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Barriers and facilitators to implementation of musculoskeletal injury mitigation programmes for military service members around the world: a scoping review

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ABSTRACT

Introduction Musculoskeletal injury (MSK-I) mitigation and prevention programmes (MSK-IMPPs) have been developed and implemented across militaries worldwide. Although programme efficacy is often reported, development and implementation details are often overlooked, limiting their scalability, sustainability and effectiveness. This scoping review aimed to identify the following in military populations: (1) barriers and facilitators to implementing and scaling MSK-IMPPs; (2) gaps in MSK-IMPP research and (3) future research priorities.

Methods A scoping review assessed literature from inception to April 2022 that included studies on MSK-IMPP implementation and/or effectiveness in military populations. Barriers and facilitators to implementing these programmes were identified.

Results From 132 articles, most were primary research studies (90; 68.2%); the remainder were review papers (42; 31.8%). Among primary studies, 3 (3.3%) investigated only women, 62 (69%) only men and 25 (27.8%) both. Barriers included limited resources, lack of stakeholder engagement, competing military priorities and equipment-related factors. Facilitators included strong stakeholder engagement, targeted programme design, involvement/proximity of MSK-I experts, providing MSK-I mitigation education, low burden on resources and emphasising end-user acceptability. Research gaps included variability in reported MSK-I outcomes and no consensus on relevant surveillance metrics and definitions.

Conclusion Despite a robust body of literature, there is a dearth of information about programme implementation; specifically, barriers or facilitators to success. Additionally, variability in outcomes and lack of consensus on MSK-I definitions may affect the development, implementation evaluation and comparison of MSK-IMPPs. There is a need for international consensus on definitions and optimal data reporting elements when conducting injury risk mitigation research in the military.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Many military injury mitigation and prevention programmes in the military have shown efficacy and effectiveness but have been limited by implementation challenges in real-world settings.

⇒ Barriers and facilitators to implementation have not been adequately assessed and summarised, and it is unknown how well these have been reported in the current literature.

WHAT THIS STUDY ADDS

⇒ While hundreds of injury mitigation and prevention programmes have been implemented in military settings, factors hindering or facilitating programme implementation have not been systematically identified, until now.

⇒ This review has identified gaps in understanding and/or reporting of programme implementation, lack of international consensus on definitions and programme reporting standards and programmes addressing members' unique needs are greatly lacking.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Understanding barriers and facilitators for military musculoskeletal injury mitigation and prevention programmes enables military stakeholders (researchers, clinicians, policymakers, leaders and service members) to improve future implementation efforts.

INTRODUCTION

Musculoskeletal injuries (MSK-I) in military service members are a significant problem worldwide,[1–5] adversely impacting work, combat readiness and national security.[6] In the USA and the UK, MSK-I are the leading cause for seeking medical care[1] and discharge from military service.[7] In 2019, 53% of all US soldiers had an MSK-I, accounting for over >2 million medical encounters and 10 million limited

duty days.[8] The proportion of MSK-I is similar in other US military branches. Musculoskeletal conditions also account for the largest proportion of service-connected disabilities in the Department of Veterans Affairs.[9] With an average cost of US$2000 per injury, estimated annual direct costs exceed US$3 billion across the US military.[10] Indirect costs can exceed direct costs by fourfold.[11] Lifetime costs for injured US service members (including those with combat trauma) are estimated at US$2 million per individual.[12] The British Army estimated the financial burden of MSK-I in 2016 with the prevailing MSK-I rate at the time would result in capitation costs alone exceeding £1.2 billion over 15 years (2016–2031).[13] These figures are considered conservative estimates; the full economic impact of MSK-I in military populations remains unknown. Several US reports suggest the true incidence of MSK-I is even higher than reported. In some settings, at least half of all MSK-I sustained by US service members have gone unreported to medical providers,[14 15] a phenomenon also noted in UK personnel.[13]

In response to the high burden of MSK-I,[1 2 16] MSK-I mitigation and prevention programmes (MSK-IMPP) have been developed and studied across different global militaries and within different military arms and branches.[17–20] MSK-IMPPs have focused on various strategies to mitigate injury risk, including embedding medical assets,[21] modifying physical training programming (eg, decreasing running mileage),[22] neuromuscular warm-ups,[23] bracing and equipment,[24] nutritional interventions and dietary supplementation.[25 26] Although several MSK-IMPPs have demonstrated success at reducing injuries,[21 27 28] a recent systematic review revealed that some programmes increased injury rates compared with control groups.[29] Reported reasons for varied effectiveness across military studies are numerous. First, conducting research in military environments is difficult due to large populations with heterogenous backgrounds and responsibilities (eg, services with different priorities and focuses; large variations in occupational demands), coupled with time/resource constraints resulting in insufficient prioritisation of MSK-IMPPs. Additionally, MSK-IMPPs are often subgroup-specific and have primarily been designed, implemented and evaluated in western military populations, limiting their international scalability and generalisability.[24 30 31] Comparing military MSK-IMPP effectiveness across studies is also challenging, as the methodology to measure outcomes varies.[30 32] Importantly, even programmes with documented success in reducing injuries cannot always be well-implemented, hindering their long-term effectiveness.

Feasibility of implementation, including the translating and executing intervention components in real-world practice, can facilitate or impede MSK-IMPP adoption. Findings from injury prevention studies conducted in sport settings have cited implementation barriers (eg, cost, resources, knowledge, self-efficacy) to the adoption and scalability of MSK-IMPPs, and implementation fidelity (eg, programme adherence) as specifically influencing programme outcomes.[33–36] Known barriers to implementing and adopting military MSK-IMPPs include leadership priorities not aligning with programme implementation, competing time and resource demands specific to training or missions, accommodating large populations, unpredictable schedules and operational demands.[6 30 37] However, detailed descriptions of barriers and facilitators to military MSK-IMPP implementation, adoption and fidelity have not been adequately and systematically summarised.

In 2022, an international expert panel convened to identify and address barriers concerning implementation and scalability of military MSK-IMPPs. The expert panel first conducted the scoping review of the MSK-I prevention literature presented here to synthesise current knowledge about military MSK-IMPP implementation. Additional aims included identifying gaps in military MSK-IMPP research and identifying future research priorities for MSK-I mitigation in military settings. The panel's conclusions will inform military leaders, policymakers, human performance teams, clinicians and researchers about knowledge gaps limiting MSK-IMPP development and implementation. This should promote greater MSK-IMPP effectiveness and a healthier, fitter fighting force.

METHODS

Scoping review panel formation

A 15-person panel consisting of active-duty service members, veterans, military leaders, medical professionals (athletic trainers, physicians and physiotherapists), epidemiologists, researchers and exercise physiologists working in US and UK military settings with experience in policy, execution or investigation of military MSK-IMPPs were included in the research question development. A group subset led the planning and execution of the scoping review and met virtually to develop the search strategy, deliver training for a consistent review process, review preliminary results and interpret findings, review manuscript drafts and plan for dissemination of findings.

Study design

A scoping review was deemed most appropriate to address the research question; scoping reviews are broad in nature and designed to describe all available evidence, capturing findings from all possible sources.[38–40] Best practice methods were used for the scoping review's design and implementation[38–41]; the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for scoping reviews was followed when reporting the results.[42] A five-stage process was performed: identify the research question; identify relevant studies; select articles using a priori inclusion/exclusion criteria; chart data and collate, summarise and report results.[39–41] The current study protocol was developed and uploaded a priori on Open Science Framework (https://osf.io/5jsre/).[43]

Stage 1: identify the research question

The research question, developed through a combination of literature searches and research panel group discussion, was '*What are the barriers and facilitators to implementing and scaling military MSK-IMPPs?*' An MSK-IMPP was defined as any intervention or measure that was introduced to help reduce the risk of sustaining an MSK-I.[44 45] Implementation could include the insertion, adoption (ie, use) and/or assessment of an MSK-IMPP and/or its fidelity. MSK-I was defined using the Defense Centers for Public Health-Aberdeen (DCPH-A) injury taxonomy definition of mechanical energy injury: '*damage of or interruption to the normal functioning of body tissues that results when mechanical energy transfer exposure exceeds the threshold of tissue tolerance either suddenly (acute traumatic injury) or gradually (cumulative microtraumatic injury)*'.[46] While the UK adopts the international codes for injury reporting, a similar taxonomy was not available. Thus, the US definitions were used. Within the DCPH-A taxonomy, mechanical injury is delineated into musculoskeletal and non-musculoskeletal; only MSK-I were investigated in the current review.[46]

Stage 2: identify relevant studies

A preliminary search was conducted of the major clinical and grey literature databases to evaluate literature density and

identify keywords.[39–41] Databases included MEDLINE and the Defense Technical Information Center (DTIC). Exploratory search terms were kept broad, to maximise inclusivity.[41] Search terms included *'military'*, *'injury prevention'*, *'barriers'*, *'facilitators'* and *'review'*. Sixty-six articles were identified as pertinent from MEDLINE and DTIC. The references of these 66 articles were then searched for further relevant articles, with none identified in this preliminary search. Titles and abstracts of these 66 articles were then analysed for relevant search terms. From this process, the final search strategy was created to cast a broad net ensuring greatest inclusion while excluding specific irrelevant studies identified through the preliminary search. A medical librarian (RA) assisted in creating the final search strategy for each database and compiled the final search results.

Search strategy

Five databases (MEDLINE, CINAHL, Embase, Cochrane Library and Web of Science) were electronically searched. DTIC was searched for grey literature. The search was performed on 21 April 2022 (search terms available in online supplemental appendix SA.1).

Stage 3: study selection

The research team was divided into eight pairs to screen articles for eligibility. All screeners attended a training session to review specific inclusion and exclusion criteria (online supplemental appendix SA.2). Following training, a priori selection of titles and associated abstracts were randomly assigned in equal numbers to the screening pairs for eligibility screening. The same screening pairs then obtained and screened all full-text articles deemed eligible per title and abstract screening.[41] Each screening pair resolved title, abstract and full-text article, handling disputes by consensus. If consensus could not be reached, the lead author (GSB) provided final resolution after consensus with panel members if necessary. Full-text articles were obtained through university online library or interlibrary loans. If necessary, the authors were contacted to request full text. If a full-text article could not be retrieved, the article was excluded from the review (including conference abstracts without a corresponding full-text report). Multiple manuscripts describing the same study (eg, secondary analyses) were all included as reports about barriers and facilitators could vary. All screening was performed using the Covidence systematic review software (Veritas Health Innovation, Melbourne, Australia).

Stage 4: data extraction

Data were extracted from full-text articles by the screening pairs and entered into a customised electronic database, abiding by recommended practice guidelines.[47] The customised electronic database was based on the National Institute for Health and Care Excellence evidence tables.[48] Each screening pair member independently extracted data. Screening pairs resolved discrepancies by consensus. The lead author (GSB) settled unresolved discrepancies. Data extracted included author, title, publication year, journal, country of origin, military branch, study design, level of prevention (primary, secondary), prevention programme description, body part(s) or segment(s) targeted by the MSK-IMPP, implementation barriers, implementation facilitators, fidelity, injury mitigation results and recommended injury mitigation/prevention strategies (systematic/scoping reviews only). Extracted data were uploaded into the Open Science Framework.[43]

Stage 5: collating, summarising and reporting the results

Data and key findings were initially collated and summarised for descriptive analysis (GSB), with themes and categories finalised after group discussion and consensus. There was no minimum number of articles necessary to specify a theme. Individual article data were meta-aggregated to explore reported barriers and facilitators for implementing military MSK-IMPPs, which were then reviewed for final analysis and interpretation (GSB, CED, EAR, NA, JLF, DIR, SJdlD). Publication rates by year were also calculated, using R V.4.02.[49] The *dplyr* package was used for cleaning, coding and analyses. The *ggplot2* package was used for data visualisation.

Patient and public involvement

Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

RESULTS

Study characteristics

A total of 7835 titles and abstracts were screened, with 132 total articles included (figure 1). Study characteristics are summarised in online supplemental appendix SA.3. After only 11 relevant studies published up through 1994, a steady increase in publications began with the greatest 5-year publication rate between 2000 and 2004 (29 studies; 22.0%), followed by 2010–2014 (27 studies, 20.5%; figure 2). Of the 132 articles, 49.2% (n=65) addressed US military populations. Most articles (n=76; 57.6%) investigated Army populations. Most articles used a primary study design (n=90; 68.2%), primarily randomised controlled trials (n=49; 54.4% of primary design studies). The remaining 42 (31.8%) articles used a secondary study design (eg, review paper). Among articles using a primary study design, 62 (68.9%) included only men, 3 (3.3%) included only women and 25 (27.8%) included men and women.

MSK-IMPP types

The types of interventions delivered in MSK-IMPPs described in primary research studies could be grouped into 10 categories (studies with the intervention out of total n=90): education (n=5; 5.5%), embedding medical personnel (n=1; 1.1%), equipment (n=33; 36.7%), adding an exercise intervention (n=25; 27.8%), data-driven approach (n=1; 1.1%), modifying existing physical training (n=13; 14.4%), nutrition/supplementation (n=3; 3.3%), pharmacological (n=1; 1.1%), postinjury treatment/rehabilitation (n=1; 1.1%) and pretraining injury symptom screening and referral (n=1; 1.1%). Six studies (6.7%) implemented multiple interventions.

Barriers to successful MSK-IMPP implementation

Reported barriers were categorised into four common themes: lack of stakeholder engagement, limited resources, competing military priorities and equipment-related factors (table 1). These themes are not mutually exclusive; some barriers were categorised into multiple themes. Examples to illustrate each theme are presented in the 'Discussion' section.

Facilitators of successful MSK-IMPP implementation

Reported facilitators were grouped into six themes: strong stakeholder engagement, targeted design of MSK-IMPP, involvement/proximity of experts, providing injury mitigation education, low burden and emphasising end-user acceptability (table 1). Like the barriers, some facilitators fell under multiple themes. Examples to illustrate each theme are presented in the 'Discussion' section.

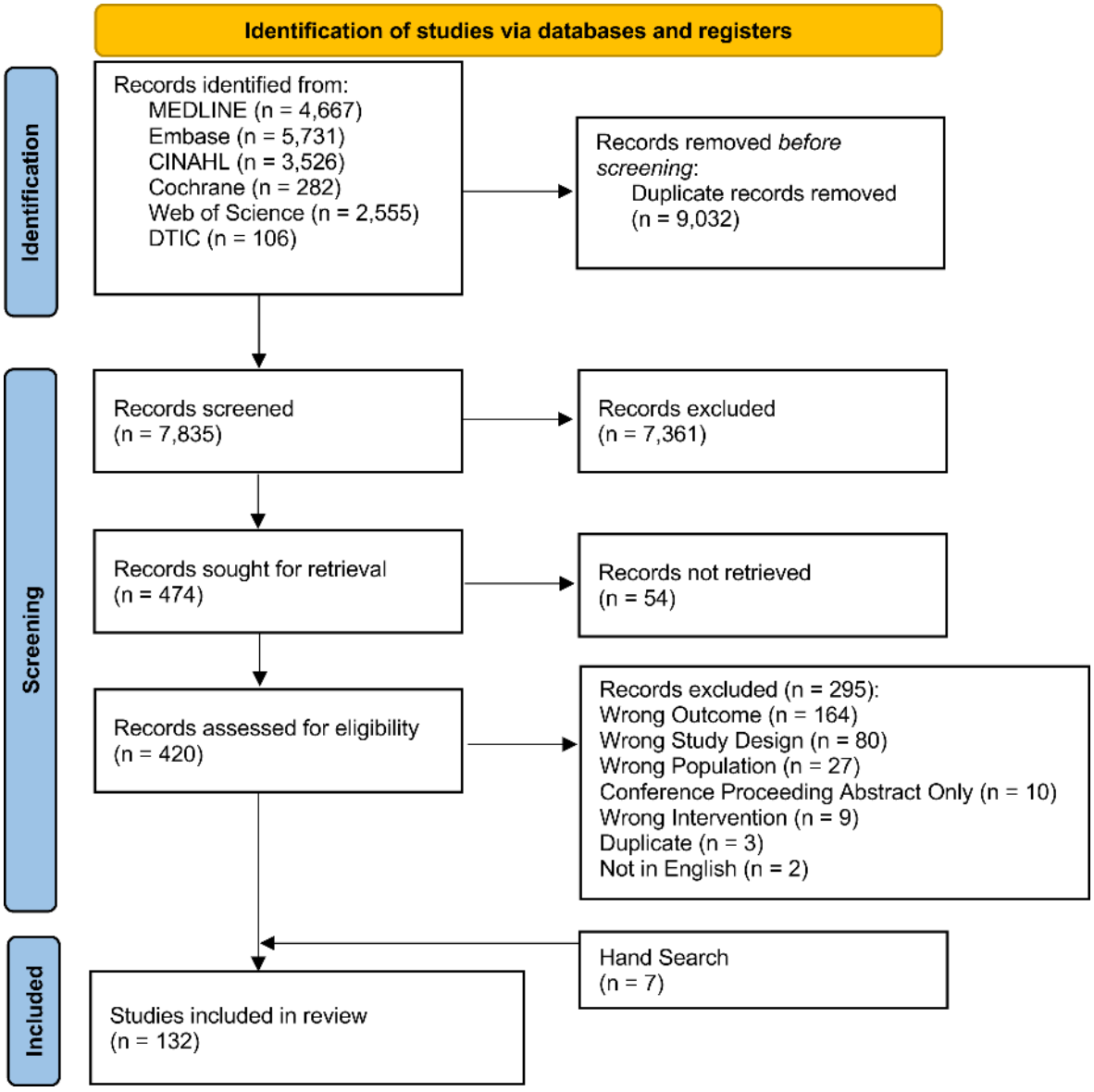

Figure 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram. CINAHL, Cumulated Index to Nursing and Allied Health Literature; DTIC, Defense Technical Information Center; MEDLINE, US National Library of Medicine bibliographic database.

DISCUSSION

This review identified 132 articles forming the current knowledge base about military MSK-IMPP implementation. A structured analysis of the results from the review identified four common barrier and six common facilitator themes affecting implementation. The results highlight relevant knowledge and translation gaps and underscore future research priorities.

Implementation barriers

MSK-IMPP implementation barriers were summarised by four themes. These barriers impeded military MSK-IMPP implementation, even if the programmes effectively reduced injuries.

Lack of stakeholder/end-user engagement

MSK-IMPP implementation may be hindered by insufficient engagement with and/or from stakeholders, including leaders responsible for programme implementation and programme end-users. It can be challenging to convince leadership about the benefits of MSK-IMPPs to the extent necessary to change current training routines and protocols merely to implement MSK-IMPPs. One report noted resistance among supervisors to adhere to the MSK-IMPP being implemented in the organisation.[50] Drill sergeants leading physical training disregarded MSK-IMPP training guidance as 'merely a suggestion', leading to programme non-adherence. The authors also noted deeply held cultural beliefs among supervisors about the type and volume of training (eg, long distance runs) necessary to prepare for military physical fitness testing. Some of these beliefs did not align with MSK-IMPP's training principles.[50] This highlights how conflicting beliefs and practices between MSK-IMPP designers and those responsible for implementing the programme may decrease fidelity and compromise implementation.

Successful MSK-IMPP implementation also relies on end-user adherence (eg, exercise programming participation, taking recommended nutritional supplements, using recommended equipment). Partial or non-adherence poses a barrier to implementation. For example, in a programme requiring participants to take supplements to mitigate MSK-I (eg, calcium or vitamin

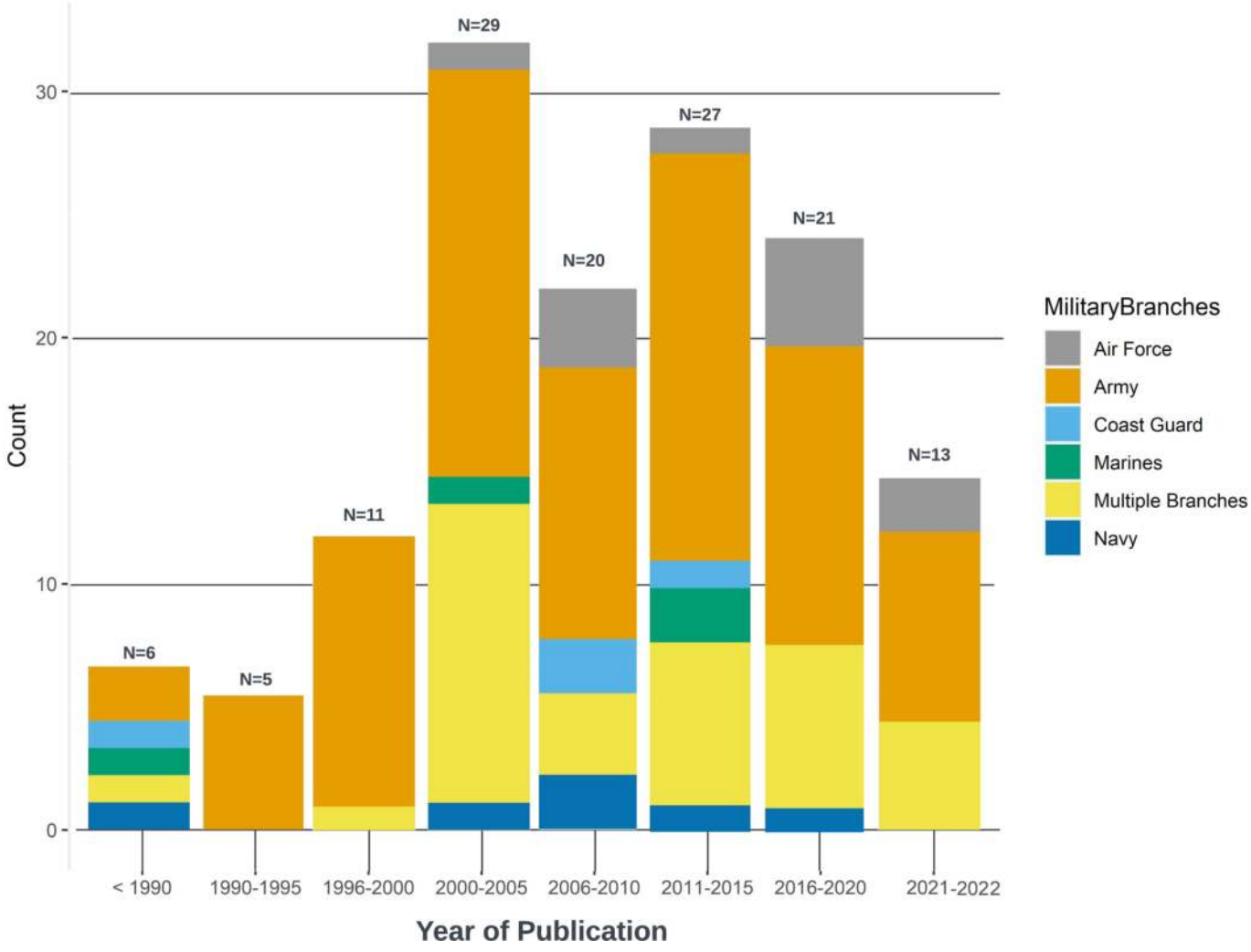

Figure 2 Publication rates by 5-year period and military branch.

D), some participants did not reliably take the supplements.[25 26] MSK-IMPP implementation may also be compromised due to changes in military training schedules, as seen in a study assessing the effect of hamstring stretching on lower extremity injuries. In one MSK-IMPP, compliance with the recommended hamstring stretching intervention was limited while trainees underwent multiday field training exercises.[27]

Limited resources

Limited financial, time and personnel resources may serve as barriers to military MSK-IMPP implementation. Limited financial resources can constrain implementation of equipment-related programmes, such as those using orthoses, shoe insoles and ankle braces.[24 51–54] Despite low cost of many equipment-related programmes[24 51–54] and a significant reduction of back and lower extremity injuries during a trial testing custom foot orthoses across 3 months of military training in Denmark, the high cost of the orthoses made the intervention infeasible beyond the confines of the research study.[51]

Limited time resources can also be a barrier, especially when military training schedules are already constrained. When implementing an exercise intervention during military training, there may be insufficient time during the training course to accommodate a recommended gradual increase in exercise volume and/or intensity or appropriate surveillance time to evaluate effectiveness.[23 55] Limited time is also reflected in the 'competing military priorities' barrier, described in detail in the next immediate section.

Limited personnel resources may also serve as a barrier to implementation. For certain interventions, personnel must be adequately educated and trained to conduct or supervise the programme. However, trained individuals may not be available to ensure the programme is properly performed.[50 56–58] In a study assessing the ability of a screening tool and referral process to reduce MSK-I during advanced training, a noted limitation was reliance on drill sergeants' abilities to assess whether a soldier had an injury and refer them appropriately. This may have been impacted by the drill sergeants' inexperience and lack of training in identifying injuries.[56] Other investigators noted the importance of adequate programme oversight to ensure fidelity of the intervention.[58] High turnover among training cadre, supervisory or leadership personnel can also pose a barrier, as awareness of the MSK-IMPP or the ability to adequately facilitate programme implementation may disappear when personnel familiar with the programme leave the organisation.[50] Successful implementation of any MSK-IMPP will require resources in some capacity, the absence of which may impede implementation, regardless of demonstrated programme efficacy.

Table 1 Barriers and facilitators to implementation themes from MSK-IMPP by study

Barriers to implementation	Study	Facilitators to implementation	Study
Limited resources (n=21)	Aaltonen, 2007[109] Berg Rice et al 2002[50] Berg Rice et al 2007[56] Brushøj et al 2008[23] Bullock et al 2010[24] Coakwell et al 2004[57] Dijksma, 2019[110] Gillespie and Grant 2000[54] Heard, 2020[111] Jones, 1999[112] Knapik et al 2005[83] Knapik, 2009[93] Knapik, 2009[66] Knapik, 2019[78] Larsen et al 2002[51] Olmsted, 2004[113] Rome et al 2005[55] Scott et al 2012[58] Sharma, 2014[114] Withnall et al 2006[52] Zimmermann et al 2017[53]	Low burden on resources (n=12)	Amako et al 2003[71] Äng, 2009[115] Barnes et al 2015[26] Baxter et al 2011[100] Bonanno, 2017[97] Brushøj et al 2008[23] Childs et al 2014[98] Coppack et al 2011[72] Goodall et al 2013[99] Hartig and Henderson 1999[27] Lappe et al 2008[25] Slater, 2009[116]
Competing military priorities (n=14)	Alricsson et al 2004[59] Berg Rice et al 2002[50] Brushøj et al 2008[23] Burgess, 1998[117] Dettori, 1995[118] Dijksma, 2019[110] Dijksma, 2020[119] Hartig and Henderson 1999[27] Heard, 2020[111] Milgrom et al 2004[62] Robitaille et al 2021[60] Ross, 2002[120] Rudzki, 1997[3] Zeng, 2021[121]	Targeted design of MSK-IMPP (n=11)	Alricsson et al 2004[59] Brushøj et al 2008[23] Burgess et al 1998[117] Childs et al 2010[20] Hartig and Henderson 1999[27] Knapik et al 2002[82] Knapik et al 2003[80] Knapik et al 2005[83] Parkkari et al 2011[18] Sell et al 2016[85] Suni et al 2013[81]
Lack of stakeholder/end-user engagement (n=9)	Barnes et al 2015[26] Berg Rice et al 2002[50] Brushøj et al 2008[23] Hartig and Henderson 1999[27] Knapik et al 2004[95] Lappe et al 2008[25] Murray et al 2015[19] Rudzki, 1997[3] Rudzki, 1999[122]	Strong stakeholder engagement (n=22)	Amako et al 2003[71] Berg Rice et al 2002[50] Burgess, 1998[117] Coppack et al 2011[72] George et al 2011[74] Hartig and Henderson 1999[27] House et al 2013[75] Knapik, 2002[82] Knapik, 2019[78] Larsen et al 2002[51] Milgrom, 2017[123] Parkkari et al 2011[18] Pope et al 1998[76] Robitaille et al 2021[60] Rome et al 2005[55] Rudzki, 1997[3] Scott et al 2012[58] Sherrard et al 2004[70] Shumway et al 2016[77] Steinberg et al 2021[69] Yeung et al 2001[73] Ziemke et al 2001[86]
Equipment-related factors (n=18)	Amoroso et al 1998[88] Bullock et al 2010[24] Esterman and Pilotto 2005[61] Finestone et al 1992[68] Finestone et al 1999[63] Finestone et al 2004[64] Gillespie and Grant 2000[54] Gross and Liu 2003[67] Jones, 2002[1] Knapik et al 2008[65] Knapik, 2009[66] Knapik, 2019[78] Lappe et al 2008[25] Milgrom, 2004[64] Milgrom, 2005[62] Rome et al 2005[55] Schmidt, 2005[124] Schumacher, 2000[125]	Involvement/Proximity of MSK-I experts (n=19)	Alricsson, 2004[59] Amoroso, 1998[88] Äng, 2009[115] Cameron, 2014[16] Cancelliere, 2019[96] Carow, 2016[92] Fisher, 2021[21] Gillespie, 2000[54] Grier, 2018[87] Knapik, 2004[95] Knapik, 2010[89] Lappe, 2008[25] Larsson, 2012[94] Pihlajamäki, 2006[126] Pope, 1998[76] Pope, 2000[90] Roos, 2015[127] Thacker, 2002[91] Ziemke, 2001[86]

Continued

Table 1 Continued

Barriers to implementation	Study	Facilitators to implementation	Study
		Providing MSK-I mitigation education (n=7)	Brushoj et al 2008[23] Cancelliere et al 2019[96] Childs et al 2010[20] Fisher et al 2021[21] Knapik, 2009[93] Scott et al 2012[58] Suni et al 2013[81]
		Emphasising end-user acceptability (n=9)	Brushøj et al 2008[23] Dijksma, 2020[119] Gross and Liu 2003[67] Knapik, 2006[128] McDevitt et al 2004[102] Milgrom et al 2005[62] Mundermann et al 2001[103] Pope, 1999[101] Thacker et al 2002[91]

MSK-I, musculoskeletal injury; MSK-IMPP, musculoskeletal injury mitigation and prevention programme.

Competing military priorities

High priority duty requirements, tightly controlled training schedules and varying routines based on current operations serve as competing demands, potentially disrupting MSK-IMPP implementation. Competing demands can limit consistent exercise programming implementation; highlighting time as a limited resource.[59 60] Physical training sessions as part of an MSK-IMPP for Canadian Infantry trainees were sometimes 'unexpectedly replaced with prioritised (military) training' or supplanted by frequent 'unscheduled tasking requests', highlighting how MSK-IMPPs can be deprioritised for other activities.[60] Similarly, researchers studying a strengthening programme to reduce neck pain in Air Force pilots reported that although the intervention was to be performed three times weekly, competing training requirements resulted in most participants performing the intervention less than twice weekly.[59]

Many military training courses have rigorous schedules which significantly alter an individual's availability; this may interfere with performing MSK-IMPP interventions. Decreased adherence to MSK-IMPP during field training may be due to lack of end-user buy-in and/or competing military field training demands on service members' time.[27]

Lack of stakeholder engagement can also manifest as competing or conflicting military priorities. As previously noted in one report, supervisors' beliefs about the type and volume of training (eg, long distance runs) necessary to prepare for military physical fitness testing conflicted with their MSK-IMPP's training guidance.[50] The supervisors were evaluated on their trainees' physical fitness test performances, but not on their adherence to the MSK-IMPP. Supervisors were thus reluctant to alter their traditional physical training practices. Their competing or conflicting priorities (fitness test performance vs MSK-IMPP adherence) compromised MSK-IMPP implementation.[50]

Equipment-related factors

Besides high equipment costs, equipment-related discomfort, lack of trust in the equipment or equipment compromising military task performance can also pose as barriers. Several studies noted non-adherence with MSK-IMPP equipment wear/use due to discomfort.[61–67] One study investigated foot orthoses worn by Royal Australian Air Force Recruits; half of the participants failed to wear the orthoses as directed due to discomfort, the orthoses fitting poorly in recruits' footwear, cumbersomeness of use, burden of switching orthoses among multiple pairs of shoes and perception that the orthoses would not help or might even cause injury.[61] In another study, the single available shoe width accommodated only 50% or less of the recruits. Consequently, recruits with wider feet compensated for the lack of available shoe widths by choosing larger shoe sizes. Three shoe widths for each shoe length are recommended to adequately accommodate the population.[68]

Perceptions that MSK-IMPP equipment interfered with military tasks also impacted use. When testing parachuting ankle braces, some Army airborne students reported poorly fitting braces slipping off their heels and hindering walking. Two students attributed brace use to causing injuries during parachute landing falls.[65] Sustained MSK-IMPP implementation will likely fail if perceived harm or risk outweighs perceived benefits.

Implementation facilitators

MSK-IMPP implementation facilitators were summarised into six themes that could potentially improve programme effectiveness. Some facilitators can even help overcome barriers, demonstrating the need for careful evaluation, and understanding of which barriers might be mitigated with certain facilitators.

Strong stakeholder engagement

Engaging stakeholders throughout the implementation process can facilitate programme adoption and fidelity. Intuitively, while lack of stakeholder engagement was a noted barrier, strong stakeholder engagement was as a facilitator to MSK-IMPP implementation, with studies noting that leadership buy-in and support were key to successful implementation.[50 69 70] Leadership buy-in and support can have a top-down effect, leading to end-user engagement that facilitates implementation. Leadership buy-in and support can also facilitate MSK-IMPP adherence; many researchers noted successful implementation when leaders enforced programme implementation as standard operating procedure and/or held subordinate leaders responsible for MSK-I rates or programme adherence.[3 18 27 50 55 71–77]

Collaborating with leadership and stakeholders before MSK-IMPP implementation can also facilitate success.[60 78 79] A structured, collaborative process between programme designers and Canadian military training personnel included leadership, training, fitness and medical personnel while planning and designing a modified physical training programme.[60] The authors emphasised early collaboration with relevant stakeholders to optimise potential for MSK-IMPP success.[60] Pre-implementation collaboration enables those implementing the programme to

proactively identify and mitigate potential barriers, and promote further leadership buy-in and support. Continued stakeholder engagement ensures consistent MSK-IMPP visibility from inception to implementation, subsequently improving adherence to programme guidelines and improving its effectiveness.[58]

Targeted design of MSK-IMPP

Military MSK-IMPP can be tailored to facilitate implementation by accounting for the military setting's unique needs and constraints (eg, target population, environment) and pertinent timing for targeted prevention during programme design.[18 80–84] Working with unit personnel to design the content of an educational guidebook about back safety for Finnish military conscripts improved the guidebook's relevance to the conscripts,[81] likely improving its adoption. Tailoring exercise programming to individual end-users was an important facilitator for MSK-IMPPs implementing exercise training interventions.[59] Tailoring exercise programmes to groups of individuals with similar fitness levels (ie, streaming) was both recommended if individually tailored exercise programmes were infeasible.[83] Collaborating with the organisation's personnel facilitates programme implementation.[18 20 23 27 85]

In some cases, designing interventions led by existing military personnel, rather than requiring embedded subject matter experts, can improve MSK-IMPP practicality, adoption and scalability. Having committed instructors or unit leaders delivering and supporting the programme creates group accountability and buy-in to improve implementation.[18 20 23] Several studies implemented MSK-IMPPs using 'train-the-trainer' models, where programme designers taught organisational personnel to administer the intervention. One study described a pilot phase after training the trainers, during which the trained drill sergeants conducted the exercise programming. Programme designers and the trained drill sergeants collaborated daily (including focus group sessions) during the pilot phase to modify the programme as necessary.[80] This ensured a programme was tailored to the trainers' and specific service members' needs, further facilitating implementation. Accounting for end-user characteristics and their operational environment enables targeted programme designs having better chances of success versus 'one-size-fits-all' solutions.

Involvement/Proximity of MSK-I experts

Involvement and/or proximity of experts can facilitate MSK-IMPP implementation in multiple ways. Ensuring end-users' proximity and/or access to embedded medical providers or other relevant experts (eg, human performance coaching staff) has improved programme adoption by end-users.[16 21 86 87] Unit personnel familiarity with embedded medical staff increased their interactions and acceptance of the MSK-IMPP interventions.[86 87] Embedding medical providers and human performance professionals in multidisciplinary care teams can foster collaboration with unit staff, creating a team approach to facilitate programme implementation.[16 21 87] Having subject matter experts (eg, athletic trainers and physiotherapists) provide end-users with ongoing, performance-related feedback may facilitate programme implementation, adherence and fidelity.[25 54 59 88–92] Having organisational personnel implement MSK-IMPPs (eg, via train-the-trainer model) can also facilitate implementation, but continued involvement of experts is recommended to maintain programme fidelity. Ongoing collaboration between subject matter experts and organisational personnel optimises MSK-IMPP adoption, adherence and fidelity.

Providing MSK-I mitigation education

Incorporating MSK-I mitigation education into MSK-IMPPs may improve stakeholders' understanding of the programme's importance.[58 93 94] Providing leadership with education and prevention recommendations led to senior leaders acknowledging the need to proactively reduce overuse injuries.[58] Subject matter experts (eg, athletic trainers, health coaches, physiotherapists) can provide stakeholders with timely, relevant updates about injury rates and/or high-risk activities. Injury advisory committees can increase collaboration between experts and organisational members.[50 93 95] Informing stakeholders about their MSK-I burden can improve recognition of the need for MSK-IMPPs, increase buy-in and foster an environment supporting implementation efforts. Educational materials (eg, posters, training cards, websites) can facilitate adherence through visual reminders, and optimise fidelity through accurate MSK-IMPP delivery and performance.[20 23 96]

Low burden on resources

MSK-IMPPs must compete with multiple organisational demands for prioritisation of effort. The primary goal of 'mission readiness' may require diverting resources, (eg, finances, time, personnel) from these programmes. MSK-IMPPs that minimise resources and burden on stakeholders have greater likelihood of adoption. Low intervention cost and end-user burden (eg, minimal time commitment) facilitate MSK-IMPP implementation.[25 26 97] Integrating MSK-IMPP into existing training facilitates adoption and adherence.[23 25 27 98 99] MSK-IMPP education easily taught (by experts or organisational personnel) in a short period of time can also facilitate programme adoption.[23 98 100] This was demonstrated in a course taught for only 2 hours to the Danish Army Sergeants who led the programme.[23] MSK-IMPPs that contain exercise interventions with low technical demands (eg, body weight-resisted exercises vs specialised equipment requirements) more easily integrate into group settings (eg, basic military training), and can be scaled for varying fitness levels. For example, adherence was improved when an exercise intervention relied only on body weight resistance rather than weights or other exercise equipment.[72] Stakeholders are more likely to adopt and adhere to programmes that are perceived to be a low burden.

Emphasising end-user acceptability

MSK-IMPP can only be effective when accepted and used by those they are designed for—that is, the end-user. Educating end-users on the importance and effectiveness of MSK-IMPP, how specific interventions can lead to that end state and soliciting and incorporating feedback from end-users can improve MSK-IMPP acceptance and implementation. End-users in several studies reported that MSK-IMPPs improved their performance on military duties or tasks, likely contributing to programme adherence.[23 67 101] When modifying physical training to reduce pelvic stress fracture risk in female Australian Army recruits, training instructors perceived the programme to help achieve training objectives by reducing recruit injuries and fatigue.[101] Several studies noted improvements in physical performance measured via methods such as the Cooper test, broad jump distance, shuttle run or sprint times.[23 67] In addition to educating end-users on a programme's positive impact on unit training objectives, this impact can also increase leadership support, acting as a positive feedback loop.

Table 2 Identified research gaps for implementation of military injury mitigation and prevention programmes

Research gaps	Explanation
Effectiveness of injury mitigation and prevention programmes for female compared with male military service members	Three percent of primary articles investigated MSK-IMPPs exclusively in military women, while 69% included only men. In studies with mixed populations, assessing outcomes by sex (eg, sex-specific modelling with appropriately powered studies) can elucidate factors relevant to each sex. Also, including qualitative methods, such as focus groups, may help stakeholders understand the unique needs of women regarding injury mitigation and prevention programmes, and how they might differ from those tailored to men.
Investigating and reporting MSK-IMPP implementation frameworks and strategies	Implementation frameworks can be used to evaluate the context of MSK-IMPPs during its design and formulate strategies for implementation. However, this review found that implementation context and strategies were rarely evaluated formally and/or reported in studies. The curated information about MSK-IMPP implementation was extracted from discussion sections and author comments in reviews, rather than formal evaluation and reporting of implementation context, strategies or outcomes. This further underscores the existing gap of poor implementation reporting in the military MSK-IMPP.
Investigating and reporting MSK-IMPP implementation outcomes	Systematic evaluation of MSK-IMPP includes evaluating and reporting specific implementation outcomes, such as fidelity and maintenance. Evaluating implementation outcomes allows one to identify whether the implementation of the MSK-IMPP was successful separately from evaluating the effectiveness (ie, reduction in MSK-I) of the MSK-IMPP. Few studies included in this review specifically reported implementation outcomes, highlighting a gap in the MSK-IMPP literature.
Lack of consensus and variability in MSK-I definitions	Studies demonstrated wide heterogeneity in definitions of MSK-I, which influences how these programmes are assessed for effectiveness. MSK-I definitions in this review alone included: (1) conditions that required seeking medical care; (2) conditions that prevented subjects from completing their military duties; (3) specific ICD-9 diagnosis codes from medical records; (4) self-reported MSK-I and (5) other information (eg, training data, limited duty time or discharge rates) used either as a surrogate for or in addition to specific injury surveillance data. Further research is needed to reach consensus on standard definitions and common data elements that should be reported in all studies.
MSK-IMPP transportability to other countries and cultures	Few studies investigated MSK-IMPP programmes outside of Western Europe and North America. Further research is needed to understand the effectiveness and unique needs for MSK-IMPPs in other countries. However, these findings may be affected by only including studies written in English.
MSK-IMPP scalability	Few studies investigated expanding MSK-IMPPs to broader populations (ie, across multiple military branches, bases or countries). Programme coordination between multiple entities is needed to assess potential programme scalability.

MSK-I, musculoskeletal injury; MSK-IMPP, musculoskeletal injury mitigation and prevention programme.

Equipment-based MSK-IMPPs must gain end-user acceptance for the equipment to be worn or used. Some participants reported a greater feeling of safety and confidence when wearing a knee brace after anterior cruciate ligament reconstruction; this may have improved adherence to the equipment intervention.[102] Equipment that is comfortable to wear or use (eg, foot orthoses or shoe inserts) likely facilitates implementation.[91 103] End-user acceptability of MSKI-MPPs can be measured, understood and where indicated, implementation of MSKI-MPPs can be adjusted; in these studies, methods for obtaining user feedback and measuring acceptability included questionnaires,[91 102] informal conversations,[101] visual analogue scales for assessing comfort.[103] Successful MSK-IMPP implementation and adherence rely heavily on end-user acceptance; acceptance often depends on the intervention's perceived impact on military task performance, comfort and/or safety.

Identified gaps and research priorities for MSK-IMPP in the military

Research gaps that should be prioritised in future research are highlighted in table 2. Specific outcomes regarding MSK-IMPP implementation should be evaluated and reported by systematically assessing the implementation context and using implementation frameworks when designing and delivering military MSK-IMPPs (eg, Translating Research into Injury Prevention Practice framework,[104] Reach, Effectiveness, Adoption, Implementation and Maintenance planning and evaluation framework,[105 106] Standards for Reporting Implementation studies statement[107] and Consolidated Framework for Implementation Research).[108] From an implementation science perspective, implementation outcomes include factors such as fidelity, maintenance and scalability (table 3).

Limitations

Although the literature search was exhaustive, only articles in English were included. This limited the geographical spread of the data evaluated. Articles could have potentially been missed due to using different keywords, grey literature search or manuscript access. Most studies reported findings in North America, Western Europe or Australasia. Including non-English studies would have likely resulted in more diverse representation. Risk of bias was not formally assessed for each individual study. There was heterogeneity in the settings where the studies took place, even within the same countries, and the barriers and facilitators to MSK-IMPP implementation are likely more relevant to some settings than others.

CONCLUSION

This scoping review identified a variety of barriers and facilitators to military MSK-IMPP implementation. Barriers included lack of stakeholder engagement, limited resources, competing military priorities and equipment-related factors. Facilitators included strong stakeholder engagement, targeted

Table 3 Key implementation outcomes to evaluate and report

Implementation outcomes	Definition
Fidelity	Refers to the degree to which 'programme providers implement programmes as intended by the programme developers'.[129] Measured using components such as compliance, adherence and quality of delivery.
Compliance	A component of fidelity; refers to whether the intervention components were performed as directed, relative to a fixed standard (eg, performed exercises correctly).[130]
Adherence	A component of fidelity; refers to whether the intervention components were performed as directed within the organisation/military unit (dosage, timing, frequency of the intervention).[129 130]
Uptake	Degree to which an intervention is adopted.[130]
Maintenance	Degree to which a behaviour or intervention becomes routine for an individual or organisation.[105 131 132]
Scalability	Increasing the reach and extension of an intervention to a greater number of end-users while retaining effectiveness.[133]

MSK-IMPP design, involvement/proximity of MSK-I mitigation/prevention experts, providing mitigation education, low burden and end-user acceptability. MSK-IMPP implementation context, strategy and/or outcomes were not often formally evaluated or reported; MSK-I outcomes varied widely across all studies. Future MSK-IMPP research should systematically evaluate[84] and formally report details about implementation context (including barriers, facilitators and implementation strategies). Reporting both implementation outcomes and effectiveness outcomes will improve MSK-I mitigation and prevention efforts in the military.

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REFERENCES

1 Jones BH, Canham-Chervak M, Canada S, *et al*. Medical surveillance of injuries in the US military: descriptive epidemiology and recommendations for improvement. *Am J Prev Med* 2010;38:S42–60.
2 Lovalekar M, Hauret K, Roy T, *et al*. Musculoskeletal injuries in military personnel-descriptive epidemiology, risk factor identification, and prevention. *J Sci Med Sport* 2021;24:963–9.
3 Rudzki SJ. Injuries in Australian army recruits. Part I: decreased incidence and severity of injury seen with reduced running distance. *Mil Med* 1997;162:472–6.
4 Heir T, Glomsaker P. Epidemiology of musculoskeletal injuries among Norwegian conscripts undergoing basic military training. *Scand J Med Sci Sports* 1996;6:186–91.
5 Fenn BP, Song J, Casey J, *et al*. Worldwide epidemiology of foot and ankle injuries during military training: a systematic review. *BMJ Mil Health* 2021;167:131–6.
6 Molloy JM, Pendergrass TL, Lee IE, *et al*. Musculoskeletal injuries and United States Army readiness part I: overview of injuries and their strategic impact. *Mil Med* 2020;185:e1461–71.
7 Ministry of Defence. Annual medical discharges in the UK regular armed forces 1 April 2015 to 31 March 2020; 2020.
8 United Stated Arm Public Health Center. Health of the force; 2019.

9 United States Department of Veteran Affairs. VBA annual benefits report fiscal year 2022; 2023.
10 Teyhen DS, Goffar SL, Shaffer SW, *et al*. Incidence of musculoskeletal injury in US army unit types: a prospective cohort study. *J Orthop Sports Phys Ther* 2018;48:749–57.
11 Forrest LJ, Jones BH, Barnes SR, *et al*. The cost of lower extremity fractures among active duty US army soldiers, 2017. *MSMR* 2021;28:6–12.
12 Bilmes L. The financial legacy of Iraq and Afghanistan: how wartime spending decisions will constrain future national security budgets. *SSRN Journal* 2013.
13 Management Consultancy Services (Army). Understanding the financial cost of muscular skeletal injuries; 2016.
14 Smith L, Westrick R, Sauers S, *et al*. Underreporting of musculoskeletal injuries in the US army: findings from an infantry brigade combat team survey study. *Sports Health* 2016;8:507–13.
15 Cohen BS, Pacheco BM, Foulis SA, *et al*. Surveyed reasons for not seeking medical care regarding musculoskeletal injury symptoms in US army trainees. *Mil Med* 2019;184:e431–9.
16 Cameron KL, Owens BD. The burden and management of sports-related musculoskeletal injuries and conditions within the US military. *Clinics in Sports Medicine* 2014;33:573–89.
17 Zambraski EJ, Yancosek KE. Prevention and rehabilitation of musculoskeletal injuries during military operations and training. *J Strength Cond Res* 2012;26 Suppl 2:S101–6.
18 Parkkari J, Taanila H, Suni J, *et al*. Neuromuscular training with injury prevention counselling to decrease the risk of acute musculoskeletal injury in young men during military service: a population-based, randomised study. *BMC Med* 2011;9:35.
19 Murray M, Lange B, Nørnberg BR, *et al*. Specific exercise training for reducing neck and shoulder pain among military helicopter pilots and crew members: a randomized controlled trial protocol. *BMC Musculoskelet Disord* 2015;16:198.
20 Childs JD, Teyhen DS, Casey PR, *et al*. Effects of traditional sit-up training versus core stabilization exercises on short-term musculoskeletal injuries in US army soldiers: a cluster randomized trial. *Phys Ther* 2010;90:1404–12.
21 Fisher R, Esparza S, Nye NS, *et al*. Outcomes of embedded athletic training services within United States air force basic military training. *J Athl Train* 2021;56:134–40.
22 Dawson GM, Broad R, Orr RM. The impact of a lengthened Australian army recruit training course on recruit injuries. *J Mil Vet Health* 2015;23:14–9.
23 Brushøj C, Larsen K, Albrecht-Beste E, *et al*. Prevention of overuse injuries by a concurrent exercise program in subjects exposed to an increase in training load: a randomized controlled trial of 1020 army recruits. *Am J Sports Med* 2008;36:663–70.
24 Bullock SH, Jones BH, Gilchrist J, *et al*. Prevention of physical training–related injuries: recommendations for the military and other active populations based on expedited systematic reviews. *Am J Prev Med* 2010;38:S156–81.
25 Lappe J, Cullen D, Haynatzki G, *et al*. Calcium and vitamin D supplementation decreases incidence of stress fractures in female Navy recruits. *J Bone Miner Res* 2008;23:741–9.
26 Barnes KR, Tchandja JN, Webber BJ, *et al*. The effects of prenatal vitamin supplementation on operationally significant health outcomes in female air force trainees. *Mil Med* 2015;180:554–8.
27 Hartig DE, Henderson JM. Increasing hamstring flexibility decreases lower extremity overuse injuries in military basic trainees. *Am J Sports Med* 1999;27:173–6.
28 Baxter ML, Ribeiro DC, Milosavljevic S. Do orthotics work as an injury prevention strategy for the military *Physical Therapy Reviews* 2012;17:241–51.
29 Wardle SL, Greeves JP. Mitigating the risk of musculoskeletal injury: a systematic review of the most effective injury prevention strategies for military personnel. *J Sci Med Sport* 2017:S3–10.
30 Rhon DI, Molloy JM, Monnier A, *et al*. Much work remains to reach consensus on musculoskeletal injury risk in military service members: a systematic review with meta-analysis. *Eur J Sport Sci* 2022;22:16–34.
31 Jones BH, Hauschild VD, Canham-Chervak M. Musculoskeletal training injury prevention in the U.S. Army: evolution of the science and the public health approach. *J Sci Med Sport* 2018;21:1139–46.
32 Hayhurst D, Warner M, Stokes M, *et al*. Musculoskeletal injury in military specialists: a 2-year retrospective study. *BMJ Mil Health* 2022:e002165.
33 Minnig MC, Hawkinson L, Root HJ, *et al*. Barriers and facilitators to the adoption and implementation of evidence-based injury prevention training programmes: a narrative review. *BMJ Open Sport Exerc Med* 2022;8:e001374.
34 Dix C, Logerstedt D, Arundale A, *et al*. Perceived barriers to implementation of injury prevention programs among collegiate women's soccer coaches. *J Sci Med Sport* 2021;24:352–6.
35 Richmond SA, Donaldson A, Macpherson A, *et al*. Facilitators and barriers to the implementation of iSPRINT: a sport injury prevention program in junior high schools. *J Clin Sport Med* 2020;30:231–8.
36 Verhagen EALM, Hupperets MDW, Finch CF, *et al*. The impact of adherence on sports injury prevention effect estimates in randomised controlled trials: looking beyond the CONSORT statement. *J Sci Med Sport* 2011;14:287–92.
37 Molloy JM, Pendergrass TL, Lee IE, *et al*. Musculoskeletal injuries and United States Army readiness. Part II: management challenges and risk mitigation initiatives. *Mil Med* 2020;185:e1472–80.
38 Peters MDJ, Godfrey CM, Khalil H, *et al*. Guidance for conducting systematic scoping reviews. *Int J Evid Based Healthc* 2015;13:141–6.
39 Arksey H, O'Malley L. Scoping studies: towards a methodological framework. *Int J Soc Res Methodol* 2005;8:19–32.
40 Levac D, Colquhoun H, O'Brien KK. Scoping studies: advancing the methodology. *Implement Sci* 2010;5:69.
41 Murray AD, Daines L, Archibald D, *et al*. The relationships between golf and health: a scoping review. *Br J Sports Med* 2017;51:12–9.
42 Tricco AC, Lillie E, Zarin W, *et al*. PRISMA extension for scoping reviews (PRISMA-SCR): checklist and explanation. *Ann Intern Med* 2018;169:467–73.
43 Bullock GS, Collins GC, Allard R, *et al*. Barriers and facilitators of injury prevention programs in the military. 2023. Available: https://osf.io/5jsre/
44 van Mechelen W. Sports injury surveillance systems. *Sports Medicine* 1997;24:164–8.
45 van Mechelen W, Hlobil H, Kemper HCG. Incidence, severity, aetiology and prevention of sports injuries. *Sports Medicine* 1992;14:82–99.
46 Hauschild V, Hauret K, Richardson M, *et al*. A Taxonomy of injuries for public health monitoring and reporting. Addendum 1, body regions and injury types. Addendum 2, fiscal year 2018 update. Army Public Health Center Aberdeen Proving Ground United States; 2017.
47 Munn Z, Tufanaru C, Aromataris E. JBI's systematic reviews: data extraction and synthesis. *Am J Nurs* 2014;114:49–54.
48 Conaghan PG, Dickson J, Grant RL, *et al*. Care and management of osteoarthritis in adults: summary of NICE guidance. *BMJ* 2008;336:502–3.
49 Team RC. A language and environment for statistical computing. R foundation for statistical computing. Vienna, Austria Team RC; 2022. Available: https://www.R-project.org/
50 Berg Rice VJ, Pekarek D, Connolly V, *et al*. Participatory ergonomics: determining injury control "buy-in" of US army cadre. *Work* 2002;18:191–203.
51 Larsen K, Weidich F, Leboeuf-Yde C. Can custom-made biomechanic shoe orthoses prevent problems in the back and lower extremities? A randomized, controlled intervention trial of 146 military conscripts. *J Manipulative Physiol Ther* 2002;25:326–31.
52 Withnall R, Eastaugh J, Freemantle N. Do shock absorbing Insoles in recruits undertaking high levels of physical activity reduce lower limb injury? A randomized controlled trial. *J R Soc Med* 2006;99:32–7.
53 Zimmermann WO, Helmhout PH, Beutler A. Prevention and treatment of exercise related leg pain in young soldiers; a review of the literature and current practice in the dutch armed forces. *J R Army Med Corps* 2017;163:94–103.
54 Gillespie WJ, Grant I. Interventions for preventing and treating stress fractures and stress reactions of bone of the lower limbs in young adults. *Cochrane Database Syst Rev* 2000:CD000450.
55 Rome K, Handoll HHG, Ashford R. Interventions for preventing and treating stress fractures and stress reactions of bone of the lower limbs in young adults. *Cochrane Database Syst Rev* 2005;2005:CD000450.
56 Berg Rice VJ, Connolly VL, Pritchard A, *et al*. Effectiveness of a screening tool to detect injuries during army health care specialist training. *Work* 2007;29:177–88.
57 Coakwell MR, Bloswick DS, Moser R. High-risk head and neck movements at high G and interventions to reduce associated neck injury. *Aviat Space Environment Med* 2004;75:68–80.
58 Scott SJ, Feltwell DN, Knapik JJ, *et al*. A multiple intervention strategy for reducing femoral neck stress injuries and other serious overuse injuries in U.S. *Mil Med* 2012;177:1081–9.
59 Alricsson M, Harms-Ringdahl K, Larsson B, *et al*. Neck muscle strength and endurance in fighter pilots: effects of a supervised training program. *Aviat Space Environment Med* 2004;75:23–8.
60 Robitaille E, Larter V, Heipel S, *et al*. The feasibility of implementing an evidence-based physical training program during a Canadian armed forces basic infantry course. *J Sci Med Sport* 2021;24:886–93.
61 Esterman A, Pilotto L. Foot shape and its effect on functioning in royal Australian air force recruits. Part 2: pilot, randomized, controlled trial of orthotics in recruits with flat feet. *Military Medicine* 2005;170:629–33.
62 Milgrom C, Finestone A, Lubovsky O, *et al*. A controlled randomized study of the effect of training with orthoses on the incidence of weight bearing induced back pain among infantry recruits. *Spine* 2005;30:272–5.
63 Finestone A, Giladi M, Elad H, *et al*. Prevention of stress fractures using custom biomechanical shoe orthoses. *Clin Orthop Relat Res* 1999;360:182–90.
64 Finestone A, Novack V, Farfel A, *et al*. A prospective study of the effect of foot orthoses composition and fabrication on comfort and the incidence of overuse injuries. *Foot Ankle Int* 2004;25:462–6.
65 Knapik JJ, Spiess A, Swedler D, *et al*. Injury risk factors in parachuting and acceptability of the parachute ankle brace. *Aviat Space Environ Med* 2008;79:689–94.
66 Knapik JJ, Swedler DI, Grier TL, *et al*. Injury reduction effectiveness of selecting running shoes based on plantar shape. *J Strength Cond Res* 2009;23:685–97.

67 Gross MT, Liu HY. The role of ankle bracing for prevention of ankle sprain injuries. *J Orthop Sports Phys Ther* 2003;33:572–7.
68 Finestone A, Shlamkovitch N, Eldad A, *et al*. A prospective study of the effect of the appropriateness of foot-shoe fit and training shoe type on the incidence of overuse injuries among infantry recruits. *Mil Med* 1992;157:489–90.
69 Steinberg N, Bar-Sela S, Moran U, *et al*. Injury prevention exercises for reduced incidence of injuries in combat soldiers. *J Strength Cond Res* 2021;35:3128–38.
70 Sherrard J, Lenné M, Cassell E, *et al*. Injury prevention during physical activity in the Australian defence force. *J Sci Med Sport* 2004;7:106–17.
71 Amako M, Oda T, Masuoka K, *et al*. Effect of static stretching on prevention of injuries for military recruits. *Mil Med* 2003;168:442–6.
72 Coppack RJ, Etherington J, Wills AK. The effects of exercise for the prevention of overuse anterior knee pain: a randomized controlled trial. *Am J Sports Med* 2011;39:940–8.
73 Yeung SS, Yeung EW, Gillespie LD. Interventions for preventing lower limb soft-tissue injuries in runners. *Cochrane Database Syst Rev* 2011;2001:CD001256.
74 George SZ, Childs JD, Teyhen DS, *et al*. Brief Psychosocial education, not core stabilization, reduced incidence of low back pain: results from the prevention of low back pain in the military (POLM) cluster randomized trial. *BMC Med* 2011;9:128.
75 House C, Reece A, Roiz de Sa D. Shock-absorbing Insoles reduce the incidence of lower limb overuse injuries sustained during Royal Marine training. *Mil Med* 2013;178:683–9.
76 Pope R, Herbert R, Kirwan J. Effects of ankle dorsiflexion range and pre-exercise calf muscle stretching on injury risk in army recruits. *Aust J Physiother* 1998;44:165–72.
77 Shumway JD, Anderson DN, Bishop B. Effectiveness of an injury prevention warm-up for unit physical training: a case series of two flying squadrons. *Mil Med* 2016;181:95–103.
78 Knapik JJ. United States military parachute injuries: part 2: interventions reducing military parachute injuries in training and operations. *J Spec Oper Med* 2019;19:109.
79 Scott SJ, Feltwell DN, Knapik JJ, *et al*. A multiple intervention strategy for reducing femoral neck stress injuries and other serious overuse injuries in U.S. army basic combat training. *Mil Med* 2012;177:1081–9.
80 Knapik JJ, Hauret KG, Arnold S, *et al*. Injury and fitness outcomes during implementation of physical readiness training. *Int J Sports Med* 2003;24:372–81.
81 Suni JH, Taanila H, Mattila VM, *et al*. Neuromuscular exercise and counseling decrease absenteeism due to low back pain in young conscripts: a randomized, population-based primary prevention study. *Spine (Phila Pa 1976)* 2013;38:375–84.
82 Knapik JJ, McCollam R, Canham-Chervak M, *et al*. Injuries and injury prevention among senior military officers at the army war college. *Mil Med* 2002;167:593–9.
83 Knapik J, Darakjy S, Scott SJ, *et al*. Evaluation of a standardized physical training program for basic combat training. *J Strength Cond Res* 2005;19:246–53.
84 Canham-Chervak M, Hooper TI, Brennan FH, *et al*. A systematic process to prioritize prevention activities: sustaining progress toward the reduction of military injuries. *Am J Prev Med* 2010;38:S11–8.
85 Sell TC, Abt JP, Nagai T, *et al*. The eagle tactical athlete program reduces musculoskeletal injuries in the 101st airborne division (air assault). *Military Medicine* 2016;181:250–7.
86 Ziemke GW, Koffman RL, Wood DP. "Tip of the spear" physical therapy during a 6-month deployment to the Persian Gulf: a preliminary report. *Mil Med* 2001;166:505–9.
87 Grier T, Anderson MK, Depenbrock P, *et al*. Evaluation of the US army special forces tactical human optimization, rapid rehabilitation, and reconditioning program. *J Spec Oper Med* 2018;18:42.
88 Amoroso PJ, Ryan JB, Bickley B, *et al*. Braced for impact: reducing military paratroopers' ankle sprains using outside-the-boot braces. *J Trauma* 1998;45:575–80.
89 Knapik JJ, Spiess A, Swedler DI, *et al*. Systematic review of the parachute ankle brace: injury risk reduction and cost effectiveness. *Am J Prev Med* 2010;38:S182–8.
90 Pope RP, Herbert RD, Kirwan JD, *et al*. A randomized trial of preexercise stretching for prevention of lower-limb injury. *Med Sci Sports Exerc* 2000;32:271–7.
91 Thacker SB, Gilchrist J, Stroup DF, *et al*. The prevention of Shin splints in sports: a systematic review of literature. *Med Sci Sports Exerc* 2002;34:32–40.
92 Carow SD, Haniuk EM, Cameron KL, *et al*. Risk of lower extremity injury in a military cadet population after a supervised injury-prevention program. *J Athl Train* 2016;51:905–18.
93 Knapik JJ, Rieger W, Palkoska F, *et al*. United States Army physical readiness training: rationale and evaluation of the physical training doctrine. *J Strength Cond Res* 2009;23:1353–62.
94 Larsson H, Tegern M, Harms-Ringdahl K. Influence of the implementation of a comprehensive intervention programme on premature discharge outcomes from military training. *Work* 2012;42:241–51.
95 Knapik JJ, Bullock SH, Toney E. Influence of an injury reduction program on injury and fitness outcomes among soldiers. *Injury Prevention* 2004;10:37–42.
96 Cancelliere C, Sutton D, Côté P, *et al*. Implementation interventions for musculoskeletal programs of care in the active military and barriers, facilitators, and outcomes of implementation: a scoping review. *Implement Sci* 2019;14:82.
97 Bonanno DR, Murley GS, Munteanu SE, *et al*. Effectiveness of foot orthoses for the prevention of lower limb overuse injuries in naval recruits: a randomised controlled trial. *Br J Sports Med* 2018;52:298–302.
98 Childs JD, Wu SS, Teyhen DS, *et al*. Prevention of low back pain in the military cluster randomized trial: effects of brief psychosocial education on total and low back pain-related health care costs. *Spine J* 2014;14:571–83.
99 Goodall RL, Pope RP, Coyle JA, *et al*. Balance and agility training does not always decrease lower limb injury risks: a cluster-randomised controlled trial. *Int J Inj Contr Saf Promot* 2013;20:271–81.
100 Baxter ML, Baycroft C, Baxter GD. Lower limb injuries in soldiers: feasibility of reduction through implementation of a novel orthotic screening protocol. *Military Medicine* 2011;176:291–6.
101 Pope RP. Prevention of pelvic stress fractures in female army recruits. *Mil Med* 1999;164:370–3.
102 McDevitt ER, Taylor DC, Miller MD, *et al*. Functional bracing after anterior cruciate ligament reconstruction: a prospective, randomized, multicenter study. *Am J Sports Med* 2004;32:1887–92.
103 Mündermann A, Stefanyshyn DJ, Nigg BM. Relationship between footwear comfort of shoe inserts and anthropometric and sensory factors. *Med Sci Sports Exerc* 2001;33:1939–45.
104 Finch C. A new framework for research leading to sports injury prevention. *J Sci Med Sport* 2006;9:3–9.
105 Glasgow RE, Vogt TM, Boles SM. Evaluating the public health impact of health promotion interventions: the RE-AIM framework. *Am J Public Health* 1999;89:1322–7.
106 Glasgow RE, Harden SM, Gaglio B, *et al*. RE-AIM planning and evaluation framework: adapting to new science and practice with a 20-year review. *Front Public Health* 2019;7.
107 Pinnock H, Barwick M, Carpenter CR, *et al*. Standards for reporting implementation studies (Stari) statement. *BMJ* 2017;356:i6795.
108 Damschroder LJ, Aron DC, Keith RE, *et al*. Fostering implementation of health services research findings into practice: a consolidated framework for advancing implementation science. *Implementation Sci* 2009;4.
109 Aaltonen S, Karjalainen H, Heinonen A, *et al*. Prevention of sports injuries: systematic review of randomized controlled trials. *Arch Intern Med* 2007;167:1585–92.
110 Dijksma I, Perry S, Zimmermann W, *et al*. Effects of agility training on body control, change of direction speed and injury attrition rates in Dutch recruits: a pilot study. *J Mil Vet Health* 2019;27:28–40.
111 Heard C, Willcox M, Falvo M, *et al*. Effects of linear Periodization training on performance gains and injury prevention in a garrisoned military unit. *J Mil Vet Health* 2020;28:23–34.
112 Jones BH, Knapik JJ. Physical training and exercise-related injuries. surveillance, research and injury prevention in military populations. *Sports Med* 1999;27:111–25.
113 Olmsted LC, Vela LI, Denegar CR, *et al*. Prophylactic ankle Taping and bracing: A numbers-needed-to-treat and cost-benefit analysis. *J Athl Train* 2004;39:95–100.
114 Sharma J, Weston M, Batterham AM, *et al*. Gait retraining and incidence of medial Tibial stress syndrome in army recruits. *Med Sci Sports Exerc* 2014;46:1684–92.
115 Ang BO, Monnier A, Harms-Ringdahl K. Neck/shoulder exercise for neck pain in air force helicopter pilots: a randomized controlled trial. *Spine (Phila Pa 1976)* 2009;34:E544–51.
116 Slater MA, Weickgenant AL, Greenberg MA, *et al*. Preventing progression to Chronicity in first onset, subacute low back pain: an exploratory study. *Arch Phys Med Rehabil* 2009;90:545–52.
117 Burgess JE. Analysis of Y listings and medical discharges of officer cadets at RMAS from January 1994 to may 1997, with actions to prevent injuries. *J R Army Med Corps* 1998;144:152–5.
118 Joseph R. Dettori LC, H. Bullock CS, G. Sutlive CT, *et al*. The effects of spinal flexion and extension exercises and their associated postures in patients with acute low back pain. *Spine* 1995;20:2303–12.
119 Dijksma I, Bekkers M, Spek B, *et al*. Epidemiology and financial burden of musculoskeletal injuries as the leading health problem in the military. *Mil Med* 2020;185:e480–6.
120 Ross RA, Allsopp A. Stress fractures in royal marines recruits. *Mil Med* 2002;167:560–5.
121 Zeng J, Zhang R-B, Ke J-J, *et al*. Reliability evaluation of functional movement screen for prevention of military training injury: A prospective study in China. *J Occup Health* 2021;63:e12270.
122 Rudzki SJ, Cunningham MJ. The effect of a modified physical training program in reducing injury and medical discharge rates in Australian army recruits. *Mil Med* 1999;164:648–52.
123 Milgrom C, Finestone AS. The effect of stress fracture interventions in a single elite infantry training unit (1983-2015). *Bone* 2017;103:S8756-3282(17)30225-9:125–30.:.
124 Schmidt MD, Sulsky SI, Amoroso PJ. Effectiveness of an outside-the-boot ankle brace in reducing parachuting related ankle injuries. *Inj Prev* 2005;11:163–8.
125 Schumacher JT, Creedon JF, Pope RW. The effectiveness of the Parachutist ankle brace in reducing ankle injuries in an airborne Ranger battalion. *Mil Med* 2000;165:944–8.

126 Pihlajamäki HK, Ruohola J-P, Kiuru MJ, *et al*. Displaced femoral neck fatigue fractures in military recruits. *J Bone Joint Surg Am* 2006;88:1989–97.
127 Roos L, Boesch M, Sefidan S, *et al*. Adapted marching distances and physical training decrease recruits' injuries and attrition. *Mil Med* 2015;180:329–36.
128 Knapik JJ, Darakjy S, Hauret KG, *et al*. Increasing the physical fitness of low-fit recruits before basic combat training: an evaluation of fitness, injuries, and training outcomes. *Mil Med* 2006;171:45–54.
129 Dusenbury L, Brannigan R, Falco M, *et al*. A review of research on fidelity of implementation: implications for drug abuse prevention in school settings. *Health Educ Res* 2003;18:237–56.
130 McKay CD, Verhagen E. 'Compliance' versus 'adherence' in sport injury prevention: why definition matters. *Br J Sports Med* 2016;50:382–3.
131 Goodman RM, McLeroy KR, Steckler AB, *et al*. Development of level of Institutionalization scales for health promotion programs. *Health Education Quarterly* 1993;20:161–78.
132 Marlatt GA, Donovan DM. *Relapse prevention: Maintenance strategies in the treatment of addictive behaviors*. Guilford press, 2005.
133 Milat AJ, King L, Bauman AE, *et al*. The concept of scalability: increasing the scale and potential adoption of health promotion interventions into policy and practice. *Health Promotion International* 2013;28:285–98.