fitter, and b) to help in the future is worth doing, so...so I said yes.
Motivation related to operation Operation as a target	Reflective motivation	71,	E2	Ummmm, targets. Without a doubt. Knowing that you've got to reach the target, or, the operation is in……. in jeopardy. It's got to be as tough as that I think.
		104	C2	**And the first question is…..could you tell me a bit about your motivation for taking part in the study?** Well, mainly, it was because of the operation
Motivation related to weight loss for the operation	Reflective motivation	110	C2	**Okay, and so tell me why you decided to do that?** Well it wasn't so much...I had to. I had to lose the weight for the

				operation. So I was, I think they weighed me in at 94 kilos.
		125	C2	But I was worried that if, because the previous appointment he said that if I didn't haven't lost the weight by then, they might think about doing another MRI, another biopsy and I don't want to go through all that again. I'm not worried about the MRI, but the biopsy is uncomfortable, and you have to rely on somebody to take you home.
		129	C2	**And, do you think that if you didn't have the motivation to lose weight that you would still go to the gym.** No probably not. I probably wouldn't have done, If there was no motivation there, I probably wouldn't have done the gym. I'll be honest.
		133	C2	**Okay, so do you think, why do you think that you need to lose weight for the operation why do you think that the role of physical exercise is?** Well he obviously explained to me that is obviously cuts the, it can um, improve the er recovery time. And obviously there's less of the chance of heart attack and stroke.
		142	C2	I'm worried about the after effects, but other people have coped, so I think I can do it and I feel a bit more determined now, especially with doing the gym and that, I think that's given me more motivation than anything.
		152	C2	But this, as I say, the main motivation for losing the weight, I mean, I feel better for the exercise, but I wouldn't say I was the sort of person who lives for doing a bit of exercise,
Enablers during the study				
Good understanding of study aims and	Psychological capability	32	E2	to measure pre-operative motivations and fitness, and so forth.

procedures and concept of prehab				Um, I get the impression, though, that this is the first part of a much larger piece of research that you are going to have to do compared to post-op.
	Psychological capability	71	E2	And, it's knowing that just little things like that cumulatively can affect whether or not you go for surgery, and I don't think the general public grasp that.
	Psychological capability	86	C1	**Great, and do you think that that aims of the study were made clear to you? Do you know what the study was about?** Yes, yes, well I think, I mean from what [Dr X] said, I did yes. You know you can physically prepare people without um, necessarily medication.
		132	C2	**Okay, so do you think, why do you think that you need to lose weight for the operation why do you think that the role of physical exercise is?** Well he obviously explained to me that is obviously cuts the, it can um, improve the er recovery time. And obviously there's less of the chance of heart attack and stroke.
Realistic goal setting	Reflective motivation	11	E1	**So did you think the goals they set for you were realistic?** Oh yeah, they were realistic, if I had the sort of nonce and will power to do them. Oh yeah, the goals were easy. Realistic. Yeah.
Clear aims of study	Psychological capability	3	E1	I think so. Yeah, yeah I think so, I mean it, it depended on I s'pose your lifestyle. It's sometimes a bit difficult to do the things they want you to do…but yeah the aims were made perfectly clear to me.
Support from study staff	Social opportunity	12	E1	Dr X emailed me and this sort of thing, yeah, which was good but and I knew that if I had an issue I could get in touch with her and

				she would come back with the answer
		84	E2	. The staff have been unbelievably helpful and sympathetic. Um, they really have been really really helpful. Um, and everything has happened really quickly
Phone calls from physiotherapist helped to refocus	Social opportunity	15	E1	Yeah, they tended to refocus me a little bit yeah, certainly tended to refocus Well, you need to get up a bit more"... and all that, but, you know, I didn't really do that.
Collaborative decision making with study team for preference of exercise	Psychological capability Reflective motivation	56	E2	did yes, when there was a phone interview with [Dr X] and the 2 physios, and I told them there, that I was taking up cycling. They were very pleased about that.
Positive emotion associated with intervention	Automatic motivation	14	E1	I mean, I just sort of flew along on my own, quite happily.
		17	E1	the walks have been very pleasant.
		70	E2	Yes, this morning we got up at 8 o'clock and and cycled for 10kms which is something we've never done before. We kind of just lie in bed and watch the news or get up slowly. But I tell you what, the coffee afterwards is just....ahhh, to die for. (laughs).
Demotivating factors and barriers in study				
Difficulty getting to hospital due to traffic	Physical capability	106	C2	, all I could think about was getting the appointment done and getting out of there before I hit the traffic, but unfortunately that didn't work
Dealing with multiple interactions in one appointment	Physical capability Social opportunity	107	C2	I was going for my pre-op that day...and in fact, I got approached by another doctor to do another research thing,
Patient dealing with making multiple decisions and interaction with different health professionals in	Psychological capability	69	E2	. I've been to see my GP. I'm kind of balancing whether or not it's, whether the side effects are worth the fewer visits to the bathroom at night, so um....the

managing symptoms and cancer				er….the jury's out on that for the moment
Mental burden of organising routine to fit in exercise	Physical capability	130	C2	But I shall cut it back down to 2 nights a week I expect. Because it can be a bit of a pain getting home at gone midnight all the time, rather than being home at 20 to 11.
Annoyance of not having had operation yet, when weight loss was the motivator to exercise linked to having surgery	Reflective motivation	126	C2	So, the motivation was obviously to lose the weight, and I eventually got there, but now I'm annoyed because I am still waiting to get the operation.
Delay in operation a demotivator as already lost weight Impact of NHS pressures and waiting times to deliver 'incentive' after exercise of having surgery	Reflective motivation	149	C2	I'm in limbo now. I've reached the weight target, and now I'm still waiting for the operation. But I know the NHS is under pressure, I know it is, but it just... a lot of people say ooooh I'd be on the phone everyday, well there's no point in ringing every day, and I just want it done as soon as really.
Short term goal until operation, may be difficult to maintain afterwards when that motivator is gone	Reflective motivation	130	C2	**Okay, but now when the motivation goes away, once you've had your operation….** I am still gonna try and do at least 2 nights a week if I can, just to keep the weight to a, you know.
		131	C2	**Okay, and so your motivation is maintaining weight?** Yeah, well, obviously it's helped the physical And if it's good for my cardiovascular then that's what I shall do. But I shall cut it back down to 2 nights a week I expect
Boredom as a demotivator	Automatic motivation	91	C1	In walking, I mean, obviously I …..ummmm….when you go for a walk in some lovely scenery or when you go on holiday in the Lake District for example, I mean that's, that's different, but at home, just to walk around, you know 5 minutes, 10 minutes a day I find just boring. I'd rather

				watch an interesting television programme or read a book (laughs), or something. Gardening's alright.
Sleep quality as a factor for capability to do exercise, significant in urology patients with urinary symptoms	Physical capability	67	E2	**What's the difference between those days and the days where you think, actually, I can do it today?** Umm, I've no idea, just your demeanor on the day, I suppose. And, perhaps if I've um slept, or not. And that's a big thing for me, because I have an enlarged prostate which means I sometimes get up a lot, and don't sleep as well as I could do.
Data from monitor not relating to real life activity as perceived by patient, trying to explain the monitoring data	Psychological capability Reflective motivation	60	E2	But conversely on 2 days in a weekend, were sort of, really hot and I thought, (whispers) I'm not gonna do anything, and I really didn't do very much for those 2 days, but it came up as quite active on the charts And um, the physios thought that was my heart coping with the heat. Maybe temperature is a big variable.
Previous back operation, wary of injury with activity	Physical capability	55, 63, 112, 145, 151		
Fear associated with time spent exercising and leaving other responsibilities Difficulty with time, doing exercise after work and getting home not too late	Reflective motivation Social opportunity	16	E1	I don't tend to go out for really long periods, because of [wife], you know because at home, if she gets up out of the wheelchair to do something sort of thing, she's really unsteady and I don't want her falling over.
Admits they do not enjoy exercise and they have to do it	Reflective motivation	36, 152		
Activity Monitoring				
Easy to use monitoring equipment	Physical capability Psychological capability	8, 14, 51, 135, 136	E1	Well, no problem at all. You know, once you've got it on, the thing, and then you put your shirt on and you forget it's on. You literally forget it's on there. And then, just at night, you know, you, you put the little

				monitor here, near the...near the bigger thing, and then plug the little monitor in, coz the big one's been plugged in all day, and that was it. So it... it was easy. I didn't notice it at all.
		14	E1	The rest of the time, you know, I mean, I just sort of flew along on my own, quite happily.
		51	E2	But, for the most part, I got into a habit of taking it off and charging it at night. And getting dressed in the morning and put it on. Yes, that is the trick, to make it part of your routine.
		135		**Okay, and so um the last question is about your experience of using the monitoring equipment, so the monitoring equipment that Helen gave you. How did you find it?** Well not a problem really. No. None at all. Apart from the second time I tried it, I think I damaged it at work It didn't restrict me in any way. But I didn't have a problem wearing it.
Difficulties with monitoring equipment, discomfort and technical issues	Physical capability Automatic motivation	13	E1	large monitor seemed to have a peculiar thing flashing on and off. It was 2 arrows going up and down and a cross by it, sort of thing (okay) and I phoned Dr X up, and she said, oh, it's, it's run out of um credit So, so they had to put more credit on, and then that stopped. Yeah, and that's the only thing that happened that I had to get in touch.
		47	E2	It took a couple of days to get used to it,
Discomfort		47	E2	I got some irritation to start with.
		48	E2	But that soon wore off and the hub thing stopped working after a while, so [Dr X] had to come

				out to me and collect the thing and give me a new uh, monitor.
Hub not working		49	E2	she couldn't get the hub to work. We live in the middle of nowhere (laughs) The reception is very bad in our village.
Forget to put monitor on		51	E2	. I did forget to put it on once, so, there's a 3 hour gap this week, when I thought I had it on, but I didn't.
Difficult to use Boring process		101	C1	Yup. Well, It's just fiddly. A bit boring. I mean I didn't really know what the point of it was. I just did what [Dr X] told me. And um, there was no problem. But, um, I'm glad it was only 4 days (laughs).
		102	C1	**Was it comfortable to wear?**
Discomfort		102	C1	Not really, no. No, A bit tight. And I think it was a bit too tight, the one that I had on. But, it's okay.
Monitor not working Fear of damaging device during work		135	C2	Apart from the second time I tried it, I think I damaged it at work, because the work I was doing, like um, I was on a reacher I got home and I thought, err the lights not flashing and I went to put it on charge and nothing happened, no blue came on and I thought, oooh, so I had to ring up [Dr X] and get her, she came round with another one. So um yeah I think I got one days worth of data out of that, but then I obviously damaged it, I think. But I didn't have a problem wearing it
Discomfort		136	C2	I wouldn't say it was comfortable. It irritated a bit because of the plastic strap, you know, where the monitor fits, that irritated a little bit.
Feedback from activity monitor interesting, new information for	Psychological capability Reflective motivation	59	E2	**Yeah. Okay. Did you use the monitoring equipment? Did you have a look at your data?**

patient on sedentary time		59	E2	I did. the first week, [Dr X] sent me the results which were quite interesting. I was staggered to see how much time I spent sitting around. I was staggered to see how much time I spent sitting around. That was really quite a shock. How much time I'm slumped in a chair, or not doing anything especially vigorous. I really didn't do very much for those 2 days, but it came up as quite active on the charts
		9	E1	, I was surprised how little I did. I thought, God, I'm sure I've done more than that I was surprised just how inactive I was really.
Awareness physical activity will show up on monitor	Automatic motivator Psychological capability	9	E1	**And um did you, did you look at the data?** Oh yeah, yeah, I looked at it and I mean, I was surprised how little I did. I thought, God, I'm sure I've done more than that, but, you know I had peaks when I went into moderate activity, and then, but most of my thing was um sort of light activity, you know, but I, I did the walks and all this sort of thing, but um, I was surprised just how inactive I was really.
		16	E1	times I've been conscious, and you know and I've thought, yeah well this will show up on the monitor
		138	C2	Yeah, well I wore it several times when I did the gym, So she obviously got a bit more information off that one.
Self-efficacy with process of monitoring	Physical capability	14	E1	I just sort of flew along on my own, quite happily.
Made part of routine		48	E2	I got into a habit of taking it off and charging it at night. And getting dressed in the morning and put it on.

Interpreting data	Psychological capability Automatic motivation	59	E2	But conversely on 2 days in a weekend, were sort of, really hot and I thought, (whispers) I'm not gonna do anything, and I really didn't do very much for those 2 days, but it came up as quite active on the charts.
Usefulness of visual feedback for baseline activity but not over time Using feedback to increase regularity of exercise, doing own problem solving	Self-efficacy Psychological capability Reflective motivation	62	E2	they spoke about doing 10 mins every now and again, whereas I was spending a lot of time slumped in a chair. When I wasn't, um I was lumping the exercise together, when I should have been spacing it out And that, that was very apparent in the graphs that I saw, and that was useful. Um, I printed out the first lot. I had a look at, I don't know, the second, the third week and didn't do a lot of comparison.
Control group patient did not have access to own data so not influenced by presence of monitoring, importance of visual feedback		137	C2	**And do you know what it was monitoring?**
Not understanding what the monitor was measuring		137	C2	I think, well as far as I know it was just heart rate, but I think it may have been a few other things as well. But I can't remember what she said. (laughs)
Ways intervention could be improved				
Feedback on effectiveness of exercise – could be improved to educate patients how exercise is benefitting them and how to know if exerting at right level	Psychological capability Reflective motivation Social opportunity	116	C2	**And did you notice, apart from the weight loss which was obviously your goal, were there any other benefits? Did you feel any different?** I know it's good for the cardiovascular bit, and I feel better for that, I must admit. And, I don't get breathless. You know I sweat a lot on the bike, but I don't feel breathless at the end of it, or anything like that.

Realisation takes a long time to lose weight through exercise, risk of demotivation, could be helped with more support and education to achieve own weight loss goals		143	C2	, it had to be done, even though I kept looking in the mirror and thinking, doh, my stomach's not going down, but I obviously have lost the weight, and I do feel slightly better for it.
Short term goal until operation, may be difficult to maintain afterwards when that motivator is gone	130, 131	130		**And, do you think that if you didn't have the motivation to lose weight that you would still go to the gym** No probably not. I probably wouldn't have done, If there was no motivation there, I probably wouldn't have done the gym. I'll be honest. **Okay, but now when the motivation goes away, once you've had your operation….** I am still gonna try and do at least 2 nights a week if I can, just to keep the weight to a, you know.
				Okay, and so your motivation is maintaining weight?
Failure of individual tailoring to patient as patient decided on own exercise plan	Physical capability Automatic motivation	10	E1	I sort of feel fine. You know what I mean? I thought...um, I'm strong enough, you know or subconsciously thought... I'm strong enough, I don't need to do that. It just went out of my head and these poor physios, you know I thought, oh God...I can't lie to them
Exercise not aligned with baseline fitness and capability	Physical capability Reflective motivation	53	E2	Um, well……. Oh yes, for sure. I was fairly active anyway and there wasn't much they could recommend. Apart from doing a brisk 10 minute walk, um, as often as I could. Um, and I kind of…… (laughs) I decided not to do that, and didn't tell them…….but took up

				cycling instead, because I prefer that.
		56	E2	I did yes, when there was a phone interview with [Dr X] and the 2 physios, and I told them there, that I was taking up cycling. They were very pleased about that.
Supervision using telephone calls from study physiotherapists not that useful, no meaningful advice	Social opportunity Psychological capability	58	E2	I don't know if they were helpful. They might have been helpful to the physios. I've no idea. Um I don't know that they were particularly helpful to me in any way, other than to say, I'm not doing a lot of walking, but I've taken up cycling.
Feeling that follow up was for technical issues rather than emotional support	Social opportunity Automatic motivation	12	E1	Dr X emailed me and this sort of thing, yeah, which was good but and I knew that if I had an issue I could get in touch with her and she would come back with the answer,
Fear of not meeting study expectations	Automatic motivation	10	E1	these poor physios, you know I thought, oh God...I can't lie to them
Exercising to meet expectations of clinical team as an obligation	Reflective motivation Social opportunity	19	E1	I think you owe it to the poor surgeon and everyone to get a lot, set a lot of that off, so it's just down to the individual.
Not understanding what the monitor was measuring	Psychological capability	137	C2	I think, well as far as I know it was just heart rate, but I think it may have been a few other things as well. But I can't remember what she said. (laughs)
Difficulties with monitoring equipment, discomfort and technical issues				
Data from monitor not relating to real life activity as perceived by patient, trying to explain the monitoring data	Psychological capability Reflective motivation	60	E2	But conversely on 2 days in a weekend, were sort of, really hot and I thought, (whispers) I'm not gonna do anything, and I really didn't do very much for those 2 days, but it came up as quite active on the charts. And um, the physios thought that was my heart coping with

				the heat. Maybe temperature is a big variable.

F. Thematic analysis of the qualitative data relevant to the COM-B model of behaviour change

Self-identity

A major theme that ran through the interviews was self-identity, expressed as the participants' roles and experiences at work and at home. Although they were not asked directly about their current or previous employment, or how work or retirement affected their views on physical activity, all of the participants chose to discuss exercise in relation to these roles. Included in the theme of self-identity, were the participants views on their own characteristics, including how they felt about their weight and age, and how what they judged to be their own degree of motivation and effectiveness, or self-efficacy for doing exercise.

Their identity related to work came through in all four interviews. They expressed pride at their previous or current work, and their attitudes to exercise also stemmed from their occupation. C2 talked of always having had a physical job, and therefore he was used to the more intense level of activity he was now doing at the gym to try and lose weight before his operation.

> 'over the years I haven't done much exercise, I just rely on my work.' (C2, 117)

For E1 who had retired, no longer being active in his job meant that retirement had a big impact on his fitness, and also his weight. Retirement had come with a loss in identity from the previous physically active working man who was thin.

> 'I've been physically active all my life. I stopped being physically active really when I retired.' (E1,5)

E2 was also retired but previously had a sedentary job and so took retirement as a opportunity to be more active.

> ‘at work I used to sit in front of a computer screen most of the time… when I retired I thought, there wasn’t enough in the garden to give me the full exercise I needed so I went off and saw the instructor and got a series of exercises to do…I’ve been retired now…5 years and I’ve been to the gym every week.’ (E2, 46,75)

For participant, C1, his previous work also influenced his attitude to exercise indirectly. He had an academic career and therefore placed importance on activities which were interesting to him, and this also meant that exercise should be, in his view, with specific purpose and only enjoyable if competitive.

> ‘I went to a gym for a while, I quite enjoyed it but then lost interest… just the repetition…row row row for hours on end…just utterly soul destroying…I find…independent activity by itself a bit pointless…I’d play cricket or tennis…there’s a point in it. I mean, you’re trying to win.’ (C1, 96-100)

The experience of physical activity in relation to work and their self-identity at work may influence their reflective motivation for exercise and physical capability. This suggests that in establishing baseline exercise capability and attitudes to exercise, participants should be asked about work related physical activity as well as recreational exercise experience. The impact of retirement, if relevant, should also be explored, as this may influence their self-efficacy and physical capability, if they feel retirement has reduced or increased their ability and motivation to do exercise.

In addition to work identity, the participants would mention other life priorities and events. These other life priorities would then be related to the competing priorities of their cancer diagnosis, operation and preoperative exercise regime. Other life priorities are therefore an important influence on physical opportunity, mainly time, and reflective motivation. E1 was a carer for his wife, and this limited his time available to go for long walks. C2 was still employed and was therefore, mainly concerned about the impact of the side effects of the operation on his ability to work comfortably. C1 was concerned that if he became too overweight it may mean he cannot do the things he enjoys which take physical effort such as cooking. Although all the participants did discuss the impact of the cancer diagnosis and their thoughts on treatment, they also emphasised the importance of other priorities and health issues, such as the impact of urinary symptoms on sleep, the ability to work after the operation and prebooked events which they did not want to miss out on if the operation was delayed.

Thoughts on weight and ageing and how this influenced their self-identity were also raised by the participants without prompting by the interviewer. E1 and C1 both discussed the importance of not being overweight and identified themselves in relation to a change in their own weight, or the weight of others.

> I'm overweight. I've been trying to do something about it… I was always as skinny as a rake all my life, and it was only when I retired I started putting weight on.' (E1, 1-5)

> 'there's quite a few people here in reception who are very obese.. I was quite disappointed to see them….as long as I don't become grossly overweight so I can do the things I enjoy.' (C1, 96)

Three of the participants also made a point of highlighting their status as an older person, with suggestions this automatically would point towards certain behaviours.

> 'I think its my age, I'm just a grump old git aren't I?' (E2,79)

> 'my main game is lacrosse which is for young people…so I gave that up.' (C1, 81)

These beliefs on ageing and weight may influence exercise behaviour as part of social opportunity and automatic motivation. Social norms and stigma around ageing and weight provide a reference point for patients to judge themselves. This may provide positive automatic motivation if they feel societal pressure to not be overweight, or negative automatic motivation if they feel older people should not be exercising.

The themes discussed around identity also relate to the theme of self-efficacy, or the their own perceived ability to be able achieve the behaviour of doing more exercise. Their degree of perceived self-motivation or self-efficacy is closely related to the theme of their ‘experience of exercise’. Self-efficacy for the behaviour change of doing more exercise, as can be expected, is greater in those who already had exercise habits. However, their own perception of how motivated, or optimistic they are about being able to achieve the goals of exercise prehabilitation is an important factor to consider for behavioural change techniques. For E1 and C1, this was linked to a core belief that the responsibility for being fit for surgery is ‘down to the individual’ (E1,19), and the individual must have the motivation and willpower to do the exercise. This was felt to be the most important factor, regardless of any other facilitating factors such as peer support, education or access to gyms.

> ‘unless an individual has got the motivation to do it themselves…it’s the old lead a horse to water, you can’t make it drink’ (E1,19)

> ‘you can’t persuade someone to do something if they’re not interested and don’t really want to’ (C1,95)

The way in which the participants described their own actions revealed their level of self-efficacy and optimism. E2 had a high level of self-efficacy revealed by his confidence with his own ability to plan and do exercise.

> ‘I will certainly be doing my best to rehabilitate myself after the surgery… I don’t see that as a problem, because I am reasonably fit beforehand and I want to maintain that’

On the other hand, E1 consistently referred to himself as being the main barrier to achieving his exercise goals.

> I'm quite happy…with the goals I've been given…once again it comes down to me as an individual to either fulfil them or not' (E1, 25)

His lower self-efficacy was also reflected in his motivation being directed at fulfilling the expectations of the surgeon and the study – 'you owe it to the poor surgeon and everyone' (E1,19) - rather than his own goals.

The theme of self-identity and its related sub-themes of work identity, views on weight and ageing and degree of self-efficacy link to the motivation and opportunity aspects of the COM-B behaviour change model. Where relevant, the impact of retirement may be a strong influence on a participant's physical opportunity for physical activity. Their previous employment and current roles may influence their underlying reflective motivations, which may manifest as concerns of weight gain with retirement and being less active, or a renewed determination to take up more exercise. Patients' attitudes to age may affect their physical and social opportunity, to do activities they may consider as not suitable for older people. Core beliefs on individual responsibility and how a participant perceives their own degree of self-efficacy will impact on their reflective motivation for exercise and the ability to adhere to exercise prescription. Those with a high level of belief in individual responsibility but low self-efficacy and capability and opportunity may become easily demotivated during exercise intervention and be less likely to engage with support.

Experience of exercise

All participants were directly asked about their history of and relationship to exercise. Although objective measures such as baseline activity level measured with the accelerometer or an activity questionnaire can give an impression of how active they are, the details discussed in the interviews provided more insight into their attitudes to exercise as shaped by their previous experience of exercise.

Previous experience of exercise is a determinant of baseline physical capability. As already discussed for the theme of self-efficacy, those participants who were already in the habit of going to the gym or formulating their own exercise plans expressed greater enjoyment of exercise and willingness to adhere to prescribed exercise. E2 had previously adapted to being retired and not having the facilities to exercise at home, to finding an instructor and going to the gym. This enabled him to decide to start cycling because this was easier with his previous back injury, although this was not part of his prescribed exercise in the study.

> ‘I didn’t tell them (the physiotherapists)…but took up cycling instead because I prefer that. I still get the aerobic workout but it doesn’t hurt my back’ (E2,53)

Three participants discussed the influence of other people, who were not healthcare professionals, on their attitude to exercise. Two participants E1 and E2 mentioned their fathers’ attitude to exercise. E2 felt he was comparatively ‘lazy’ compared to his father who ‘just loved sport’ and E1 attributed ‘inheriting’ his attitude of competitiveness to his parents. C1 mentions the influence of his daughter

> ‘my daughter’s come to live with me now…she’s very active and pushes me to do much more in the garden.’ (C1, 92)

Positive and negative associations with exercise, and how a patient compares their own activity level to others, are important considerations for how they assess their own physical capability and their understanding, or psychological capability of what constitutes exercise. They may be striving to reach the expectations or previous achievement of exercise ‘role models’ that they know, which may increase or decrease motivation to do exercise based on their capabilities in comparison.

As well as discussing their reflective motivations for exercise, including not wishing to be overweight, or replacing exercise that used to be part of work, all participants discussed their emotional responses to exercise. C1 emphasised that exercise that was not competitive sport ‘bored’ him and that repetitive exercises at the gym were ‘soul destroying’ which meant he lost interest in the gym even though it was enjoyable. This is linked to his attitude to exercise as a sport, which he attributes to his parents’ influence and his academic background which priorities activities ‘with purpose’. On the other hand, E2 emphasised that exercise has to be ‘enjoyable’ and has found ways to make it enjoyable through trying a range of activities, exercising with his wife and watching TV whilst exercising at the gym.

Neither of the intervention arm participants described their exercise regime as difficult and none of the participants emphasised the physical labour of exercise as a demotivating factor. This suggests that the aspects of exercise which participants may find enjoyable or boring are highly specific to the experiences of the individual and their previous emotional responses to different types of exercise. This is important to consider for using automatic motivation as part of behaviour change technique.

When discussing their previous experiences of exercise, the extent of each participant’s psychological capability in terms of understanding what is effective exercise was revealed. Unsupervised home exercise intervention relies on a certain extent to participants being able to evaluate their own progress. None of the patients mentioned using objective measures to measure the amount of exercise they were doing, other than setting amount of time spent they spent doing exercise. They evaluated the work done based on how they felt. C2 gauged the effectiveness of his exercise based on how much weight he had lost and the sweating as a result of exercise, which was similar to his description of his physical job.

> ‘ I don’t know if I felt fitter… I know its good for the cardiovascular bit and I feel better for that… I sweat a lot on the bike but I don’t feel breathless at the end of it.
>
> You had to clean out the mixer… I used to sweat like hell doing that’ (C2, 118)

However, as C2 was only motivated by weight, he expressed disappointment when he felt he did not look thinner in the mirror and suggests a lack of understanding of assessing progress when exercising. The way in which patients evaluate their own exercise efforts, as part of psychological capability, can affect their motivation to undertake an exercise intervention and alter their behaviours whilst doing exercise. Patients may mistakenly believe they are exercising effectively or not based on previous experience of how they felt doing exercise if they are not used to using objective measures such as heart rate or calories burned.

Purpose of exercise

The purpose of exercise for prehabilitation was explained to all the participants, however, the purpose or goal of exercise as perceived by each participant had a wider remit than prehabilitation. Although each participant recognised the importance of fitness for health and the operation, other goals of exercise were also discussed. As previously mentioned, C1 repeatedly talked about the purpose of exercise being for competitive sport in order to 'have a point'. E2 emphasised the importance of exercise being 'enjoyable'. However, E1 and C2 were both strongly motivated by weight loss, and C1 also discussed his desire to not be able overweight. E2 states that his weight is not a problem, when discussing the motivation for prehabilitation, linking weight to his operation, although this was not an aspect of prehabilitation that was emphasised to the participants. E1 discussed the social stigma of being overweight, and the importance to him of not being overweight as he was previously 'skinny'.

> 'I'm overweight. I've been trying to do something about it.' (E1,1)

> 'I come from a generation where…you were told…you're too fat.' (E1,20)

Whereas C2 was motivated by fear of delaying or not being able to have his cancer surgery, rather than a personal desire to not be overweight.

> 'I had to lose the weight for the operation….if there was no motivation there I probably wouldn't have done the gym.' (C2, 122)

> 'I was worried…he said if I haven't lost the weight by then, they might think about doing another MRI, another biopsy and I don't want to go through all that again' (C2, 125)

Therefore, motivation to exercise for weight loss may be due to a number of reasons, and amongst these participants, only one gave a positive reason to be able to do the things he enjoyed which would be difficult if he was 'grossly overweight'. The other two participants were driven by a degree of fear and social embarrassment. For certain participants it is likely weight loss can be strong factor when considering reflective motivation for prehabilitation, and this can be used to help motivate patients for behaviour change. However, this has to be balanced with the disadvantage that losing weight is hard to do during the time frame of prehabilitation, and change in diet is also required. As discussed for psychological capability, a lack of understanding of how diet, exercise and weight loss work together and the time frame needed to achieve this can lead to demotivation and worry, as was the case for participant C2.

Prehabilitation context

As can be expected, the recent diagnosis of cancer and the expectations for the operation were preoccupations for the participants. The diagnosis of cancer was stated explicitly as a reflective motivator for two participants to think about fitness and change their exercise behaviours.

> ‘its pretty poor really (when asked about exercise history) until I got diagnosed with cancer then I asked to join the gym at work’ (C2, 109)

> ‘that (the diagnosis of cancer) brought it home… that grabs your attention…and maybe that is the time when you are looking at the surgery option to say provided you can maintain this level of fitness…’ (E2, 74)

C2 also describes the additive affect to motivation from going to gym, which was originally motivated by the operation in order to lose weight, but which has also increased his sense of self-efficacy to be able to cope with the side effects of the operation.

> ‘I’m worried about the after effects but other people have coped, so I think I can do it and I feel a bit more determined now, especially with doing the gym, I think that’s given me more motivation than anything’. (C2, 142)

Aside from participant C2 who had a specific instruction from the surgeon to lose weight with the understanding the operation may not happen otherwise, the other participants revealed competing and sometimes conflicting thought processes as to the benefits of prehabilitation and their motivations for exercising in this period. E1 expressed conflicting thought processes of wishing to follow the prescribed exercise regime but also feeling that the exercise was not beneficial to him as he already felt ‘strong enough’.

> ‘I’d just forget to do it (the exercises)… I don’t know why, possibly because I sort of feel fine… subconsciously thought… I’m strong enough, I don’t need to do that. I just went out of my head…’ (E1, 10)

In contrast to C2, participant E2 did not attribute any motivation to exercise to his impending operation, as the option for surgery was never in jeopardy and he already felt he had a good level of fitness.

> 'my BMI is such that its not a problem… that wasn't a motivator me…it was an option right at the start, surgery or radiology. It wasn't a case of surgery if you can get to this level of fitness' (E2, 71)

These comments suggest that efforts to inform the patient about the benefits of prehabilitation may work in conflict with their existing knowledge and beliefs about the purpose of exercise and how fit they feel they are. Patients that self-identify as feeling strong or fit or not overweight at baseline, may not perceive the messages of the benefits of prehabilitation as being relevant to them. This relates to risk perception as a factor in reflective motivation for exercise behaviours. Although, efforts to improve psychological capability by educating patients about the benefits of prehabilitation may motivate them to exercise, their own cost benefit analysis based on their risk perception may decrease reflective motivation.

Patients' views on the impact of their cancer diagnosis can also be seen to affect their attitude to preoperative exercise intervention. The participants who discussed their cancer diagnosis emphasised their relief at the cancer having been diagnosed and confidence that it would be treated. Aside from participant C2 who made a direct link between baseline health status and the impact of side effects after the operation, the other participants did not dwell on outcomes from the operation as a motivator for improving fitness, despite saying that the diagnosis of cancer made them think about their exercise behaviours.

> 'I'm surprised how unconcerned I am about having cancer… because the bloke said well it hasn't spread so you know you're in time, maybe if he started mentioning chemotherapy…I'd have a different attitude.' (E1, 26)

E2 described the disconnect between healthcare professionals who were preoccupied with the cancer diagnosis and the operation, and his own view of the life issues that were important to him.

> ‘because the operation and everything is all about cancer. And I was taking a wider view, about my life and my sleep patterns’ (E2, 83)

The participants in this study reveal that the way they think about exercise in context of the operation is grounded in their judgments about their own health status and the extent to which they feel concern regarding their symptoms and the forthcoming operation. Participants who do not suffer from worrying symptoms of their cancer, or are reassured that their operation is not high risk, may not benefit from the psychological capability offered by educating them about prehabilitation.. The emotional reaction to a cancer diagnosis is often thought to be an important automatic motivator for behaviour change before cancer surgery. However, as the comments from these participants show, this emotional reaction is not always predictable and may not be a useful motivator for exercise behaviours.

Barriers to exercise

In addition to the barriers to successful exercise intervention as discussed in the previous section on participant feedback on the study procedures, more general barriers to exercise were identified from the patient interviews. The themes related to barriers to exercise fell under two categories. The first was related to physical capability, and restrictions on the ability to exercise due to other health conditions. The other category is the previous experience and relationship the participants had with healthcare professionals, and how this may influence their behaviour during prehabilitation.

Two participants mentioned the existence of physical limitations to exercise due to back problems and one also complained of sleep disturbance due to urinary symptoms. All participants mentioned their previous interactions with health professionals, including take advice from the clinical team as well as their wider network including family and acquaintances. These interactions are usually beneficial and motivational as part of social opportunity, with participants taking encouragement from their network to exercise more, or to be able to exercise with their partner. However, for those who had negative or unsatisfactory experiences with healthcare professionals this could present a barrier to receiving support from the clinical team as part of prehabilitation. Both C2 and E2 volunteered previous experiences with healthcare professionals that they found unsatisfactory, and led to the feeling of not being fully supported or being able to rely on healthcare professionals.

> ‘I dodged a bullet there…it was only because of that video, you know no-one called me in to say you need your prostate checked. So I think it’s a bit of an omission in the GPs sort of practice’ (E1,24)

> ‘I went to the GP several times…and they had a book (about dieting)…you can get it online apparently. We never did get round to getting it.’ (C2, 147)

Two patients also discussed their feeling of obligation to meet the expectations of healthcare professionals or a pressure to conform to the constraints of the system in the wait time for their operation.

> ‘I’m in limbo now. I’ve reached the weight target and now I’m still waiting for the operation. But I know the NHS is under pressure… there’s no point in ringing every day and I just want it done as soon as really’ (C2, 149)

> ‘I think you owe it to the poor surgeon… so its just down to the individual’ (E1, 19)

At the point of receiving their cancer diagnosis and entering into preoperative exercise intervention, a patient will have had numerous interactions with the healthcare team, some of which may be negative. Although it was not explicitly stated that this affected their motivation for exercise intervention in these interviews, it is a consideration for the social opportunity component of the COM-B behaviour change model. The participants in this study were willing to engage with the advice and supervision of the physiotherapy team, but previous experiences with healthcare professionals could be a factor in patients’ receptiveness to the social influence of healthcare support during prehabilitation.

In terms of physical opportunity barriers, access to physical resources was not mentioned as a barrier during the interviews. All participants had the access and facilities to do the exercises they wished, whether this was walking or access to gyms. Time was the main barrier facing two participants due to caring responsibilities and work commitments, highlighting the importance to the patient of other life priorities such as their disabled wife, having to look after grandchildren, and spending time with their family.

References

1. Nepogodiev, D. *et al.* Global burden of postoperative death. *The Lancet* **393**, 401 (2019).

2. Findlay, G. P., Goodwin, A. P. L., Protopapa, K. L., Smith, N. C. E. & Mason, M. *Knowing the Risk. A review of the peri-operative care of surgical patients. National Confidential Enquiry into Patient Outcome and Death* http://www.ncepod.org.uk/2011poc.htm (2011) doi:10.1038/sj.ph.1900728.

3. Abbott, T. E. F. *et al.* Frequency of surgical treatment and related hospital procedures in the UK: a national ecological study using hospital episode statistics. *BJA: British Journal of Anaesthesia* **119**, 249–257 (2017).

4. Lin, H.-S., Watts, J. N., Peel, N. M. & Hubbard, R. E. Frailty and post-operative outcomes in older surgical patients: a systematic review. *BMC Geriatrics* **16**, 157 (2016).

5. Aylin, P., Alexandrescu, R., Jen, M. H., Mayer, E. K. & Bottle, A. Day of week of procedure and 30 day mortality for elective surgery: retrospective analysis of hospital episode statistics. *BMJ* **346**, (2013).

6. Konety, B. R., Allareddy, V. & Herr, H. Complications after radical cystectomy: Analysis of population-based data. *Urology* **68**, 58–64 (2006).

7. Hii, M. W. *et al.* Impact of postoperative morbidity on long-term survival after oesophagectomy. *BJS* **100**, 95–104 (2013).

8. Khuri, S. F. *et al.* Determinants of long-term survival after major surgery and the adverse effect of postoperative complications. *Annals of surgery* **242**, 323–326 (2005).

9. Grocott, M. P. W., Edwards, M., Mythen, M. G. & Aronson, S. Peri-operative care pathways: re-engineering care to achieve the 'triple aim.' *Anaesthesia* **74**, 90–99 (2019).

10. Wijeysundera, D. N. *et al.* Assessment of functional capacity before major non-cardiac surgery: an international, prospective cohort study. *The Lancet* **391**, 2631–2640 (2018).

11. Pearse, R. M. *et al.* Mortality after surgery in Europe : a 7 day cohort study. *The Lancet* **380**, 1059–1065 (2011).

12. Older, P., Hall, A. & Hader, R. Cardiopulmonary Exercise Testing as a Screening Test for Perioperative Management of Major Surgery in the Elderly. *Chest* **116**, 355–362 (1999).

13. The Royal College of Anaesthetists. *Perioperative medicine the pathway to better surgical care*. *Royal College of Anaesthetics* (2015).

14. Grocott, M. P. W., Plumb, J. O. M., Edwards, M., Fecher-Jones, I. & Levett, D. Z. H. Re-designing the pathway to surgery: better care and added value. *Perioperative Medicine* **6**, 9 (2017).

15. Wynter-Blyth, V. & Moorthy, K. Prehabilitation: Preparing patients for surgery. *BMJ (Online)* vol. 358 (2017).

16. Desborough, J. P. The stress response to trauma and surgery. *BJA: British Journal of Anaesthesia* **85**, 109–117 (2000).

17. Davies, S. J. & Wilson, R. J. T. Preoperative optimization of the high-risk surgical patient. *BJA: British Journal of Anaesthesia* **93**, 121–128 (2004).

18. Evans, T. W. & Smithies, M. ABC of intensive care: organ dysfunction. *BMJ (Clinical research ed.)* **318**, 1606—1609 (1999).

19. Moran, J. *et al.* The preoperative use of field tests of exercise tolerance to predict postoperative outcome in intra-abdominal surgery: a systematic review. *Journal of Clinical Anesthesia* **35**, 446–455 (2016).

20. Bland, R. D., Shoemaker, W. C., Abraham, E. & Cobo, J. C. Hemodynamic and oxygen transport patterns in surviving and non surviving postoperative patients. *Critical care medicine* **13**, 85—90 (1985).

21. Lugo, G., Arizpe, D., Domínguez, G., Ramírez, M. & Tamariz, O. Relationship between oxygen consumption and oxygen delivery during anesthesia in high-risk surgical patients. *Critical care medicine* **21**, 64—69 (1993).

22. Carli, F. & Zavorsky, G. S. Optimizing functional exercise capacity in the elderly surgical population. *Current Opinion in Clinical Nutrition & Metabolic Care* **8**, (2005).

23. Christensen, T. & Kehlet, H. Postoperative fatigue. *World Journal of Surgery* **17**, 220–225 (1993).

24. Moran, J. *et al.* Role of cardiopulmonary exercise testing as a risk-assessment method in patients undergoing intra-abdominal surgery: a systematic review. *BJA: British Journal of Anaesthesia* **116**, 177–191 (2016).

25. Levett, D. Z. H., Edwards, M., Grocott, M. & Mythen, M. Preparing the patient for surgery to improve outcomes. *Best Practice & Research Clinical Anaesthesiology* **30**, 145–157 (2016).

26. Macmillan Cancer Support. *Prehabiliation for people with cancer.* https://www.macmillan.org.uk/assets/prehabilitation-guidance-for-people-with-cancer.pdf (2017).

27. World Health Organisation. Global recommendations on physical activity for health. http://www.who.int/dietphysicalactivity/publications/9789241599979/en/ (2010).

28. Ding, D. *et al.* The economic burden of physical inactivity: a global analysis of major non-communicable diseases. *The Lancet* **388**, 1311–1324 (2016).

29. Moran, J. *et al.* The preoperative use of field tests of exercise tolerance to predict postoperative outcome in intra-abdominal surgery: a systematic review. *Journal of Clinical Anesthesia* **35**, 446–455 (2016).

30. American Society of Anesthesiologists. ASA Physical Status Classification System. https://www.asahq.org/resources/clinical-information/asa-physical-status-classification-system (2014).

31. National Institute of Clinical Excellence. Routine Preoperative Tests for Elective Surgery: Recommendations. https://www.nice.org.uk/guidance/ng45/chapter/Recommendations (2016).

32. Wolters, U. *et al.* ASA classification and perioperative variables as predictors of postoperative outcome. *British Journal of Anaesthesia* **77**, 217–222 (1996).

33. Cohen, M. E., Bilimoria, K. Y., Ko, C. Y., Richards, K. & Hall, B. L. Effect of Subjective Preoperative Variables on Risk-Adjusted Assessment of Hospital Morbidity and Mortality. *Annals of Surgery* **249**, (2009).

34. Mak, P. H. K., Campbell, R. C. H., Irwin, M. G. & American Society of Anesthesiologists. The ASA Physical Status Classification: inter-observer consistency. American Society of Anesthesiologists. *Anaesthesia and intensive care* **30**, 633—640 (2002).

35. Hlatky, M. A. *et al.* A brief self-administered questionnaire to determine functional capacity (The Duke Activity Status Index). *The American Journal of Cardiology* **64**, 651–654 (1989).

36. Li, M. H.-G. *et al.* Comparison of Duke Activity Status Index with cardiopulmonary exercise testing in cancer patients. *Journal of Anesthesia* (2018) doi:10.1007/s00540-018-2516-6.

37. Wijeysundera, D. N. *et al.* Integration of the Duke Activity Status Index into preoperative risk evaluation : a multicentre prospective cohort study. **124**, 261–270 (2020).

38. Moran, J. *et al.* The ability of prehabilitation to influence postoperative outcome after intra-abdominal operation: A systematic review and meta-analysis. *Surgery* **160**, 1189–1201 (2016).

39. Older, R., Smith, R., Courtney, B. & Hone, R. Preoperative Evaluation of Cardiac Failure and Ischemia in Elderly Patients by Cardiopulmonary Exercise Testing. *Chest* **104**, 701–704 (1993).

40. Hennis, P. J., Meale, P. M. & Grocott, M. P. W. Cardiopulmonary exercise testing for the evaluation of perioperative risk in non-cardiopulmonary surgery. *Postgraduate Medical Journal* (2011).

41. Smith, T., Stonell, C., Purkayastha, S. & Paraskevas, P. Cardiopulmonary exercise testing as a risk assessment method in non cardio-pulmonary surgery: a systematic review. *Anaesthesia* **64**, 883–893 (2009).

42. Levett, D. Z. H. *et al.* Perioperative cardiopulmonary exercise testing (CPET): consensus clinical guidelines on indications, organization, conduct, and physiological interpretation. *British Journal of Anaesthesia* **120**, 484–500 (2018).

43. O'Doherty, A. F., West, M., Jack, S. & Grocott, M. P. W. Preoperative aerobic exercise training in elective intra-cavity surgery: A systematic review. *British Journal of Anaesthesia* **110**, 679–689 (2013).

44. West, M., Jack, S. & Grocott, M. P. W. Perioperative cardiopulmonary exercise testing in the elderly. *Best Practice & Research Clinical Anaesthesiology* **25**, 427–437 (2011).

45. Reeves, T. *et al.* Cardiopulmonary exercise testing (CPET) in the United Kingdom—a national survey of the structure, conduct, interpretation and funding. *Perioperative Medicine* **7**, 2 (2018).

46. Balady, G. J. *et al.* Clinician's Guide to Cardiopulmonary Exercise Testing in Adults. A Scientific Statement From the American Heart Association. *Circulation* (2010).

47. Physicians, A. T. S. / A. C. of C. ATS/ACCP Statement on Cardiopulmonary Exercise Testing. *American Journal of Respiratory and Critical Care Medicine* **167**, 211–277 (2003).

48. Prentis, J. M. *et al.* Impaired cardiopulmonary reserve in an elderly population is related to postoperative morbidity and length of hospital stay after radical cystectomy. *BJU International* **112**, E13–E19 (2013).

49. Stephen, T. *et al.* Cardiopulmonary reserve as determined by cardiopulmonary exercise testing correlates with length of stay and predicts complications after radical cystectomy. *BJU International* **115**, 554–561 (2014).

50. Fleisher, L. A. *et al.* 2014 ACC/AHA Guideline on Perioperative Cardiovascular Evaluation and Management of Patients Undergoing Noncardiac Surgery. *Journal of the American College of Cardiology* **64**, e77 LP-e137 (2014).

51. Members, A. F. *et al.* 2014 ESC/ESA Guidelines on non-cardiac surgery: cardiovascular assessment and management. The Joint Task Force on non-cardiac surgery: cardiovascular assessment and management of the European Society of Cardiology (ESC) and the European Society of Anaesthesia. *European Heart Journal* **35**, 2383–2431 (2014).

52. Biccard, B. M. Improving the evidence-base for preoperative cardiopulmonary exercise testing. *British Journal of Anaesthesia* **120**, 419–421 (2018).

53. Lee, K. *et al.* The association of the distance walked in 6 min with pre-operative peak oxygen consumption and complications 1 month after colorectal resection. *Anaesthesia* **68**, 811–816 (2013).

54. Moriello, C., Mayo, N. E., Feldman, L. & Carli, F. Validating the Six-Minute Walk Test as a Measure of Recovery After Elective Colon Resection Surgery. *Archives of Physical Medicine and Rehabilitation* **89**, 1083–1089 (2008).

55. Paisani, D. M., Fiore Jr, J. F., Lunardi, A. C. & Colluci, Daniela BB Santoro, Ilka Lopes Carvalho, Celso RF Chiavegato, Luciana Dias Faresin, S. M. Preoperative six-min walking distance does not predict pulmonary complications in upper abdominal surgery. *Respirology* **17**, 1013–1017 (2012).

56. Arruda, K. A., Cataneo, D. C. & Cataneo, A. J. M. Surgical risk tests related to cardiopulmonary postoperative complications: comparison between upper abdominal and thoracic surgery . *Acta Cirurgica Brasileira* vol. 28 458–466 (2013).

57. Nutt, C. & Russell, J. Use of the pre-operative shuttle walk test to predict morbidity and mortality after elective major colorectal surgery. *Anaesthesia* **67**, 839–849 (2012).

58. Thijssen, D., Redington, A., George, K., Hopman, M. & Jones, H. Association of exercise preconditioning with immediate cardioprotection: A review. *JAMA Cardiology* **3**, 169–176 (2018).

59. Kannel, W., Wilson, P. & Blair, S. Epidemiological assessment of the role of physical activity and fitness in development of cardiovascular disease. *American Heart Journal* **109**, 876–885 (1985).

60. Kannel, W. B., Belanger, A., D'Agostino, R. & Israel, I. Physical activity and physical demand on the job and risk of cardiovascular disease and death: The Framingham Study. *American Heart Journal* **112**, 820–825 (1986).

61. Davidson, T., Vainshelboim, B., Kokkinos, P., Myers, J. & Ross, R. Cardiorespiratory fitness versus physical activity as predictors of all-cause mortality in men. *American Heart Journal* **196**, 156–162 (2018).

62. Myers, J. *et al.* Fitness versus physical activity patterns in predicting mortality in men. *The American Journal of Medicine* **117**, 912–918 (2004).

63. Lakka, T. A. *et al.* Relation of Leisure-Time Physical Activity and Cardiorespiratory Fitness to the Risk of Acute Myocardial Infarction in Men. *New England Journal of Medicine* **330**, 1549–1554 (1994).

64. Dunn, A. *et al.* Comparison of lifestyle and structured interventions to increase physical activity and cardiorespiratory fitness: A randomized trial. *JAMA* **281**, 327–334 (1999).

65. Myers, J. *et al.* Recommendations for Clinical Exercise Laboratories. *Circulation* **119**, 3144 LP – 3161 (2009).

66. Myers, J. *et al.* Physical Activity and Cardiorespiratory Fitness as Major Markers of Cardiovascular Risk: Their Independent and Interwoven Importance to Health Status. *Progress in Cardiovascular Diseases* **57**, 306–314 (2015).

67. Davies, S., Burns, H., Jewell, T. & McBride, M. *Start Active, Stay Active. A report on physical activity for health from the four home countries' Chief Medical Officers.* (2011).

68. Strath, S. J. *et al.* Guide to the Assessment of Physical Activity: Clinical and Research Applications. *Circulation* **128**, 2259 LP – 2279 (2013).

69. US Department of Health and Human Services. *Physical Activity and Health: A Report of the Surgeon General.* (1996).

70. Donaldson, L. *At least five a week. Evidence on the impact of physical activity and its relationship to health. A report from the Chief Medical Officer.* (2004).

71. Shephard, R. J. Absolute versus relative intensity of physical activity in a dose-response context. *Medicine and science in sports and exercise* **33**, S400—18; discussion S419—20 (2001).

72. Borg, G. *Borg's perceived exertion and pain scales. Borg's perceived exertion and pain scales.* (Human Kinetics, 1998).

73. Centers for Disease Control and Prevention. Perceived exertion. Borg rating of perceived exertion scale. https://www.cdc.gov/physicalactivity/basics/measuring/exertion.htm (2015).

74. Centers for Disease Control and Prevention. Target heart rate and estimated maximum heart rate. https://www.cdc.gov/physicalactivity/basics/measuring/heartrate.htm (2015).

75. Ainsworth, B. *et al.* Compendium of physical activities: an update of activity codes and MET intensities. *Medicine and science in sports and exercise* **32**, S489–S504 (2000).

76. Caspersen, C. J., Powell, K. E. & Christenson, G. M. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Reports* **100**, 126–131 (1985).

77. Hills, A. P., Mokhtar, N. & Byrne, N. M. Assessment of Physical Activity and Energy Expenditure: An Overview of Objective Measures. *Frontiers in Nutrition* **1**, 5 (2014).

78. Centers for Disease Control and Prevention. General physical activities defined by level of intensity. https://www.cdc.gov/nccdphp/dnpa/physical/pdf/PA_Intensity_table_2_1.pdf (2015).

79. Ainsworth, B., Cahalin, L., Buman, M. & Ross, R. The Current State of Physical Activity Assessment Tools. *Progress in Cardiovascular Diseases* **57**, 387–395 (2015).

80. Levine, J. A. Measurement of energy expenditure. *Public Health Nutrition* **8**, 1123–1132 (2005).

81. Westerterp, K. R. Assessment of physical activity: A critical appraisal. *European Journal of Applied Physiology* **105**, 823–828 (2009).

82. Crouter, S. E., Schneider, P. L., Karabulut, M. & Bassett, D. R. J. Validity of 10 electronic pedometers for measuring steps, distance, and energy cost. *Medicine and science in sports and exercise* **35**, 1455–1460 (2003).

83. Tudor-Locke, C. *et al.* How fast is fast enough? Walking cadence (steps/min) as a practical estimate of intensity in adults: a narrative review. *British Journal of Sports Medicine* **52**, 776 LP – 788 (2018).

84. Bravata, D., Smith-Spangler, C. & Sundaram, V. Using pedometers to increase physical activity and improve health: A systematic review. *JAMA* **298**, 2296–2304 (2007).

85. Jack, S. The Wessex Fit-4-Cancer Surgery Trial (Wesfit). *Clinicaltrials.gov* https://clinicaltrials.gov/ct2/show/NCT03509428?term=prehabilitation&cond=Surgery&cntry=GB&rank=5 (2018).

86. Govindarajan, A. Prehabilitation to improve cancer surgery outcomes. The PICaSO trial. *Clinicaltrials.gov* https://clinicaltrials.gov/ct2/show/NCT03502317?term=PICaSO&rank=1 (2018).

87. Doherty, A. *et al.* Large Scale Population Assessment of Physical Activity Using Wrist Worn Accelerometers: The UK Biobank Study. *PLOS ONE* **12**, 1–14 (2017).

88. Lieber, B., Taylor, B. E. S., Appelboom, G., McKhann, G. & Connolly, E. S. Motion Sensors to Assess and Monitor Medical and Surgical Management of Parkinson Disease. *World Neurosurgery* **84**, 561–566 (2015).

89. Tsuji, S. *et al.* Is Minimally Invasive Surgery–Total Knee Arthroplasty Truly Less Invasive Than Standard Total Knee Arthroplasty?: A Quantitative Evaluation. *The Journal of Arthroplasty* **25**, 970–976 (2010).

90. Landry, G. J. *et al.* Objective measurement of lower extremity function and quality of life after surgical revascularization for critical lower extremity ischemia. *Journal of Vascular Surgery* **60**, 136–142 (2014).

91. Axivity. Axivity AX3. https://axivity.com/product/ax3 (2015).

92. Matthew, C. E. Calibration of accelerometer output for adults. *Medicine and science in sports and exercise* **37**, S512—22 (2005).

93. Actigraph. Actigraph GT3X. https://www.actigraphcorp.com/actigraph-wgt3x-bt/ (2018).

94. Gastin, P. B., Cayzer, C., Dwyer, D. & Robertson, S. Validity of the ActiGraph GT3X+ and BodyMedia SenseWear Armband to estimate energy expenditure during physical activity and sport. *Journal of Science and Medicine in Sport* **21**, 291–295 (2018).

95. Jefferis, B. J. *et al.* Objectively measured physical activity, sedentary behaviour and all-cause mortality in older men: does volume of activity matter more than pattern of

accumulation? *British Journal of Sports Medicine* bjsports-2017-098733 (2018) doi:10.1136/bjsports-2017-098733.

96. Staudenmayer, J., He, S., Hickey, A., Sasaki, J. & Freedson, P. Methods to estimate aspects of physical activity and sedentary behavior from high-frequency wrist accelerometer measurements. *Journal of Applied Physiology* **119**, 396–403 (2015).

97. Evenson, K. R., Buchner, D. M. & Morland, K. B. Objective Measurement of Physical Activity and Sedentary Behavior Among US Adults Aged 60 Years or Older. *Preventing Chronic Disease* **9**, E26 (2012).

98. Bond, D. S. *et al.* Pre- to postoperative physical activity changes in bariatric surgery patients: Self report vs. objective measures. *Obesity* **18**, 2395–2397 (2010).

99. Feeney, C., Reynolds, J. v. & Hussey, J. Preoperative physical activity levels and postoperative pulmonary complications post-esophagectomy. *Diseases of the Esophagus* **24**, 489–494 (2011).

100. Lyden, K., Kozey, S. L., Staudenmeyer, J. W. & Freedson, P. S. A comprehensive evaluation of commonly used accelerometer energy expenditure and MET prediction equations. *European journal of applied physiology* **111**, 187–201 (2011).

101. Howe, C. A., Staudenmayer, J. W. & Freedson, P. S. Accelerometer prediction of energy expenditure: Vector magnitude versus vertical axis. *Medicine and Science in Sports and Exercise* **41**, 2199–2206 (2009).

102. Activinsights. GENEActiv original. https://www.activinsights.com/actigraphy/geneactiv-original/ (2017).

103. Esliger, D. W. *et al.* Validation of the GENEA Accelerometer. *Medicine and science in sports and exercise* **43**, 1085–1093 (2011).

104. Pavey, T. G., Gomersall, S. R., Clark, B. K. & Brown, W. J. The validity of the GENEActiv wrist-worn accelerometer for measuring adult sedentary time in free living. *Journal of Science and Medicine in Sport* **19**, 395–399 (2016).

105. Chen, K. Y. & Bassett, D. R. The technology of accelerometry-based activity monitors: Current and future. *Medicine and Science in Sports and Exercise* **37**, (2005).

106. Chen, K. Y. & Bassett, D. R. J. R. The Technology of Accelerometry-Based Activity Monitors: Current and Future. *Medicine & Science in Sports & Exercise* **37**, (2005).

107. van Hees, V. T. *et al.* Autocalibration of accelerometer data for free-living physical activity assessment using local gravity and temperature: an evaluation on four continents. *Journal of Applied Physiology* **117**, 738–744 (2014).

108. Migueles, J. H. *et al.* Accelerometer Data Collection and Processing Criteria to Assess Physical Activity and Other Outcomes: A Systematic Review and Practical Considerations. *Sports Medicine* **47**, 1821–1845 (2017).

109. Atallah, L., Lo, B., King, R. & Yang, G. Z. Sensor Positioning for Activity Recognition Using Wearable Accelerometers. *IEEE Transactions on Biomedical Circuits and Systems* **5**, 320–329 (2011).

110. Preece, S. J. *et al.* Activity identification using body-mounted sensors—a review of classification techniques. *Physiological Measurement* **30**, R1 (2009).

111. Bracewell, R. N. The Fourier Transform. *Scientific American* **260**, 86–95 (1989).

112. DataQ Instruments. FFT (Fast Fourier Transform) Waveform Analysis. https://www.dataq.com/data-acquisition/general-education-tutorials/fft-fast-fourier-transform-waveform-analysis.html.

113. Plasqui, G. & Westerterp, K. R. Physical Activity Assessment With Accelerometers: An Evaluation Against Doubly Labeled Water. *Obesity* **15**, 2371–2379.

114. Chen, K. Y. & Sun, M. Improving energy expenditure estimation by using a triaxial accelerometer. *Journal of Applied Physiology* **83**, 2112–2122 (1997).

115. Leenders, N. Y., Sherman, W. M., Nagaraja, H. N. & Kien, C. L. Evaluation of methods to assess physical activity in free-living conditions. *Medicine and science in sports and exercise* **33**, 1233—1240 (2001).

116. Arvidsson, D., Slinde, F., Nordenson, A., Larsson, S. & Hulthén, L. Validity of the ActiReg system in assessing energy requirement in chronic obstructive pulmonary disease patients. *Clinical Nutrition* **25**, 68–74 (2006).

117. Meijer, E. P., Goris, A. H. C., Wouters, L. & Westerterp, K. R. Physical inactivity as a determinant of the physical activity level in the elderly. *International Journal Of Obesity* **25**, 935 (2001).

118. Pitta, F. *et al.* Quantifying physical activity in daily life with questionnaires and motion sensors in COPD. *European Respiratory Journal* **27**, 1040 LP – 1055 (2006).

119. Starling, R. D., Matthews, D. E., Ades, P. A. & Poehlman, E. T. Assessment of physical activity in older individuals: a doubly labeled water study. *Journal of Applied Physiology* **86**, 2090–2096 (1999).

120. Plasqui, G. Smart approaches for assessing free-living energy expenditure following identification of types of physical activity. *Obesity Reviews* **18**, 50–55 (2017).

121. Swartz, A. M. *et al.* Estimation of energy expenditure using CSA accelerometers at hip and wrist sites. *Medicine and science in sports and exercise* **32**, S450—6 (2000).

122. Wilson, R. J. T. *et al.* Optimizing functional exercise capacity in the elderly surgical population. *British Journal of Anaesthesia* **35**, 446–455 (2018).

123. Clarke, C. L. *et al.* Validation of the AX3 triaxial accelerometer in older functionally impaired people. *Aging Clinical and Experimental Research* **29**, 451–457 (2017).

124. Olguin, D. & Pentland, A. Human activity recognition: Accuracy across common locations for wearable sensors. in *10th Int. Symp. Wearable Comput. (Student Colloquium)* 11–14 (2006).

125. Tapia, E. M. *et al.* Real-Time Recognition of Physical Activities and Their Intensities Using Wireless Accelerometers and a Heart Rate Monitor. in *2007 11th IEEE International Symposium on Wearable Computers* 37–40 (2007). doi:10.1109/ISWC.2007.4373774.

126. van Blarigan, E. L. *et al.* The Fitbit One Physical Activity Tracker in Men With Prostate Cancer: Validation Study. *JMIR cancer* vol. 3 (2017).

127. Mina, D. S. *et al.* Prehabilitation for radical prostatectomy: A multicentre randomized controlled trial. *Surgical Oncology* **27**, 289–298 (2018).

128. Vanhees, L. *et al.* How to assess physical activity? How to assess physical fitness? *European Journal of Cardiovascular Prevention & Rehabilitation* **12**, 102–114 (2005).

129. Troiano, R. P., McClain, J. J., Brychta, R. J. & Chen, K. Y. Evolution of accelerometer methods for physical activity research. *British Journal of Sports Medicine* **48**, 1019 LP – 1023 (2014).

130. Hartley, R. A. *et al.* Preoperative cardiopulmonary exercise testing and risk of early mortality following abdominal aortic aneurysm repair. *BJS* **99**, 1539–1546.

131. Carlisle, J. B., Danjoux, G., Kerr, K., Snowden, C. & Swart, M. Validation of long-term survival prediction for scheduled abdominal aortic aneurysm repair with an independent calculator using only pre-operative variables. *Anaesthesia* **70**, 654–665.

132. Open Movement. Open Movement GUI Application. https://github.com/digitalinteraction/openmovement/wiki/AX3-GUI (2009).

133. van Hees, V. T. *et al.* Estimation of Daily Energy Expenditure in Pregnant and Non-Pregnant Women Using a Wrist-Worn Tri-Axial Accelerometer. *PLOS ONE* **6**, 1–10 (2011).

134. Herdman, M. *et al.* Development and preliminary testing of the new five-level version of EQ-5D (EQ-5D-5L). *Quality of Life Research* **20**, 1727–1736 (2011).

135. Ware, J. E., Kosinski, M. & Keller, S. D. A 12-Item Short-Form Health Survey: Construction of Scales and Preliminary Tests of Reliability and Validity. *Medical Care* **34**, (1996).

136. Dindo, D., Demartines, N. & Clavien, P.-A. Classification of Surgical Complications: A New Proposal With Evaluation in a Cohort of 6336 Patients and Results of a Survey. *Annals of Surgery* vol. 240 205–213 (2004).

137. Struthers, R. *et al.* Assessing fitness for surgery: a comparison of questionnaire, incremental shuttle walk, and cardiopulmonary exercise testing in general surgical patients. *BJA: British Journal of Anaesthesia* **101**, 774–780 (2008).

138. Singh, S. J., Morgan, M. D., Hardman, A. E., Rowe, C. & Bardsley, P. A. Comparison of oxygen uptake during a conventional treadmill test and the shuttle walking test in chronic airflow limitation. *European Respiratory Journal* **7**, 2016–2020 (1994).

139. Lai, C. W. *et al.* Patients' inability to perform a preoperative cardiopulmonary exercise test or demonstrate an anaerobic threshold is associated with inferior outcomes after major colorectal surgery. *BJA: British Journal of Anaesthesia* **111**, 607–611 (2013).

140. National Institute of Clinical Excellence. *Preoperative tests (update). Full clinical guideline NG45.* https://www.nice.org.uk/guidance/ng45/evidence/full-guideline-pdf-87258149468 (2016).

141. Guazzi, M. *et al.* 2016 Focused Update: Clinical Recommendations for Cardiopulmonary Exercise Testing Data Assessment in Specific Patient Populations. *Circulation* **133**, e694–e711 (2016).

142. Guthold, R., Stevens, G. A., Riley, L. M. & Bull, F. C. Worldwide trends in insufficient physical activity from 2001 to 2016: a pooled analysis of 358 population-based surveys with 1·9 million participants. *The Lancet Global Health* **6**, e1077–e1086 (2018).

143. Harvey, J. A., Chastin, S. F. M. & Skelton, D. A. Prevalence of Sedentary Behavior in Older Adults: A Systematic Review. *International Journal of Environmental Research and Public Health* **10**, 6645–6661 (2013).

144. Innerd, P., Harrison, R. & Coulson, M. Using open source accelerometer analysis to assess physical activity and sedentary behaviour in overweight and obese adults. *BMC Public Health* **18**, 543 (2018).

145. Kim, Y. *et al.* Specific physical activities, sedentary behaviours and sleep as long-term predictors of accelerometer-measured physical activity in 91,648 adults: a prospective cohort study. *International Journal of Behavioral Nutrition and Physical Activity* **16**, 41 (2019).

146. Taraldsen, K., Chastin, S. F. M., Riphagen, I. I., Vereijken, B. & Helbostad, J. L. Physical activity monitoring by use of accelerometer-based body-worn sensors in older adults: A systematic literature review of current knowledge and applications. *Maturitas* **71**, 13–19 (2012).

147. Kulinski, J. P. *et al.* Association Between Cardiorespiratory Fitness and Accelerometer-Derived Physical Activity and Sedentary Time in the General Population. *Mayo Clinic Proceedings* **89**, 1063–1071 (2014).

148. Steffens, D. *et al.* Is preoperative physical activity level of patients undergoing cancer surgery associated with postoperative outcomes? A systematic review and meta-analysis. *European Journal of Surgical Oncology* (2018) doi:https://doi.org/10.1016/j.ejso.2018.10.063.

149. Dronkers, J. J., Chorus, A. M. J., van Meeteren, N. L. U. & Hopman-Rock, M. The association of pre-operative physical fitness and physical activity with outcome after scheduled major abdominal surgery. *Anaesthesia* **68**, 67–73 (2013).

150. King, W. C. *et al.* Pre- to postoperative changes in physical activity: report from the Longitudinal Assessment of Bariatric Surgery-2 (LABS-2). *Surgery for Obesity and Related Diseases* **8**, 522–532 (2012).

151. Cleland, I. *et al.* Optimal Placement of Accelerometers for the Detection of Everyday Activities. *Sensors* **13**, 9183–9200 (2013).

152. Ellis, K. *et al.* A random forest classifier for the prediction of energy expenditure and type of physical activity from wrist and hip accelerometers. *Physiological Measurement* **35**, 2191 (2014).

153. Grimes, L., Outtrim, J. G., Griffin, S. J. & Ercole, A. Accelerometery as a measure of modifiable physical activity in high-risk elderly preoperative patients: a prospective observational pilot study. *BMJ Open* **9**, (2019).

154. Corder, K., Brage, S. & Ekelund, U. Accelerometers and pedometers: methodology and clinical application. *Current Opinion in Clinical Nutrition & Metabolic Care* **10**, (2007).

155. Rich, C. *et al.* Quality Control Methods in Accelerometer Data Processing: Defining Minimum Wear Time. *PLOS ONE* **8**, 1–8 (2013).

156. Matthews, C. E., Ainsworth, B. E., Thompson, R. W. & Bassett, D. R. J. R. Sources of variance in daily physical activity levels as measured by an accelerometer. *Medicine & Science in Sports & Exercise* **34**, (2002).

157. West MA, Jack S, Kemp G, Barben C, G. M. The Effect Of Neoadjuvant Chemoradiotherapy On Fitness In Patients Undergoing Rectal Cancer Surgery - Fit For Surgery? *AmJRespirCritCareMed* **185**, A6395–A6395 (2012).

158. West, M. A. *et al.* Effect of prehabilitation on objectively measured physical fitness after neoadjuvant treatment in preoperative rectal cancer patients : a blinded interventional pilot study †. *British Journal of Anaesthesia* **114**, 244–251 (2015).

159. Doherty, A. R. *et al.* Using wearable cameras to categorise type and context of accelerometer-identified episodes of physical activity. *International Journal of Behavioral Nutrition and Physical Activity* **10**, 22 (2013).

160. Bloom, E. *Prehabilitation evidence and insight review*. https://www.macmillan.org.uk/_images/prehabilitation-evidence-and-insight-review_tcm9-335025.pdf (2017).

161. Faithfull, S. *et al.* Prehabilitation for adults diagnosed with cancer: A systematic review of long-term physical function, nutrition and patient-reported outcomes. *European Journal of Cancer Care* **28**, e13023 (2019).

162. Wee, I. J. Y. & Choong, A. M. T. L. A systematic review of the impact of preoperative exercise for patients with abdominal aortic aneurysms. *Journal of Vascular Surgery* (2019) doi:https://doi.org/10.1016/j.jvs.2018.09.039.

163. Piraux, E., Caty, G. & Reychler, G. Effects of preoperative combined aerobic and resistance exercise training in cancer patients undergoing tumour resection surgery: A systematic review of randomised trials. *Surgical Oncology* **27**, 584–594 (2018).

164. Vermillion, S. A. *et al.* Preoperative exercise therapy for gastrointestinal cancer patients: a systematic review. *Systematic Reviews* **7**, 103 (2018).

165. Stephensen, D. *et al.* Effects of preoperative and postoperative resistance exercise interventions on recovery of physical function in patients undergoing abdominal surgery for cancer: a systematic review of randomised controlled trials. *BMJ Open Sport & Exercise Medicine* **4**, (2018).

166. Luther, A., Gabriel, J., Watson, R. P. & Francis, N. K. The Impact of Total Body Prehabilitation on Post-Operative Outcomes After Major Abdominal Surgery: A Systematic Review. *World Journal of Surgery* **42**, 2781–2791 (2018).

167. Hijazi, Y., Gondal, U. & Aziz, O. A systematic review of prehabilitation programs in abdominal cancer surgery. *International Journal of Surgery* **39**, 156–162 (2017).

168. Loughney, L. A., West, M. A., Kemp, G. J., Grocott, M. P. W. & Jack, S. Exercise interventions for people undergoing multimodal cancer treatment that includes surgery. *Cochrane Database of Systematic Reviews* **2016**, (2016).

169. Pouwels, S. *et al.* Preoperative exercise therapy for elective major abdominal surgery: A systematic review. *International Journal of Surgery* **12**, 134–140 (2014).

170. Lemanu, D. P., Singh, P. P., MacCormick, A. D., Arroll, B. & Hill, A. G. Effect of preoperative exercise on cardiorespiratory function and recovery after surgery: A systematic review. *World Journal of Surgery* **37**, 711–720 (2013).

171. O'Doherty, A. F., West, M., Jack, S. & Grocott, M. P. W. Preoperative aerobic exercise training in elective intra-cavity surgery: A systematic review. *British Journal of Anaesthesia* **110**, 679–689 (2013).

172. Singh, F., Newton, R. U., Galvão, D. A., Spry, N. & Baker, M. K. A systematic review of pre-surgical exercise intervention studies with cancer patients. *Surgical Oncology* **22**, 92–104 (2013).

173. Cho, H. *et al.* Matched Pair Analysis to Examine the Effects of a Planned Preoperative Exercise Program in Early Gastric Cancer Patients with Metabolic Syndrome to Reduce Operative Risk: The Adjuvant Exercise for General Elective Surgery (AEGES) Study Group. *Annals of Surgical Oncology* **21**, 2044–2050 (2014).

174. de Toledo Piza Soares, S. M., Nucci, L. B., de Carvalho da Silva, M. M. & Campacci, T. C. Pulmonary function and physical performance outcomes with preoperative physical therapy in upper abdominal surgery: a randomized controlled trial. *Clinical Rehabilitation* **27**, 616–627 (2013).

175. Dronkers, J.J., Lamberts, I.M., Reutelingsperger, R.H., Naber, C.M., Veldman, A., & Van Meeteren, N. L. Preoperative therapeutic programme for elderly patients scheduled for elective abdominal oncological surgery: a randomized controlled pilot study (abstract). *ClindRehabil* **24**, 614–622 (2010).

176. Barberan-Garcia, A. *et al.* Personalised Prehabilitation in High-risk Patients Undergoing Elective Major Abdominal Surgery: A Randomized Blinded Controlled Trial. *Annals of Surgery* **267**, 50–56 (2018).

177. Barakat, H. M., Shahin, Y., Khan, J. A., McCollum, P. T. & Chetter, I. C. Preoperative Supervised Exercise Improves Outcomes After Elective Abdominal Aortic Aneurysm Repair: A Randomized Controlled Trial. *Annals of Surgery* **264**, (2016).

178. Carli, F. *et al.* Randomized clinical trial of prehabilitation in colorectal surgery. *British Journal of Surgery* **97**, 1187–1197 (2010).

179. Gillis, C. *et al.* Prehabilitation versus Rehabilitation: A Randomized Control Trial in Patients Undergoing Colorectal Resection for Cancer. *Anesthesiology: The Journal of the American Society of Anesthesiologists* **121**, 937–947 (2014).

180. Jensen, B. T. *et al.* Efficacy of a multiprofessional rehabilitation programme in radical cystectomy pathways: A prospective randomized controlled trial. *Scandinavian Journal of Urology* **49**, 133–141 (2015).

181. Dunne, D. F. J. *et al.* Randomized clinical trial of prehabilitation before planned liver resection. *BJS* **103**, 504–512 (2016).

182. Cui, H. W., Turney, B. W. & Griffiths, J. The Preoperative Assessment and Optimization of Patients Undergoing Major Urological Surgery. *Current Urology Reports* **18**, (2017).

183. Santa Mina, D. *et al.* Prehabilitation for radical prostatectomy: A multicentre randomized controlled trial. *Surgical Oncology* **27**, 289–298 (2018).

184. Lemanu, D. P., Singh, P. P., MacCormick, A. D., Arroll, B. & Hill, A. G. Effect of Preoperative Exercise on Cardiorespiratory Function and Recovery After Surgery: a Systematic Review. *World Journal of Surgery* **37**, 711–720 (2013).

185. Hijazi, Y., Gondal, U. & Aziz, O. A systematic review of prehabilitation programs in abdominal cancer surgery. *International Journal of Surgery* **39**, 156–162 (2017).

186. Cui, H. W. *et al.* The association of pre-operative home accelerometry with cardiopulmonary exercise variables. *Anaesthesia* **73**, (2018).

187. Copeland, R. J. *et al. Psychological support and behaviour change interventions during the perioperative period for people with a cancer diagnosis; Consensus statements for use from Macmillan, The Royal College of Anaesthetists and the National Institute for Health Research.* (2020) doi:10.31219/osf.io/bt5qa.

188. Michie, S., van Stralen, M. M. & West, R. The behaviour change wheel: A new method for characterising and designing behaviour change interventions. *Implementation Science* **6**, 42 (2011).

189. Carli, F. *et al.* Randomized clinical trial of prehabilitation in colorectal surgery. *British Journal of Surgery* **97**, 1187–1197 (2010).

190. Kim, D. J., Mayo, N. E., Carli, F., Montgomery, D. L. & Zavorsky, G. S. Responsive Measures to Prehabilitation in Patients Undergoing Bowel Resection Surgery. *The Tohoku Journal of Experimental Medicine* **217**, 109–115 (2009).

191. Timmerman, H. *et al.* Feasibility and preliminary effectiveness of preoperative therapeutic exercise in patients with cancer: A pragmatic study. *Physiotherapy Theory and Practice* **27**, 117–124 (2011).

192. Dronkers, J. J. *et al.* Preoperative therapeutic programme for elderly patients scheduled for elective abdominal oncological surgery: a randomized controlled pilot study. *Clinical Rehabilitation* **24**, 614–622 (2010).

193. Hagberg, J. M. Effect of training on the decline of VO2max with aging. *Federation proceedings* **46**, 1830—1833 (1987).

194. Spruit, M. A. *et al.* An Official American Thoracic Society/European Respiratory Society Statement: Key Concepts and Advances in Pulmonary Rehabilitation. *American Journal of Respiratory and Critical Care Medicine* **188**, e13–e64 (2013).

195. Levett, D. Z. H. & Grimmett, C. Psychological factors, prehabilitation and surgical outcomes: evidence and future directions. *Anaesthesia* **74**, 36–42 (2019).

196. National Institute for Health and Care Excellence. *Behaviour change: individual approaches [PH49]*. (2014).

197. UK Department of Health. Physical Activity Guidelines for Adults. *NHS Choices: Live Well* http://www.nhs.uk/Livewell/fitness/Pages/physical-activity-guidelines-for-adults.aspx (2011).

198. Borg, G. Simple rating methods for estimation of perceived exertion. *Physical Work and Effort* 39–46 (1976).

199. Chen, M. J., Fan, X. & Moe, S. T. Criterion-related validity of the Borg ratings of perceived exertion scale in healthy individuals: a meta-analysis. *Journal of Sports Sciences* **20**, 873–899 (2002).

200. Cliff, D. P. *et al.* The Preschool Activity, Technology, Health, Adiposity, Behaviour and Cognition (PATH-ABC) cohort study: rationale and design. *BMC Pediatrics* **17**, 95 (2017).

201. Salsone, M. *et al.* Heart rate variability in patients with essential tremor: A cross sectional study. *Parkinsonism & Related Disorders* **33**, 134–137 (2016).

202. Ollila, A. *et al.* Postoperative Cardiac Ischemia Detection by Continuous 12-Lead Electrocardiographic Monitoring in Vascular Surgery Patients: A Prospective, Observational Study. *Journal of Cardiothoracic and Vascular Anesthesia* **31**, 950–956 (2017).

203. Reiss, A. & Stricker, D. PAMAP2 Physical Activity Monitoring Dataset. *UCI Machine Learning Repository* https://archive.ics.uci.edu/ml/datasets/pamap2+physical+activity+monitoring (2012).

204. Braun, V. & Clarke, V. Using thematic analysis in psychology. *Qualitative Research in Psychology* **3**, 77–101 (2006).

205. Carli, F. *et al.* Randomized clinical trial of prehabilitation in colorectal surgery. *British Journal of Surgery* **97**, 1187–1197 (2010).

206. Steffen, T. M., Hacker, T. A. & Mollinger, L. Age- and Gender-Related Test Performance in Community-Dwelling Elderly People: Six-Minute Walk Test, Berg Balance Scale, Timed Up \\& Go Test, and Gait Speeds. *Physical Therapy* **82**, 128–137 (2002).

207. Perera, S., Mody, S. H., Woodman, R. C. & Studenski, S. A. Meaningful Change and Responsiveness in Common Physical Performance Measures in Older Adults. *Journal of the American Geriatrics Society* **54**, 743–749 (2006).

208. Richardson, K., Levett, D. Z. H., Jack, S. & Grocott, M. P. W. Fit for surgery? Perspectives on preoperative exercise testing and training. *British Journal of Anaesthesia* **119**, i34–i43 (2017).

209. Weston, K. S., Wisløff, U. & Coombes, J. S. High-intensity interval training in patients with lifestyle-induced cardiometabolic disease: a systematic review and meta-analysis. *British Journal of Sports Medicine* **48**, 1227–1234 (2014).

210. West, M. A. *et al.* Effect of prehabilitation on objectively measured physical fitness after neoadjuvant treatment in preoperative rectal cancer patients: a blinded interventional pilot study. *BJA: British Journal of Anaesthesia* **114**, 244–251 (2014).

211. Prehabilitation to improve cancer surgery outcomes (PICaSO). *Clinicaltrials.gov* https://clinicaltrials.gov/ct2/show/NCT03502317 (2018).

212. Tudor-Locke, C. *et al.* How fast is fast enough? Walking cadence (steps/min) as a practical estimate of intensity in adults: a narrative review. *British Journal of Sports Medicine* **52**, 776–788 (2018).

213. Jakicic, J. M. *et al.* Effect of Wearable Technology Combined With a Lifestyle Intervention on Long-term Weight Loss: The IDEA Randomized Clinical Trial. *JAMA* **316**, 1161–1171 (2016).

214. Finkelstein, E. A. *et al.* Effectiveness of activity trackers with and without incentives to increase physical activity (TRIPPA): a randomised controlled trial. *The Lancet Diabetes & Endocrinology* **4**, 983–995 (2016).

215. Foster, C., Hillsdon, M., Thorogood, M., Kaur, A. & Wedatilake, T. Interventions for promoting physical activity. *Cochrane Database of Systematic Reviews* (2005) doi:10.1002/14651858.CD003180.pub2.

216. Petrella, R. J. & Lattanzio, C. N. Does counseling help patients get active? Systematic review of the literature. *Canadian Family Physician* **48**, 72–80 (2002).

217. Groen, W. G., van Harten, W. H. & Vallance, J. K. Systematic review and meta-analysis of distance-based physical activity interventions for cancer survivors (2013–2018): We still haven't found what we're looking for. *Cancer Treatment Reviews* **69**, 188–203 (2018).

218. Bourke, L. *et al.* Interventions to improve exercise behaviour in sedentary people living with and beyond cancer: a systematic review. *British Journal of Cancer* **110**, 831–841 (2014).

219. Turner, R. *et al.* Interventions for promoting habitual exercise in people living with and beyond cancer. *Cochrane Database of Systematic Reviews* (2018) doi:10.1002/14651858.CD010192.pub3.

220. Samdal, G. B., Eide, G. E., Barth, T., Williams, G. & Meland, E. Effective behaviour change techniques for physical activity and healthy eating in overweight and obese adults; systematic review and meta-regression analyses. *International Journal of Behavioral Nutrition and Physical Activity* **14**, 42 (2017).

221. Kelly, M. P. & Barker, M. Why is changing health-related behaviour so difficult? *Public Health* **136**, 109–116 (2016).

222. Waterland, J. L. *et al.* Patient acceptance of prehabilitation for major surgery: an exploratory survey. *Supportive Care in Cancer* (2020) doi:10.1007/s00520-020-05547-1.

223. Ferreira, V. *et al.* Maximizing patient adherence to prehabilitation: what do the patients say? *Supportive Care in Cancer* **26**, 2717–2723 (2018).

224. Weinstein, N. D. Exploring the links between risk perceptions and preventive health behavior. in *Social psychological foundations of health and illness* (eds. Suls, J. & Wallston, K.) 22–53 (Blackwell, 2003).

225. Lippke, S., Ziegelmann, J. P. & Schwarzer, R. Stage-specific adoption and maintenance of physical activity: testing a three-stage model. *Psychology of Sport and Exercise* **6**, 585–603 (2005).

226. Michie, S. *et al.* A refined taxonomy of behaviour change techniques to help people change their physical activity and healthy eating behaviours: The CALO-RE taxonomy. *Psychology & Health* **26**, 1479–1498 (2011).

227. Banerjee, S. *et al.* Patient perspectives of vigorous intensity aerobic interval exercise prehabilitation prior to radical cystectomy: a qualitative focus group study. *Disability and Rehabilitation* **43**, 1084–1091 (2019).

228. Kwasnicka, D., Dombrowski, S. U., White, M. & Sniehotta, F. Theoretical explanations for maintenance of behaviour change: a systematic review of behaviour theories. *Health Psychology Review* **10**, 277–296 (2016).

229. Olander, E. K. *et al.* What are the most effective techniques in changing obese individuals’ physical activity self-efficacy and behaviour: a systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity* **10**, 29 (2013).

230. Nguyen, N. H. *et al.* A qualitative evaluation of breast cancer survivors’ acceptance of and preferences for consumer wearable technology activity trackers. *Supportive Care in Cancer* **25**, 3375–3384 (2017).

231. Gell, N. M., Tursi, A., Grover, K. W. & Dittus, K. Female cancer survivor perspectives on remote intervention components to support physical activity maintenance. *Supportive Care in Cancer* **28**, 2185–2194 (2020).

232. Rosenberg, D. *et al.* Acceptability of Fitbit for physical activity tracking within clinical care among men with prostate cancer. *AMIA ... Annual Symposium proceedings. AMIA Symposium* **2016**, 1050–1059 (2017).

233. McDermott, M. M., Spring, B. & Treat-Jacobson, D. Correspondence: Use of a Wearable Activity Monitor in a Home-Based Exercise Intervention for Peripheral Artery Disease—Reply. *JAMA* **320**, 1286 (2018).

234. Wessex Cancer Clinical Network. *Informing 'WESFIT' Pilot Patient Involvement Report Feedback to participants.* (2017).

235. Moore, J. *et al.* Implementing a system-wide cancer prehabilitation programme: The journey of Greater Manchester's 'Prehab4cancer.' *European Journal of Surgical Oncology* (2020) doi:https://doi.org/10.1016/j.ejso.2020.04.042.

236. Michie, S., Abraham, C., Whittington, C., McAteer, J. & Gupta, S. Effective techniques in healthy eating and physical activity interventions: A meta-regression. *Health Psychology* vol. 28 690–701 (2009).