

**Worsening dietary and physical activity behaviours do not readily explain  
why smokers gain weight after cessation: a cohort study in young adults**

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## Abstract

**Introduction** The relationship between smoking cessation and weight gain is well-established but the underlying mechanisms remain poorly understood. We aimed to determine whether post-cessation weight gain was mediated by changing health behaviours.

**Methods** 281 smokers self-reported their demographic, smoking and lifestyle characteristics in 2004-2006 (aged 26-36) and 2009-2011 (aged 31-41). Behaviours considered as potential mediators of weight gain were changes in consumption of breakfast, discretionary foods (servings/day), fruit and vegetables (servings/day), alcohol (g/day), takeaway food (times/week), diet guideline index (DGI) score, leisure time physical activity (PA, minutes/week), total PA (minutes/week), time spent sitting (minutes/day) and TV viewing (hours/day).

**Results** 124 smokers quit smoking during five years follow-up. After adjustment for age, sex, baseline BMI, education and follow-up length, smoking cessation was associated with average excess weight gain of 2.09kg (95% CI: 0.35-3.83). Compared with continuing smokers, quitters reported a higher DGI score and less consumption of alcohol at baseline and follow-up (all  $p < 0.05$ ). In addition, there was a tendency towards healthier dietary and PA behaviours over five years among quitters than continuing smokers except for time spent sitting, although these differences did not reach statistical significance. Adjustment for changes in these behaviours made little difference to the magnitude of post-cessation weight gain ( $\beta$ : 2.32kg, 95% CI: 0.54-4.10).

**Conclusions** The weight gain associated with smoking cessation was not explained by worsening dietary and PA behaviours. Future research is needed to elucidate the complex mechanisms and particularly ways it may be prevented.

**Keywords:** smoking cessation; weight gain; dietary habits; alcohol consumption; physical activity; longitudinal studies

**Implications** Fear of weight gain often discourages smokers from trying to quit but guidance on ways to most effectively avoid weight gain is lacking. It is important to identify what causes post-cessation weight gain and the ways it may be prevented. The current study explored the effects of several changing dietary and PA behaviours on the relationship between smoking cessation and weight gain in 281 young Australian smokers. We found that quitters tended to adopt healthier dietary and PA behaviours than continuing smokers, so these behaviours did not readily explain the post-cessation weight gain. Further investigations of other potential mechanisms are needed.

## 1   **Introduction**

2   Smoking and overweight or obesity are well-documented risk factors for many diseases,  
3   including cardiovascular diseases. The changing population prevalences of these risk factors,  
4   however, are moving in opposite directions, with smoking declining and overweight  
5   increasing.<sup>1-3</sup> Quantitative analyses have shown that, on average, smokers weigh less than  
6   non-smokers, and quitters weigh more than continuing smokers.<sup>3,4</sup> A recent meta-analysis of  
7   randomized control trials (RCTs) found that those quitting smoking gained an average of 4-  
8   5kg after 12 months of abstinence, with most of the weight gain occurring in the first three  
9   months of quitting.<sup>5</sup> The estimate from a meta-analysis of prospective cohort studies was  
10   4.1kg over an average of five years, which is 2.6kg greater than the gain in continuing  
11   smokers.<sup>6</sup> Therefore, it is unsurprising that fear of weight gain is commonly cited by smokers  
12   as a reason for not quitting, especially for weight-concerned groups like women<sup>7,8</sup> and obese  
13   smokers<sup>9</sup> even though the health benefits of quitting far outweigh the health risks associated  
14   with weight gain.<sup>10,11</sup>

15       Several systematic reviews of interventions that aimed to prevent weight gain after  
16   smoking cessation, including pharmacotherapies, exercise and dietary interventions showed  
17   little success with no strong clinical recommendation available to smokers who want to  
18   quit.<sup>5,12-15</sup> It would be beneficial to identify factors that can explain or modify weight gain  
19   following smoking cessation but the literature is sparse or inconclusive.

20       Time spent in sedentary behaviours, such as sitting or television viewing, is believed to be  
21   one of the factors underlying the globally increasing prevalence of overweight and obesity.<sup>16</sup>  
22   Sitting and TV viewing time have been found to be positively associated with adiposity or  
23   weight gain in many populations;<sup>17-19</sup> however, no study has tested their roles in post-  
24   cessation weight gain among those who quit smoking. There are two longitudinal studies

1 investigating the relationship between weight gain and concurrent change of physical activity  
2 (PA) level among quitters and continuing smokers. One of these studies focused only on  
3 leisure time PA (LTPA) rather than total PA<sup>20</sup> while the sample in the other study<sup>21</sup> was  
4 limited to participants in RCTs of smoking cessation treatments and they are usually not  
5 representative of smokers in the general population.<sup>22</sup>

6 In terms of dietary factors, there is evidence suggesting that quitters have a desire to have  
7 something in their mouths to substitute for cigarettes which may result in changes in diet,  
8 such as an increase in sugar,<sup>23,24</sup> fat<sup>23,25,26</sup> and overall daily calorie intake.<sup>23,26,27</sup> Few studies  
9 have measured the effects of changing dietary behaviours after quitting smoking.<sup>28</sup> Dietary  
10 behaviours, which reflect the ways people eat (for example, consumption of fruit and  
11 vegetable, discretionary foods and takeaway food, and breakfast skipping) and their diet  
12 quality are closely associated with weight fluctuation.<sup>29-33</sup> Compared with the public health  
13 messages based on energy intake, those addressing dietary behaviours may be easier for  
14 people to understand. For example, a recommendation to limit takeaway food consumption is  
15 easier to follow than a recommendation to restrict energy intake (which would require  
16 knowledge of the energy content of all foods consumed). No reported study has assessed the  
17 effects of changing dietary behaviours on the magnitude of weight gain after smoking  
18 cessation.

19 The aim of this study was to evaluate whether the greater weight gain after cessation in  
20 quitters than continuing smokers could be attributed to changes in several dietary and PA  
21 behaviours in a cohort of young adults.

## **Methods**

### **Participants**

The Childhood Determinants of Adult Health (CDAH) study is a follow-up of children who participated in the 1985 Australian Schools Health and Fitness Survey, a nationally representative study of 8,498 children aged 7-15 years.<sup>34</sup> A two-stage probability sampling frame was used. The first stage was the sampling of schools with a probability proportional to student enrolment, and the second stage was the random sampling of boys and girls in each age group. All six Australian States and two Territories were included in the sample. The participation rates were 90.1% for schools and 67.5% for the selected children. During 2002-2004, a total of 6,840 were traced and 5,170 agreed to take part in the CDAH study and completed a brief postal or telephone questionnaire (enrolment). From 2004 to 2006, 3,521 participants (68% of those at enrolment) completed the first follow-up (CDAH-1, herein referred to as “baseline”) and 2,410 participants also attended one of 34 study clinics that were held in each state and territory of Australia for physical measurements. Five years thereafter, during 2009-2011, the second follow-up (CDAH-2, herein referred to as “follow-up”) was conducted via telephone interview, postal or online questionnaires with 2,815 participants aged 31-41 years.

The study protocol was approved by the Southern Tasmanian Health and Medical Ethics Committee. Written informed consent was obtained at both time points.

### **Smoking status assessment**

Smoking status was defined according to the responses to two questions. The first question asked “Over your lifetime, have you smoked at least 100 cigarettes, or a similar amount of tobacco?” Participants answering “yes” were classified as ever smokers, and those answering

“no” as never smokers. Ever smokers were then asked the second question “How often do you now smoke cigarettes, cigars, pipes or any other tobacco products?” Participants who answered “not at all” were classified as former smokers, those who answered “daily” or “at least once a week” or “less than weekly” were classified as current smokers.

Weekly and less than weekly smokers were defined as occasional smokers. Daily smokers were asked to report the number of cigarettes smoked per day and recall the age at which they started smoking daily. Duration of smoking in years was calculated using this age subtracted from the age at which they completed the questionnaire and pack-years of smoking was calculated by multiplying the number of packs of cigarettes smoked per day by the duration of smoking in years. People who were daily smokers at baseline but former smokers at follow-up were also asked to report the age at which they stopped daily smoking and the total number of times they had tried to quit daily smoking.

The main exposure in this longitudinal analysis was quitting smoking between baseline and follow-up, therefore participants were restricted to current smokers at baseline and categorised as continuing smokers (current smokers at baseline and follow-up) or quitters (current smokers at baseline and former smokers at follow-up).

### **Anthropometric measurements**

At baseline, weight and height were objectively measured at study clinics for most participants (n=2,410) by trained clinic staff. A subsample of these participants also self-reported their weight and height before measurements were taken to assess the accuracy of self-reported values. The difference between clinic and self-reported weight and height was used to calculate a correction factor from a linear regression model.<sup>35</sup> Participants who did not visit a study clinic (n=1,557) self-reported their weight and height, and the correction factor was applied to adjust for error. For the anthropometric measurements, participants

wore light clothing without shoes. All measurements were made by trained staff. Body weight was measured using a Heine portable scale (Heine, Dover, NH, USA) and recorded to the nearest 0.1kg. Height was measured using a portable Leicester stadiometer (Invicta, Leicester, UK) and recorded to the nearest 0.1cm. Body mass index (BMI, kg/m<sup>2</sup>) was calculated from height and weight.

Weight was self-reported at follow-up. Adjusted weight values were calculated using the correction factor applied at baseline.<sup>35</sup> BMI was calculated using adjusted height at baseline and adjusted weight at follow-up.

### **Dietary assessment**

Dietary behaviours were assessed using a meal pattern chart, a 127-item food frequency questionnaire (FFQ) and a food habit questionnaire (FHQ) at baseline and follow-up. Dietary behaviours considered as potential mediators of weight change were changes in “discretionary” foods, fruit and vegetable, diet guideline index (DGI) score, takeaway food, breakfast skipping and alcohol consumption.

A meal pattern chart for the previous day was completed and the day of the week recorded by participants. The chart divided the day into hourly intervals from 0600 to 2300 and 2300 to 0600 was combined. For each time interval, participants were asked to choose one of four responses to the question “Did you eat anything?”: “no”, “a snack”, “a small meal” or “a large meal”. Examples of each meal type were given. Breakfast was defined as eating a snack, small meal, or large meal from 0600 to 0900.<sup>36</sup> A similar method of assessing meal patterns has been used in a previous study.<sup>37</sup>

The FFQ included 127 items and participants reported how often each item was consumed in the previous 12 months, using a 9-point scale from “never or less than once a month” to

“six or more times per day”. Daily equivalents were calculated for each FFQ item, assuming one serving was consumed at each eating occasion, as described elsewhere.<sup>30</sup> The FFQ was a modified version of the one which was used in the 1995 National Nutrition Survey.<sup>38-41</sup> It was based on an existing FFQ developed for Australian populations.<sup>42</sup>

Foods that do not fit into five core food groups (fruit, vegetables, dairy, breads and cereals, lean meats) are considered “discretionary” foods. They are typically high in fat, salt and sugars and provide very few essential nutrients.<sup>43</sup> Examples of discretionary foods include ice cream, savoury pastry, pizza, hot chips, etc. Examples in detail were listed in our previous publication.<sup>30</sup> For analysis the takeaway food items (hamburgers, pizza, hot chips, fried fish and savoury pastry) were excluded from the discretionary foods variables so that they could be distinguished separately. Daily alcohol consumption in grams was estimated from the usual frequency reported in the FFQ of 10 common alcoholic beverages multiplied by the average alcohol concentration of each beverage.

The FHQ included questions on takeaway food and usual fruit and vegetable consumption. Participants were asked to answer “How many times per week would you usually eat hot takeaway meals (e.g. pizza, burgers, fried or roast chicken, Chinese/Indian/Thai takeaway)” from choosing one of five responses ranging from “I don’t eat takeaway” to “6-7 meals per week”. For analysis, the answers were dichotomised to less than twice per week or twice a week or more as we have shown that eating takeaway food twice a week or more was associated with abdominal obesity.<sup>30</sup> Four categories were created to examine change in takeaway food consumption during follow-up: twice a week at neither baseline or follow-up, twice a week or more at baseline only, twice a week or more at follow-up only, twice a week or more at both baseline and follow-up. Takeaway food consumption from the short question has been validated in a previous study.<sup>30</sup>



Self-reported daily fruit and vegetable consumption was measured using two short questions “how many servings of fruit/vegetables (excluding potatoes) do you usually eat each day”. Examples of serving sizes were given and possible response options included “I don’t eat this food”, “1 serving or less”, “2-3 servings”, “4-5 servings” or “6 or more servings”. We combined these to get an overall estimate of daily fruit and vegetable consumption. Short questions have been used in previous studies<sup>39,44</sup> and have been shown to be valid measures for fruit and vegetable intake.<sup>45</sup>

Information from the FFQ and FHQ was used to assess diet quality using a dietary guideline index (DGI) based on the Dietary Guidelines for Australian Adults<sup>46</sup> and the Australian Guide to Healthy eating.<sup>43</sup> The score included 15 components and each component was scored from 0 to 10, with 10 indicating that a participant was meeting the requirement or had an optimal intake. For example, in regard to fruit intake, 2 servings/day was the recommended amount and scored 10 points, 1 serving/day scored 5 points and no consumption of fruit scored 0 point. The total sum of DGI score ranged from 0 to 150. A higher score denoted better compliance with the dietary guidelines. The mean score was around 100 in an Australian National Nutrition Survey,<sup>39</sup> but no recommended score is currently available for the general population. If people have a score of 100 and the potential range is 0-150, then they are meeting two-thirds of the dietary guidelines. More detailed information about the scores is presented elsewhere.<sup>39</sup> This score has been shown to be a valid measure of diet quality.<sup>39,47</sup>

### **Self-reported physical activity assessment**

Self-reported physical activity was measured using the long version of the International Physical Activity Questionnaire (IPAQ-L).<sup>48</sup> Participants were asked to report the total time (mins) and frequency (times/week) of occupational, domestic, commuting and LTPA during

the past week. Minutes/week spent in each domain were calculated by multiplying frequency by duration. Time spent doing PA in each domain was summed to provide an estimate of total minutes of PA. Time spent sitting was reported for a typical weekday and weekend day. To determine the average daily sitting time (minutes/day), time spent sitting on weekdays and weekend days were summed and divided by seven. Daily TV viewing time (hours/week) in the past week was estimated from self-reported total time spent watching TV, digital video disks, or videocassettes by participants in relation to weekdays and weekend days as described in detail elsewhere.<sup>49</sup>

### **Pedometer-determined physical activity**

Participants wore a Yamax Digiwalker pedometer (SW-200) for 7 consecutive days and recorded total steps at the end of each day, daily start time and daily end time. Daily records were excluded if the pedometer was worn for less than 8 hours or >60,000 steps were reported. Mean daily steps were calculated for participants with a minimum of four valid days of readings. In general, pedometers have been shown to strongly correlate with concurrent accelerometer measures ( $\gamma=0.86$ ) and observed time spent in activity ( $\gamma=0.82$ ).<sup>50</sup>

### **Other covariates**

Socio-demographic characteristics were self-reported at baseline including age, sex, marital status (married or living as married versus other), education (high school only, vocational training, any university education) and occupation (not in the labour force, manual, non-manual, and professional or manager). Follow-up length and baseline BMI were also considered as potential confounders in the analyses.

### **Statistical analyses**

Analyses were restricted to participants who were not pregnant and who had completed 1) both baseline and follow-up smoking questionnaires and 2) baseline dietary questionnaires and the IPAQ-L. Approximately half the current smokers (49%) were missing one or more dietary or PA behaviours at follow-up. Therefore multiple imputation (MI) by chained equations was used.<sup>51</sup> The number of imputations was 40.<sup>52</sup> Changes in dietary and PA behaviours were generated based on collected information at baseline and imputed data at follow-up.

Means with standard deviations (SDs) and numbers with proportions were used to describe the socio-demographic characteristics, dietary and PA behaviours of the participants according to whether or not they quit smoking from baseline to follow-up. Comparisons between the two groups were performed using t-tests for continuous variables and chi-square tests for categorical variables. Linear regression models were used to assess the association between smoking cessation and weight change. In analyses that explored whether changes in dietary and PA behaviours could explain the post-cessation weight gain, a base model was initially fitted, adjusting for socio-demographic characteristics (age, sex, and education level), follow-up length and baseline BMI. A second model adjusted for change in dietary factors and a third model adjusted for change in PA behaviours. Change in dietary and PA variables were entered into the base model one at a time. A fourth model included both changes in dietary and PA variables. Potential confounding factors kept in the base model were variables which were associated with the outcome and were not mediators between the exposure and the outcome, and which resulted in a >10% change in the coefficient of the principal study factor when added in the model.

1        Sensitivity analyses excluding participants with imputed data were performed to examine  
2        the influence of missing data on results. The analysis was also repeated among participants  
3        with pedometer-measured PA.

4        A two-tailed P value less than 0.05 was considered statistically significant. All analyses  
5        were performed with STATA software, version 12.1 (Stata Corp, College Station, Texas  
6        77845 USA).

## Results

Of the 785 participants who were current smokers at baseline, 274 were lost to follow-up and we excluded pregnant women at baseline or follow-up (n=6), those who were missing weight or BMI change data (n=28), and those who were missing baseline dietary or PA data (n=196). This left 281 participants. 124 of them quit smoking during the 5-year follow-up. The anthropometric and socio-demographic characteristics of participants are shown in Table 1.

The age ranged from 26 to 36 years for both continuing smokers and quitters. Compared with continuing smokers, quitters were more often female, employed as professionals or managers and smoked weekly or less than weekly, smoked less cigarettes per day and had a lighter exposure to tobacco, with some differences of borderline statistical significance. There were no statistically significant differences between the two groups in age, marital status, education level, weight, BMI, weight status and duration of smoking at baseline.

During five years follow-up, continuing smokers gained an average of 2.3kg (SD: 7.4) weight and 0.7kg/m<sup>2</sup> (SD: 2.5) BMI. Quitters gained an average of 4.4kg (SD: 7.2) weight and 1.4kg/m<sup>2</sup> (SD: 2.5) BMI. The amount of post-cessation weight gain was moderately increased after taking into account baseline frequency of smoking. It was largely unchanged after adjustment for cigarettes smoked per day, duration of smoking and pack-years among daily smokers at baseline (Appendix Table S1). No significant difference was observed in post-cessation weight gain related to time since quitting and number of previous quit attempts (Appendix Table S2).

Participants lost to follow-up were more likely to be single and less educated. There were no statistically significant differences in age, weight status and occupation level at baseline between smokers who participated in the follow-up and those who did not (data not shown).

**Table 2** presents the dietary behaviours at baseline, follow-up, and their changes during follow-up. At baseline, quitters reported a higher DGI score (98.6 versus 93.8,  $P=0.031$ ) and less daily alcohol consumption (11.0 versus 15.6 g/day,  $P=0.008$ ) than continuing smokers. No other statistically significant differences were observed in baseline dietary behaviours. Similar differences were found at follow-up (DGI score: 103.5 versus 96.6,  $P=0.008$ ; alcohol consumption: 8.8 versus 13.0 g/day,  $P=0.018$ ) and quitters also consumed less discretionary foods, more fruit and vegetables, less often skipped breakfast and less often consumed takeaway food at least two times per week than continuing smokers; however, these differences did not reach statistical significance. There were no significant differences in changing dietary behaviours between quitters and continuing smokers.

**Table 3** describes the PA behaviours at baseline, follow-up, and their changes from baseline to follow-up. No statistically significant difference was observed between quitters and continuing smokers at baseline, follow-up or in their changes during follow-up. Overall, the PA behaviours in quitters tended to become healthier compared with those among continuing smokers, except time spent in sitting. Quitters reported more time spent in sitting than continuing smokers at both baseline and follow-up.

**Table 4** documents the results for the linear regression analyses of smoking cessation on weight change. Before adjustment, quitters gained an average of 2.09kg greater weight than continuing smokers. This association was largely unchanged after adjustment for baseline age, sex, BMI, education level and follow-up length. Further adjustment for change in each dietary and PA behaviour slightly altered the estimate, with changes in  $\beta$  coefficients ranging from -0.08% to 15.46%. In the final fully adjusted model, the mean weight gain was 2.32kg greater in quitters than continuing smokers, and the overall change in  $\beta$  coefficient was 20.33%. Factors included in the fully adjusted model were baseline age, sex, BMI, education

level, follow-up length, changes in dietary behaviours (discretionary foods, fruit and vegetable, DGI score, consuming takeaway food, skipping breakfast and alcohol), change in LTPA and sitting time.

When BMI replaced weight as the outcome, the effects of changes in dietary and PA behaviours on the magnitude of BMI change after quitting smoking were similar to the change in weight. The results are summarized in the **Appendix (Table S3)**.

In sensitivity analyses, similar results were observed after excluding persons with imputed data (**Appendix Table S4, S5 and S6**). Change in pedometer-measured PA was available for 52 continuing smokers and 58 quitters over follow-up (Appendix Table S7). When the analysis was repeated using pedometer-measured PA, the change in  $\beta$  coefficient was similar in magnitude to that found with change in total PA measured by the IPAQ-L.

## Discussion

We found that compared with continuing smoking, smoking cessation was associated with an excess weight gain of 2.3kg in young adults. Unexpectedly, this weight gain was not substantially attenuated after adjustment for changes in dietary and PA behaviours, implying that the effects of smoking cessation on weight may not be mediated by these lifestyle factors. Indeed, we observed a greater trend towards healthier behaviours among quitters than continuing smokers, with quitters consuming less discretionary foods, alcohol and takeaway food, having a higher DGI score, less likely to skip breakfast, eating more fruit and vegetable, spending more time in LTPA and less time watching TV.

The findings of 4.4 kg weight gain after cessation in quitters and 2.3 kg greater weight gain in quitters than continuing smokers are very similar to the 4.1 kg and 2.6 kg reported in our recent meta-analysis including 63,403 quitters and 388,432 continuing smokers from 35 prospective cohort studies.<sup>6</sup> Previous studies have reported that the magnitude of post-cessation weight gain positively related to the heaviness of tobacco smoking partly because of varying impacts on metabolic rate,<sup>3,53</sup> and this point was also supported by our data that showed taking into account baseline frequency of smoking increased the amount of weight gain after cessation by 38% (Appendix Table S1). Time since quitting and number of quit attempts might influence the amount of weight gain after quitting given most weight gain occurred during the first few months of abstinence<sup>5</sup> and the positive relationship between heaviness of smoking and number of quit attempts,<sup>54</sup> but we failed to detect a significant association in a subsample of quitters who were daily smokers at baseline, possibly due to the small sample size. Younger age has previously been associated with a higher risk of major weight gain after quitting,<sup>3,55</sup> and a similar study in young people reported a greater weight gain of approximately 5 kg in quitters than continuing smokers.<sup>56</sup> Our finding of 2.3



kg excess weight gain is lower and may reflect our inclusion of more occasional smokers at baseline and shorter follow-up time.<sup>6</sup>

In line with the notion that quitters may change their food preferences after cessation,<sup>23,24,27</sup> our results confirmed some significant changes in dietary behaviours after quitting smoking; however, all these changes were towards healthier dietary behaviours. For example, both quitters and continuing smokers reported increased DGI and decreased consumption of takeaway food as they aged, but the changes were greater in quitters than continuing smokers. These findings were consistent with national data from Australia<sup>39</sup> and the United States<sup>57</sup> which show that diet quality increases with age and adults' consumption of calories from fast food decreases with age, respectively. In addition, the difference in DGI score between continuing smokers and quitters at both baseline and follow-up (around 5 points, equivalent to one serving of fruit per day) might be clinically meaningful. It has been reported that an increment of one serving a day for fruit was associated with 6% reduction in the risk of all-cause mortality and 5% reduction in the risk of cardiovascular mortality.<sup>58</sup> Given the 5-year time interval from baseline to follow-up, and evidence suggesting that most post-cessation weight gain occurs in the first three months after quitting,<sup>5</sup> it is possible that quitters gained weight shortly after cessation and then changed their dietary behaviours to control the post-cessation weight gain, such as consuming less discretionary foods and takeaway meals, less often skipping breakfast and having a higher DGI score. It is also possible that smokers quit smoking because they wanted to be healthier, so made other changes in behaviours simultaneously. Previous studies have found a clustering of lifestyle risk factors (smoking, excessive alcohol consumption, poor diet and physical inactivity),<sup>59,60</sup> and clustering of multiple risk behaviours increased with daily cigarette consumption.<sup>61</sup>

We failed to find that dietary behaviours contributed to weight gain after quitting but the extent to which this is due to our inability to accurately measure energy intake, as noted by others,<sup>62</sup> or due to the influence of non-dietary factors is uncertain. Indeed studies exploring energy intake specifically have had contradictory findings. Some studies using self-reported dietary intake indicate that smokers increase their energy intake shortly after quitting,<sup>25-27</sup> while others find no change or a decrease in energy intake.<sup>63,64</sup> Evidence from a single clinical trial also found a very low calorie diet was not effective at preventing weight gain among quitters after 12 months follow-up.<sup>12</sup> More accurate and repeated objective measures of energy intake are needed if we are to properly understand the role of energy intake in weight gain after smoking cessation.

The only behaviour in the current study that became less healthy in quitters compared with continuing smokers was the increase in sitting time, but it did not explain why smokers gained more weight after quitting. To the best of our knowledge, this is the first study exploring the effects of changes in sedentary behaviours on the relationship of weight gain and smoking cessation. In a cohort study of middle-aged women,<sup>20</sup> which investigated whether change in exercise could modify weight gain after smoking cessation by comparing weight gain between continuing smokers who did not change their LTPA level and quitters categorized into groups according to change in LTPA (no change, increase by 8-16 metabolic equivalent of task (MET) hours per week, increase by > 16 MET hours per week), greater weight gain was observed among quitters with no change in LTPA, and the extent of weight gain was mitigated with an increase of LTPA. This result was further supported by data from participants of a one year RCT of smoking cessation treatment examining whether smokers' PA was associated with weight gain after a quit attempt using pedometer-measured total PA: it found that quitters who decreased their PA gained significantly greater weight than those who increased their PA or maintained a high level of activity.<sup>21</sup> A recent meta-analysis

1 investigating the efficacy of a range of interventions to reduce weight gain among quitters  
2 concluded that there was insufficient evidence to support specific clinical  
3 recommendations.<sup>12</sup>

4 As the behaviours we measured in our study did not seem to explain weight gain, questions  
5 arise as to its cause. The underlying mechanisms linking smoking cessation and weight gain  
6 are complex and still poorly understood. Apart from changing health behaviours, absence of  
7 nicotine could acutely increase appetite, decrease basal metabolic rate and metabolic  
8 efficiency.<sup>53</sup> Nevertheless, research on interventions with nicotine replacement therapy (NRT)  
9 to reduce post-cessation weight gain achieved little success. While NRT could limit weight  
10 gain during treatment, the benefits were smaller after the treatment had stopped.<sup>12</sup> The  
11 evidence is insufficient to be sure whether the effects could persist in the long term. Although  
12 no strong clinical recommendations can be made to smokers who want to quit and prevent  
13 excess weight gain, it is important to acknowledge that weight gain after smoking cessation  
14 can be expected. This weight gain may in part reflect a return-to-normal weight whereby  
15 quitters end up weighing the same as they would have had they never smoked.<sup>55</sup> Further  
16 prospective studies with regular anthropometric measurements (e.g. weight, height, waist  
17 circumference and waist-hip ratio), health behaviours (e.g. diet, PA and fitness), energy  
18 expenditure and metabolic factors (e.g. basal metabolic rate), and smaller well controlled  
19 clinical trials may help elucidate the complex mechanisms for post-cessation weight gain and  
20 therefore ways it may be prevented.

21 The strengths of the current study are its longitudinal design and its ability to examine  
22 changes in a range of dietary behaviours, alcohol consumption and PA behaviours  
23 accompanying smoking cessation. Some of these factors are reported for the first time in the

literature, such as takeaway food consumption, DGI score, breakfast skipping, discretionary foods consumption and sedentary behaviours.

Some limitations should be acknowledged. First, self-reported smoking status may lead to misclassification of quitters and continuous smokers,<sup>65</sup> and self-reported weight and height might result in underestimations of actual weight and BMI;<sup>66</sup> however, a correction factor was applied to reduce the error of self-reported weight and height, and the outcome of interest was difference in weight gain between quitters and continuing smokers during follow-up rather than the weight at each time point. Second, we did not collect serving size data in dietary questionnaires, and therefore, could not calculate the energy intake, which has been suggested as a main determinant of weight gain following cessation<sup>27</sup>; however, not all studies support this point<sup>53</sup> and the accuracy of energy intake from self-reported dietary recall is poor.<sup>62</sup> Third, there may be measurement error in dietary and PA behaviours as these data were collected by means of self-completed questionnaires though all measures are widely accepted in the literature. Reassuringly, the percentage of change in  $\beta$  coefficient was similar in magnitude when using pedometer-measured PA as with self-reported PA. Fourth, the sample size is small, limiting the ability to evaluate the effects of changes in dietary or PA behaviours among quitters separately. Fifth, we have only collected data 5-years apart so cannot distinguish whether the changes in diet and PA occurred before quitting, at the same time, or after. Sixth, a large amount of missing data for dietary and PA behaviours at follow-up was imputed; however, similar results were observed after excluding people with imputed data. Finally, this is a small Australian sample. Compared with data from a national survey of 24,000 people across Australia,<sup>67</sup> our smokers were younger and less dependent on nicotine. Relative to the general population of 25-34 years old Australians, a higher proportion of our sample (from whom the 281 current smokers were drawn) were married/living as married (69.9% versus 56.8%)<sup>68</sup> and were university-educated (48.3% versus 35.1%),<sup>69</sup> and a lower

1 proportion currently smoked (20.5% versus 29.8%).<sup>70</sup> In addition, some significant  
2 differences were evident between those retained and lost to follow-up with respect to baseline  
3 socio-demographics. These might limit the generalisability to the general population of  
4 smokers. However, as discussed above, our findings on the magnitude of post-cessation  
5 weight gain are very similar to a recent comprehensive meta-analysis of population-based  
6 prospective cohort studies,<sup>6</sup> suggesting that these are not major sources of bias.

7 In summary, smoking cessation was associated with excess weight gain compared with  
8 those who continued to smoke. This weight gain was not explained by changes in dietary and  
9 PA behaviours. Future research is needed to elucidate the complex mechanisms underlying  
10 weight gain after smoking cessation and to develop effective strategies for its prevention.

## **List of abbreviations**

BMI: body mass index; CDAH: childhood determinants of adult health; CI: confidence interval; DGI: diet guideline index; FFQ: food frequency questionnaire; FHQ: food habit questionnaire; IPAQ-L: international physical activity questionnaire; LTPA: leisure time physical activity; MET: metabolic equivalent of task; NRT: nicotine replacement therapy; PA: physical activity; RCTs: randomized control trials; SDs: standard deviations; TV: television.

## **Competing interests**

The authors declare that they have no competing interests.

## **Authors' contributions**

JT performed the statistical analysis and drafted the manuscript. SG provided analytical and interpretive advice and helped draft the manuscript. KS provided nutritional advice and helped draft the manuscript. TD was involved in conceptualisation of the study and provided critical revision of the manuscript. AV was involved in the conceptualisation of the study, acquisition of data and helped draft the manuscript. All authors read and approved the final manuscript.

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**Table 1. Socio-demographic and anthropometric characteristics of continuing smokers and quitters in the Childhood Determinants of Adult Health Study, Australia\***

Characteristic	Continuing smokers (n=157)	Quitters (n=124)	P-value
Age (years)	31.3±2.4	31.6±2.7	0.487
Males sex (%)	54.1	43.6	0.078
Married or living as married (%)	66.2	58.87	0.204
Education (%)			0.15
Any university education	24.8	35.48	
Vocational training	35.7	29.84	
High school only	39.5	34.68	
Occupation (%) <sup>†</sup>			0.053
Professional or manager	41.5	53.2	
Nonmanual	19.1	22.6	
Manual	27.6	15.3	
Not in the labour force	11.8	8.9	
Weight (kg)	79.1±16.0	76.4±17.8	0.188
BMI (kg/m <sup>2</sup> )	26.1±4.7	25.4±4.5	0.222
Weight status (%)			0.302
Normal (< 25)	46.5	51.6	
Overweight (25 – 29.9)	35.7	37.1	
Obese (≥ 30)	17.8	11.3	
Change in weight (kg)	<b>2.3±7.4</b>	<b>4.4±7.3</b>	<b>0.019</b>
Change in BMI (kg/m <sup>2</sup> )	<b>0.7±2.5</b>	<b>1.4±2.6</b>	<b>0.021</b>
Frequency of smoking			<b>0.001</b>
Less than weekly	<b>10.8</b>	<b>26.6</b>	
Weekly	<b>15.9</b>	<b>17.7</b>	
Daily	<b>73.3</b>	<b>55.7</b>	
Number of cigarettes/day <sup>†</sup>	<b>13.4±7.3</b>	<b>11.1±7.2</b>	<b>0.045</b>
Smoking duration (years) <sup>†</sup>	14.2±4.1	13.5±5.0	0.305
Pack-years <sup>†</sup>	9.9±6.7	8.1±6.8	0.078

Bold denotes statistically significant result.

\* Limited to participants with full information of smoking status, age, sex, change in weight, change in BMI, dietary and physical activity variables at baseline; Mean±SD except for percentages; P-values determined by t test or person  $\chi^2$  test (where appropriate).

<sup>†</sup> Sample size ranged 174-276.

SD: standard deviation; BMI: body mass index.

**Table 2.** Dietary behaviours at baseline, follow-up and changes during follow-up, for continuing smokers and quitters\*

Dietary behaviours	Continuing smokers (n=157)	Quitters (n=124)	P-value
Servings of 'discretionary' foods /day			
Baseline	4.3±2.6	3.8±2.3	0.082
Follow-up	4.0±3.3	3.4±2.5	0.101
Change from baseline to follow-up <sup>†</sup>	-0.3±2.8	-0.4±2.4	0.888
Servings of fruit and vegetables/day			
Baseline	3.6±1.5	3.6±1.7	0.808
Follow-up	3.6±1.6	3.9±1.8	0.127
Change from baseline to follow-up <sup>†</sup>	-0.0±1.6	0.2±1.5	0.162
Diet Guideline Index score			
Baseline	<b>93.8±19.3</b>	<b>98.6±17.3</b>	<b>0.031</b>
Follow-up	<b>96.6±21.0</b>	<b>103.5±21.1</b>	<b>0.008</b>
Change from baseline to follow-up <sup>†</sup>	2.8±19.5	4.9±19.4	0.386
Alcohol consumption (grams/day)			
Baseline	<b>15.6±20.3</b>	<b>11.0±9.6</b>	<b>0.020</b>
Follow-up	<b>13.0±17.3</b>	<b>8.8±10.9</b>	<b>0.018</b>
Change from baseline to follow-up <sup>†</sup>	-2.6±22.0	-2.2±11.2	0.867
Consuming takeaway food (≥2/wk) (%)			
Baseline	33.1	32.3	0.878
Follow-up	32.6	22.2	0.094
Change from baseline to follow-up			
Neither baseline or follow-up	54.8	59.6	0.158
Baseline only	12.6	18.1	
Follow-up only	12.1	8.1	
Both baseline and follow-up	20.5	14.1	
Skipping breakfast (%)			
Baseline	38.9	39.5	0.910
Follow-up	41.7	31.3	0.126
Change from baseline to follow-up			
Neither baseline or follow-up	39.3	44.4	0.190
Baseline only	19.0	24.2	
Follow-up only	21.8	16.0	
Both baseline and follow-up	19.9	15.3	

Bold denotes statistically significant result.

\* Mean±SD except for percentages; P-values determined by t test or person  $\chi^2$  test (where appropriate).

<sup>†</sup> Calculated using follow-up values minus baseline ones.

SD: standard deviation.

**Table 3.** Physical activity behaviours at baseline, follow-up and changes during follow-up, for continuing smokers and quitters\*

Physical activity behaviours	Continuing smokers (n=157)		Quitters (n=124)		P-value
	Mean	SD	Mean	SD	
Total PA (minutes/week)					
Baseline	889.9	541.9	796.2	526.8	0.146
Follow-up	786.1	731.8	744.9	639.6	0.600
Change from baseline to follow-up <sup>†</sup>	-103.8	774.8	-51.3	719.3	0.542
Total LTPA (minutes/week)					
Baseline	134.3	170.8	135.3	151.3	0.956
Follow-up	132.4	238.9	175.6	232.4	0.107
Change from baseline to follow-up <sup>†</sup>	-1.8	241.4	40.3	245.1	0.128
Sitting time (minutes/day)					
Baseline	324.4	175.2	340.7	154.4	0.417
Follow-up	330.5	200.2	351.8	181.3	0.336
Change from baseline to follow-up <sup>†</sup>	6.0	209.5	11.1	206.9	0.835
TV viewing time (hours/day)					
Baseline	2.4	1.4	2.1	1.8	0.088
Follow-up	2.3	2.0	2.0	1.7	0.131
Change from baseline to follow-up <sup>†</sup>	-0.1	2.1	-0.1	2.0	0.986

Bold denotes statistically significant result.

\* P-values determined by t test.

<sup>†</sup> Calculated using follow-up values minus baseline ones.

SD: standard deviation; PA: physical activity; LTPA: leisure time physical activity; TV: television.

**Table 4.** Effects of changes in dietary and physical activity behaviours on the magnitude of weight (kg) gain after quitting smoking during follow-up, compared with continuing smoking

	Models	$\beta$	95% CI	Change in $\beta^*$
	Unadjusted	2.09	0.35, 3.83	
	Model 1 <sup>†</sup>	1.93	0.18, 3.67	
Changing dietary behaviours	Model 1 + changing discretionary foods consumption	1.95	0.21, 3.69	1.11%
	Model 1 + changing fruit and vegetable consumption	1.94	0.18, 3.69	0.46%
	Model 1 + changing diet guideline index score	1.99	0.24, 3.74	3.28%
	Model 1 + changing alcohol consumption	1.99	0.23, 3.75	3.23%
	Model 1 + change in eating takeaway food	2.00	0.25, 3.76	3.83%
	Model 1 + change in skipping breakfast	1.93	0.19, 3.66	-0.07%
	Model 1 + changing all dietary behaviours	2.10	0.31, 3.88	8.66%
Changing PA behaviours	Model 1 + changing total PA	1.98	0.24, 3.72	2.70%
	Model 1 + changing LTPA	2.23	0.48, 3.97	15.46%
	Model 1 + changing sitting time	1.93	0.18, 3.67	-0.08%
	Model 1 + changing TV viewing time	1.93	0.18, 3.68	0.22%
	Model 1 + changing LTPA and sitting time	2.23	0.48, 3.97	15.61%
Changing dietary and PA behaviours	Model 1 + changing all dietary behaviours, LTPA and sitting time	2.32	0.54, 4.10	20.33%

\* Relative to Model 1.

<sup>†</sup> Adjusted for age, sex, BMI, education and follow-up length.

BMI: body mass index; CI: confidence interval; PA: physical activity; LTPA: leisure time physical activity; TV: television.

