BMJ open

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Journal:	*BMJ Open*
Manuscript ID:	bmjopen-2014-004860
Article Type:	Research
Date Submitted by the Author:	14-Jan-2014
Complete List of Authors:	Paige, Ellie; Australian National University, National Centre for Epidemiology and Population Health Korda, Rosemary; The Australian National University, National Centre for Epidemiology and Population Health Banks, Emily; The Australian National University, National Centre for Epidemiology and Population Health Rodgers, Bryan; Australian National University, Australian Demographic & Social Research Institute
Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Research methods
Keywords:	EPIDEMIOLOGY, Body weight changes, Education, Cohort studies

How weight change is modelled in population studies can affect research findings: empirical results from a large-scale cohort study

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Key words

Body weight changes, education, cohort studies

Word count

3,418

ABSTRACT

Objectives: The study objective is to investigate how results of the association between education and weight change vary when weight change is defined and modelled in different ways.

Design: Longitudinal cohort study

Participants: 60,404 men and women participating in the Social, Environmental and Economic Factors (SEEF) sub-component of the 45 and Up Study—a population-based cohort study of people aged 45 years and older, residing in New South Wales, Australia.

Outcome measures: The main exposure was self-reported education, categorised into four groups. The outcome was annual weight change, based on change in self-reported weight between the 45 and Up Study baseline questionnaire and SEEF questionnaire (completed an average of 3.3 years later). Weight change was modelled in four different ways: absolute change (kg) modelled as a 1) continuous variable and 2) categorical variable (loss, maintenance and gain); and relative (%) change modelled as a 3) continuous variable and 4) a categorical variable. Different cut-points for defining weight-change categories were also tested.

Results: When weight change was measured categorically, people with higher levels of education (compared to no school certificate) were less likely to lose or to gain weight. When weight change was measured as the average of a continuous measure, a null relationship between education and annual weight change was observed. No material differences in the education and weight-change relationship were found when comparing weight change defined as an absolute (kg) versus a relative (%) measure. Results of the logistic regression were sensitive to different cut-points for defining weight-change categories.

Conclusions: Using average weight change can obscure important directional relationship information and, where possible, categorical outcome measurements should be included in analyses.

ARTICLE SUMMARY

Strengths and limitations of this study

- First study to explore in depth and explicitly demonstrate how study outcomes differ when weight change is defined and modelled in different ways
- Large sample size and heterogeneity across the primary exposure, allowing analysis of multiple education levels
- Weight change calculated from self-reported weight, at two time points

INTRODUCTION

Obesity is a major global health problem.[1] While there are numerous population studies that address the important question of what factors influence weight change, differences in methods, particularly in how weight change is defined and modelled, make it difficult to compare and integrate research results.[2 3]

There is no agreed definition of clinically significant weight change and research studies define and model weight change over time in a variety of ways.[4] These include modelling weight change as either a continuous or categorical variable (or both); defining weight change as an absolute or relative change; and using different cut-points to define weight-change categories. It is unclear whether and, to what extent, these differences in defining and modelling weight change affect research findings.

The aim of our study is to investigate how research results vary when weight change is defined and modelled in different ways. To do this we examine the association between education and weight change, where weight change is modelled in four different ways: absolute change (kg per year) modelled as a continuous variable and as a categorical variable; and relative change (percentage change per year) also modelled as a continuous variable and as a categorical variable. Further, we test the sensitivity of the results to different cut-points for weight-change categories.

Education was chosen as the main sociodemographic factor of interest. While studies have shown education is inversely associated with weight gain, there are inconsistencies in the results across studies.[2] In addition, we explored the relationship of the various weight-change measures to other sociodemographic and behavioural factors.

METHODS

Study population

We used data from the 45 and Up Study baseline questionnaire, linked to data from the Social, Environmental and Economic Factors (SEEF) sub-study questionnaire. The 45 and Up Study is an Australian cohort involving 267,153 men and women aged 45 years and over from New South Wales (NSW), Australia. Participants in the Study were randomly sampled from the database of Medicare Australia, which provides virtually complete coverage of the general population. Approximately 10% of the entire NSW population aged 45 years or older was included. Participants joined the Study by completing a baseline questionnaire—distributed from January 2006 to December 2008—and giving signed consent for follow-up and linkage of their information to a range of health databases. The Study is described in detail elsewhere,[5] and questionnaires can be viewed at http://www.45andup.org.au.

Invitations to the SEEF sub-study were sent to the first 100,000 participants enrolled in the 45 and Up Study. Of those invited to complete the SEEF questionnaire (hereafter referred to as the follow-up questionnaire), 60,404 participants did so, with questionnaires completed in 2010. Only participants who completed both the 45 and Up Study baseline questionnaire and the follow-up questionnaire were included in the present analyses.

Consistent with previous studies on weight change, [6 7] we excluded people with a history of cancer (excluding non-melanoma skin cancer) and those whose physical health severely limited them in walking 100m at baseline. We further excluded participants with implausible values for height (outside the range of 121-213cm[8]) and people with a body mass index (BMI) of <15kg m^{-2} or >50kg m^{-2} at baseline, as measurement error becomes more likely at these extreme values of BMI.[9-11]

Measurements

Exposure

Education was self-reported on the baseline questionnaire. Participants were asked about their highest completed qualification, with options including six categories from 'no school certificate or other qualification' to 'university degree or higher'. For this analysis, education was categorised as: 'no school certificate' (no school certificate or other qualification); 'school certificate' (school or intermediate certificate, or a higher school or leaving certificate, equivalent to completing secondary school); 'apprenticeship/diploma' (trade, apprenticeship, certificate or diploma); and 'university degree' (university degree or higher).

Outcomes

Participants self-reported their weight on the baseline and follow-up questionnaires. Change in weight from baseline to follow-up was the primary outcome and this was calculated as per annum weight change to account for varying follow-up time in the cohort and to enhance comparability with other studies which differ in follow-up length. Specifically, change in weight was calculated as weight (kg) reported on the follow-up questionnaire minus weight (kg) reported on the baseline questionnaire, divided by time (years) between completion of the baseline and follow-up questionnaires. Relative (percentage) change in weight was calculated as change in annual weight divided by weight at baseline, multiplied by 100.

We modelled weight change as four different outcome variables:

i. Absolute annual weight change, modelled as a continuous variable
ii. Absolute annual weight change, modelled as a categorical variable
iii. Percentage annual weight change, modelled as a continuous variable
iv. Percentage annual weight change, modelled as a categorical variable

For the categorical variables, participants were categorised as into groups of 'weight maintenance' (absolute weight change ≤ 1kg; or relative change ≤1.25%), 'weight loss' (weight decrease >1kg or 1.25%) or 'weight gain' (weight increase >1kg or 1.25%). These cut-points were chosen based on those used in previous studies.[6 12 13]

Covariates

Potential covariates in the relationship of education to weight change were identified a priori through a literature review and included age, sex, physical activity, physical impairment and smoking status. Information on these factors was self-reported on the baseline questionnaire. Physical activity was categorised as tertiles based on the weighted number of reported weekly sessions of walking, moderate activity and vigorous activity.[14] Physical impairment was derived from responses to Medical Outcome Scale SF-36 ten-item physical functioning scale (PF-10)[15] and was categorised as: none/minor (score of 100-75); moderate (score of 50-74); and severe (score of <50). Smoking status was categorised as never, past or current.

Statistical methods

Mean annual absolute and percentage weight change and the proportion of participants in each category of weight change (weight loss, weight maintenance and weight gain) were estimated in relation to the main variables. Differences between groups were compared using analysis of variance tests for mean weight change and chi square tests for categorical weight change.

Multivariable linear and multinomial logistic regression models were used to estimate the strength of the relationship between education and weight change. For each model, unadjusted coefficients, sex- and age-adjusted coefficients and more fully adjusted coefficients (adjusted for covariates defined above) were calculated. We undertook four regression analyses, which differed only in outcome measure, and compared the results. We tested the assumptions of the two linear regression models and used robust standard errors to account for non-normality of the residuals.

To test the sensitivity to different cut-points, we re-ran the logistic regression models using cut-points of 2kg, 3kg, 3% and 5% per annum cut-points, which have been previously used in other studies.[4] We then compared the regression coefficients across models using the different cut-points using Hausman-type tests.[16] In all analyses, 95% confidence intervals were generated and, in line with previous studies, p-values less than 0.05 were considered as statistically different.

All analyses were performed using Stata version 12.0. Ethics approval for this project was obtained from the University of Sydney Human Research Ethics Committee and the Australian National University Human Research Ethics Committee.

RESULTS

The final sample size was 45,037, after excluding those with: a history of cancer (n=9,411); a severe limitation in the ability to walk 100m (n=964); missing education data (n=673); missing data on weight (n=1,893) or height (n=1,950); implausible height values (n=263); and BMI<15kg m^{-2} or >50kg m^{-2} (n=213). The mean time between the baseline and follow-up questionnaires was 3.3 years (range=1.7-5.1 years).

Characteristics of the sample are presented in Table 1. Just over half the participants had either a university degree (28%) or an apprenticeship/diploma qualification (33%), while about a third (30%) of the participants had a school certificate as their highest qualification and 9% had no school certificate.

[Insert Table 1]

Factors associated with weight change

Mean annual weight gain in the cohort was 0.24kg overall and was higher in women (0.27kg) than in men (0.21kg). Overall, 60% of the sample maintained their weight (≤ 1kg change) while 17% had an annual weight loss of >1kg and 23% (24% of women and 22% of men) had an annual weight gain of >1kg. In the univariate analysis, all factors were statistically associated with weight change, although weight change for physical functioning impairment was only statistically different when weight change was measured categorically (Table 2).

Mean weight gain decreased with increasing age, and those aged 75 years or older had a mean weight loss. Participants with a healthy profile (high levels of physical activity or little to no physical impairment) generally had greater mean weight gain but were also more likely

to have maintained their weight compared to those with less healthy profiles. Similarly, people with an apprenticeship/diploma or a university degree had a greater mean weight gain than those with a school certificate or no school certificate, but also had higher proportions of people maintaining their weight.

[Insert Table 2]

Continuous versus categorical modelling of weight change

The results of the linear regression analyses are shown in Table 3. The unadjusted results show that, compared to people without a school certificate, those with a higher qualification gained slightly more weight annually. However, after adjusting for covariates, there was no statistical association between education level and annual weight change.

When weight change was modelled categorically, both the unadjusted and adjusted associations between education and weight change were statistically different (Table 4). Compared to people with no school certificate, those with a school certificate, apprenticeship/diploma or a university degree were less likely to lose weight and were less likely to gain weight, i.e. they were more likely to have maintained their annual weight.

Results for the other variables included in the analyses also statistically differed when modelling weight change using continuous versus categorical variables (Table 5 and Table 6). Where a variable was both associated with weight loss and weight gain, the results between the categorical and continuous outcomes differed. For example, participants with moderate or severe physical impairment (compared to none/minor physical impairment) and those who were past or current smokers (compared to never smokers) were more likely to

gain weight and were more likely to lose weight. However, when weight change was modelled as a continuous variable, no relationship between weight change and physical impairment and smoking was found.

[Insert Tables 3, 4, 5 and 6]

Absolute versus relative weight change measures

The overall association between education and weight change did not differ materially when weight change was measured as a relative (%/year) variable rather than as an absolute variable (kg/year) (Tables 5 and 6), with one exception When modelled as a categorical variable (Table 6), the direction and magnitude of the effect size for sex changed between the absolute and relative weight measures. For weight loss, when measured as an absolute change, females were less likely to have lost weight than males, but when measured as a relative change they were more likely to have lost weight. For weight gain, there was no significant sex effect when measured as an absolute change, but when measured as a relative change, females were more 50% more likely to gain weight than males. Notably, females had a lower mean starting weight compared to males (69.7kg compared to 83.9kg); thus for a given value of absolute weight change, the percentage change in weight was higher in females compared to males. For all other variables, mean baseline weight was similar between groups and there were no material differences observed between absolute and relative measures.

Sensitivity of categorical cut-points

The results of the logistic regression using different cut-points to define weight-change categories are presented in Table 7 and Table 8. Using the 2kg cut-point, 6.57% (n=2,959) of

participants were in the weight-loss category and 8.98% (n=4,043) were in the weight-gain category, while a 3kg cut-point decreased the proportions to 3.21% (n=1,446) and 4.29% (n=1,933), respectively. When a 3% cut-point was used to categorise weight change, 4.89% (n=2,203) of participants were in the weight-loss group and 7.49% (n=3,374) were in the weight-gain group, while the corresponding proportions for a cut-point of 5% were 1.49% (n=669) and 2.63% (1,186). Those with a school certificate, apprenticeship/diploma or university degree were still more likely to maintain their annual weight than those with no school certificate, but this was no longer statistically different for some education levels based on the 5% cut-point, possibly due to smaller numbers in these groups (<5% of the sample were in the weight-loss and weight-gain groups). Formal testing of the differences in effects sizes using different cut-points showed they statistically differed in magnitude, but not direction, from the results of the main logistic regression analyses ($p<0.001$), except for weight loss using the 2kg cut-point ($p=0.097$).

[Insert Tables 7 and 8]

DISCUSSION

Principal findings

Weight change in this middle-aged cohort of Australians was common, with 23% of people gaining weight and 17% losing weight during the follow up period. This study shows that observed relationships of exposures to weight change can vary according to how weight change is defined and modelled. Specifically, when weight change was measured as the average of a continuous variable, we found no statistical association between education and weight change. However, when weight change was modelled as a categorical variable, we found that people with higher levels of education (compared to no school certificate) were more likely to maintain their weight annually within 1kg or 1.25% of their baseline weight — they were less likely to lose weight and less likely to gain weight. For other factors where participants were both more likely to lose and gain weight, we found similar differences in results when weight change was modelled as a continuous rather than categorical variable. Further, we found that the results of the logistic regression were also sensitive to different cut-points for defining weight-change categories.

Strengths and weakness of this study

The main strength of this study is the large sample size and heterogeneity across the primary exposure allowing different levels of education to be examined. There are three important limitations to our study. First, weight change was calculated from self-report weight at baseline and follow-up. It is well established that people tend to underestimate their weight when self-reporting.[17] A validation study using participants from the 45 and Up Study found a high correlation between self-reported and measured weight of 0.99,[18] suggesting the effect estimates calculated from this self-reported data are still likely to be valid. Further, if people underestimated their weight by approximately the same amount at both time points

there will be minimal to no bias in the change measurement. However, we do note the overall mean weight change observed in the participants (0.24kg per year) is small and falls within expected error margins. Second, weight was reported at only two time points; thus the observed weight change may be due to regression to the mean. However, the majority of previous studies also analysed data from two time points only and the purpose of this study was to use similar techniques to previous studies in order to compare results when using different outcome measures, not to estimate the actual strength of the association between education and weight change. Third, height was only recorded at baseline and as such we could not examine change in BMI. While height at follow-up was not reported, the short follow-up time (mean 3.3 years) means that no material change in height would be expected in the cohort as height generally remains stable in adults over this time period (except in the very elderly). Given this, and the fact that weight change and BMI change are mathematically equivalent when height is constant,[4] these findings can be applied to studies examining change in BMI in situations where height remains constant over time.

Strengths and weakness of the study in relation to other studies

We are not aware of any studies that have explicitly tested whether differences in the modelling of weight change can affect research findings. However, two previous studies[19 20] used data from the United States (US) National Health and Nutrition Examination Survey to examine the association between education and weight change where weight change was measured as both a continuous and as a categorical outcome. While the authors did not specifically look at the impact of different weight change modelling on research findings, the results of their study showed slight differences in findings when weight change was modeled as a continuous versus categorical outcome. In contrast to our study where we found no clear pattern between education level and average weight change after adjusting for covariates, the

two US studies found that, after adjusting for multiple covariates, mean weight gain was slightly higher in men and women with a lower education level (12th grade or below) than in those with higher education (above 12th grade). When the authors modelled weight change in categories (major weight gain and major weight loss based on change in BMI points), they found no statistical association between education and weight change. While the US studies used weight change based on measured rather than self-reported weight, their sample sizes were relatively small (n=1552 and 4836, respectively) and it is not clear whether the study was sufficiently powered to detect effects particularly in analyses using weight change categories. In contrast to the US studies, our study sought to test the effect of different modelling of weight change on research findings and within this we examined use of different cut-points to define categories and the use of absolute versus weight change measures; aspects which were not included in the US study designs.

What does this study mean?

Our results indicate that findings from studies examining factors associated with weight change can vary depending on how weight change is modelled and defined. This limits comparability across study results where different measures have been used and may affect interpretation of individual study results, contributing to inconsistences in the literature.

Based on our results we suggest, where sample sizes allow, weight change should be modelled as both a continuous and categorical variable. The common statistical viewpoint is that reducing continuous variables into categories can obscure linear relationships [21 22] and result in a loss of information and statistical power.[21-23] We counter that, in research studies where both weight gain and weight loss are of interest, use of mean weight change

alone can obscure important directional information where high proportions of people are either losing or gaining weight within the same exposure group. Modelling weight change as both as continuous and categorical variable is likely to avoid this loss of directional information and increase comparability across studies.

Further, during the planning of analyses, consideration should be given to whether weight change is modelled as an absolute or relative measure and to the cut-points used to define categories. Unless baseline weight differs substantially between exposure levels, the relative and absolute weight-change measures are likely to give similar results; however, the two different measures lend themselves to different research questions and purposes, whether it be for clinical use or for a public health message.[4]

This study was intended to compare results of the association between education and other exposures and weight change, when the definition and modelling of the outcome measure was varied. We did not aim to investigate causal relationships between weight change and other factors and we caution against such interpretation.

Unanswered questions and future research

The results and conclusions of this paper should be tested by replication, particularly in different datasets and in studies where weight is measured at multiple time points. Further, we did not examine whether inconsistencies between research studies may also be due to differences in how exposure variables were modelled and defined.

CONCLUSIONS

To our knowledge, this is the first empirical study to directly test whether research results of factors associated with weight change differ according to how weight change is defined and modelled. Specifically, where factors are both associated with weight loss and weight gain, continuous measurement of weight gain obscures the direction of the weight change. To build a more complete picture of the relationship between weight change and various factors, we suggest, where possible, weight change should be modelled as both a continuous and a categorical variable. Further, consideration should be given to the cut-points used to define categories, as these can result in changes in the magnitude of the effect size; and, when baseline weight substantially differs between exposure groups, consideration should also be given to whether absolute or relative change is used. Above and beyond this, agreed definitions for clinically significant weight loss, weight maintenance and weight gain, would greatly improve both the practical application of research and comparability between studies.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

EP primarily designed the study, carried out the statistical analysis and drafted the manuscript. RK, EB and BR participated in the design of the study and interpretation of results and provided advice on drafting of the manuscript. All authors read and approved the final manuscript.

ACKNOWLEDGEMENTS AND FUNDING

This research was completed using data collected through the 45 and Up Study (www.saxinstitute.org.au). The 45 and Up Study is managed by the Sax Institute in collaboration with major partner Cancer Council NSW; and partners: the National Heart Foundation of Australia (NSW Division); NSW Ministry of Health; beyondblue; Ageing, Disability and Home Care, Department of Family and Community Services; the Australian Red Cross Blood Service; and UnitingCare Ageing. We thank the many thousands of people participating in the 45 and Up Study. This specific project was part of the Study of Economic and Environmental Factors in health program funded by the National Health and Medical Research Council of Australia (NHMRC) Strategic Award for Preventive Healthcare and Strengthening Australia's Social and Economic Fabric (grant reference: 402810). Emily Banks and Bryan Rodgers are supported by the NHMRC (Fellowship No. 1042717 and 471429, respectively).

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TABLES

Table 1: Characteristics of participants by education categories

	Education level			
	No school certificate 9% (n=3857)	School certificate 30% (n=13635)	Trade/certificate/diploma 33% (n=15059)	University degree or higher 28% (n=12486)
	% (n)	% (n)	% (n)	% (n)
Sex				
Male	43 (1673)	36 (4951)	54 (8110)	49 (6177)
Female	57 (2184)	64 (8684)	46 (6949)	51 (6309)
Age				
45-54	19 (722)	27 (3627)	34 (5104)	45 (5578)
55-64	31 (1178)	36 (4891)	33 (5004)	33 (4134)
65-74	32 (1228)	24 (3263)	22 (3282)	15 (1846)
75-84	17 (639)	12 (1624)	10 (1481)	6 (805)
85plus	2 (90)	2 (230)	1 (188)	1 (123)
Physical activity tertile				
Low	33 (1235)	28 (3736)	27 (3994)	24 (2931)
Moderate	34 (1274)	37 (4969)	35 (5261)	36 (4414)
High	33 (1248)	35 (4755)	38 (5667)	41 (5081)
Physical impairment				
None/minor	75 (2352)	84 (10058)	86 (11688)	92 (10715)
Moderate	15 (459)	11 (1303)	9 (1264)	5 (636)
Severe	11 (335)	5 (641)	5 (622)	2 (250)
Smoking status				
Never	51 (1960)	59 (8085)	55 (8191)	65 (8079)
Past	40 (1532)	34 (4591)	39 (5910)	32 (3920)
Current	9 (347)	7 (923)	6 (919)	4 (445)

Notes: Physical impairment measured using the Medical Outcome Scale, SF-36 ten-item physical functioning scale (none/minor=score of 75-100; moderate=score of 50-74; and severe=score of <50). Percentage missing: physical activity = 1.05%; physical functioning = 10.47%; smoking status = 0.30%.

Table 2: Mean annual weight change and proportion of participants by weight change categories according to sample characteristics

	N	Mean annual weight change (kg)	p-value[1]	Annual weight change category			p-value[2]
				Loss (%) n= 7685 (17%)	Maintenance (%) n=26922 (60%)	Gain (%) n= 10430 (23%)	
Sex							
Male	20911	0.21	0.019	18	60	22	<0.001
Female	24126	0.27		16	60	24	
Age							
45-54	15031	0.41	<0.001	14	57	28	<0.001
55-64	15207	0.26		16	60	24	
65-74	9619	0.14		18	63	19	
75-84	4549	-0.07		24	61	15	
85plus	631	-0.26		32	56	13	
Education							
No school cert	3857	0.14	0.016	22	54	25	<0.001
School cert	13635	0.23		18	58	24	
Trade/cert/dip	15059	0.28		16	60	23	
University degree	12486	0.24		16	63	22	
Physical activity tertile							
Low	11896	0.19	0.025	19	56	25	<0.001
Moderate	15918	0.25		17	60	23	
High	16751	0.27		15	62	22	
Physical impairment							
None/minor	34813	0.25	0.080	16	62	23	<0.001
Moderate	3662	0.21		22	53	25	
Severe	1848	0.13		26	46	28	
Smoking status							
Never	26315	0.21	<0.001	16	62	22	<0.001
Past	15953	0.25		18	58	24	
Current	2634	0.50		18	49	33	

Notes: Physical impairment measured using the Medical Outcome Scale, SF-36 ten-item physical functioning scale (none/minor=score of 75-100; moderate=score of 50-74; and severe=score of <50). No weight change is defined as an annual weight change of between -1kg and 1kg. Weight loss is defined as >-1kg annual weight change. Weight gain is defined as >1kg weight change.

[1] p-value of analysis of variance tests

[2] p-value of chi square tests

Table 3: Relationship of education level to annual change in weight, measured as a continuous variable

	Annual weight change (kg)			Annual weight change (%)		
	β	95% CI	p-value	β	95% CI	p-value
Unadjusted						
No school cert	0.00	-	-	0.00	-	-
School cert	0.08	-0.01-0.17	0.076	0.08	-0.04-0.20	0.179
Trade/cert/dip	0.14	0.05-0.23	0.003	0.16	0.04-0.27	0.011
University degree	0.09	0.00-0.18	0.048	0.09	-0.03-0.21	0.128
Adjusted[1]						
No school cert	0.00	-	-	0.00	-	-
School cert	0.04	-0.05-0.13	0.387	0.02	-0.10-0.14	0.717
Trade/cert/dip	0.08	-0.02-0.17	0.103	0.08	-0.04-0.20	0.190
University degree	-0.01	-0.10-0.09	0.874	-0.04	-0.16-0.09	0.572
Adjusted[2]						
No school cert	0.00	-	-	0.00	-	-
School cert	0.02	-0.08-0.11	0.753	-0.01	-0.14-0.11	0.846
Trade/cert/dip	0.07	-0.02-0.17	0.141	0.07	-0.06-0.20	0.264
University degree	-0.01	-0.11-0.09	0.814	-0.04	-0.17-0.09	0.567

Abbreviations: 95% CI = 95% confidence intervals

[1]Sex- and age-adjusted only

[2]Adjusted for age group, sex, physical activity, physical impairment and smoking status

Table 4: Odds ratios of annual weight loss compared to weight maintenance, and annual weight gain compared to weight maintenance, according to education levels

	OR for annual weight loss >1kg compared to weight maintenance		OR for annual weight loss >1.25% compared to weight maintenance		OR for annual weight gain >1kg compared to weight maintenance		OR for annual weight gain >1.25% compared to weight maintenance	
	OR (95% CI)	p-value	OR (95% CI)	p-value	OR (95% CI)	p-value	OR (95% CI)	p-value
Unadjusted								
No school cert	1.00	-	1.00	-	1.00	-	1.00	-
School cert	0.75 (0.68-0.82)	<0.001	0.75 (0.69-0.83)	<0.001	0.90 (0.82-0.98)	0.014	0.92 (0.84-1.00)	0.053
Trade/cert/dip	0.68 (0.62-0.74)	<0.001	0.65 (0.60-0.72)	<0.001	0.85 (0.78-0.93)	<0.001	0.84 (0.77-0.92)	<0.001
University degree	0.62 (0.56-0.68)	<0.001	0.61 (0.56-0.67)	<0.001	0.76 (0.69-0.83)	<0.001	0.77 (0.71-0.85)	<0.001
Adjusted[1]								
No school cert	1.00	-	1.00	-	1.00	-	1.00	-
School cert	0.77 (0.71-0.85)	<0.001	0.77 (0.70-0.85)	<0.001	0.83 (0.76-0.91)	<0.001	0.84 (0.77-0.92)	<0.001
Trade/cert/dip	0.70 (0.64-0.77)	<0.001	0.72 (0.65-0.79)	<0.001	0.76 (0.70-0.83)	<0.001	0.80 (0.73-0.87)	<0.001
University degree	0.66 (0.60-0.73)	<0.001	0.68 (0.62-0.75)	<0.001	0.64 (0.58-0.70)	<0.001	0.68 (0.62-0.74)	<0.001
Adjusted[2]								
No school cert	1.00	-	1.00	-	1.00	-	1.00	-
School cert	0.84 (0.76-0.93)	0.001	0.82 (0.73-0.91)	<0.001	0.88 (0.80-0.97)	0.014	0.87 (0.79-0.96)	0.005
Trade/cert/dip	0.76 (0.68-0.84)	<0.001	0.76 (0.69-0.84)	<0.001	0.80 (0.73-0.89)	<0.001	0.82 (0.75-0.91)	<0.001
University degree	0.76 (0.68-0.85)	<0.001	0.76 (0.69-0.85)	<0.001	0.72 (0.65-0.80)	<0.001	0.74 (0.67-0.82)	<0.001

Abbreviations: OR = odds ratios; 95% CI = 95% confidence intervals

[1] Sex- and age-adjusted only

[2] Adjusted for age group, sex, physical activity, physical impairment and smoking status.

Table 5: Relationship of baseline characteristics (excluding education) to annual change in weight, measured as a continuous variable

	Annual weight change (kg)			Annual weight change (%)		
	B[1]	95% CI	p-value	β[1]	95% CI	p-value
Sex						
Male	0.00	-	-	0.00	-	-
Female	0.02	-0.03-0.07	0.498	0.09	0.03-0.16	0.004
Age						
45-54	0 .00	-	-	0.00	-	-
55-64	-0.14	-0.20--0.09	<0.001	-0.19	-0.26--0.12	<0.001
65-74	-0.28	-0.35--0.21	<0.001	-0.36	-0.45--0.27	<0.001
75-84	-0.47	-0.57--0.36	<0.001	-0.62	-0.76--0.48	<0.001
85plus	-0.83	-1.00--0.66	<0.001	-1.14	-1.40--0.88	<0.001
Physical activity tertile						
Low	0.00	-	-	0.00	-	-
Moderate	0.06	0.00-0.12	0.053	0.06	-0.02-0.14	0.128
High	0.06	0.00-0.12	0.038	0.07	0.00-0.15	0.066
Physical impairment						
None/minor	0.00	-	-	0.00	-	-
Moderate	0.05	-0.05-0.15	0.290	0.04	-0.08-0.16	0.534
Severe	0.00	-0.13-0.13	0.959	0.00	-0.17-0.16	0.956
Smoking status						
Never	0.00	-	-	0.00	-	-
Past	0.03	-0.02-0.08	0.278	0.04	-0.03-0.11	0.250
Current	0.26	0.14-0.38	<0.001	0.40	0.23-0.56	<0.001

Notes: Physical impairment measured using the Medical Outcome Scale, SF-36 ten-item physical functioning scale (none/minor=score of 75-100; moderate=score of 50-74; and severe=score of <50

Abbreviations: 95% CI = 95% confidence intervals

[1] Mutually adjusted for other variables listed in table and education.

Table 6: Adjusted[1] odds ratios of annual weight loss compared to weight maintenance and annual weight gain compared to weight maintenance according to other sample characteristics

	OR for annual weight loss >1kg compared to weight maintenance		OR for annual weight loss >1.25% compared to weight maintenance		OR for annual weight gain >1kg compared to weight maintenance		OR for annual weight gain >1.25% compared to weight maintenance	
	OR (95% CI)[1]	p-value	OR (95% CI)[1]	p-value	OR (95% CI)[1]	p-value	OR (95% CI)[1]	p-value
Sex								
Male	1.00	-	1.00	-	1.00	-	1.00	-
Female	0.92 (0.87-0.98)	0.007	1.31 (1.24-1.39)	<0.001	1.03 (0.98-1.09)	0.216	1.48 (1.41-1.56)	<0.001
Age								
45-54	1.00	-	1.00	-	1.00	-	1.00	-
55-64	1.05 (0.98-1.13)	0.133	1.03 (0.97-1.11)	0.331	0.79 (0.74-0.83)	<0.001	0.76 (0.72-0.81)	<0.001
65-74	1.05 (0.97-1.13)	0.236	1.09 (1.01-1.18)	0.030	0.56 (0.52-0.60)	<0.001	0.58 (0.54-0.62)	<0.001
75-84	1.23 (1.11-1.36)	<0.001	1.50 (1.36-1.66)	<0.001	0.39 (0.35-0.44)	<0.001	0.48 (0.43-0.53)	<0.001
85plus	1.54 (1.24-1.92)	<0.001	2.23 (1.80-2.76)	<0.001	0.29 (0.21-0.40)	<0.001	0.44 (0.33-0.59)	<0.001
Physical activity tertile								
Low	1.00	-	1.00	-	1.00	-	1.00	-
Moderate	0.86 (0.80-0.92)	<0.001	0.89 (0.83-0.96)	0.001	0.88 (0.83-0.94)	<0.001	0.91 (0.86-0.97)	0.004
High	0.77 (0.72-0.83)	<0.001	0.85 (0.79-0.91)	<0.001	0.84 (0.79-0.89)	<0.001	0.93 (0.87-0.99)	0.015
Physical impairment								
None/minor	1.00	-	1.00	-	1.00	-	1.00	-
Moderate	1.49 (1.36-1.64)	<0.001	1.33 (1.21-1.45)	<0.001	1.44 (1.32-1.57)	<0.001	1.25 (1.14-1.36)	<0.001
Severe	1.88 (1.67-2.12)	<0.001	1.69 (1.49-1.90)	<0.001	1.82 (1.62-2.05)	<0.001	1.60 (1.42-1.80)	<0.001
Smoking status								
Never	1.00	-	1.00	-	1.00	-	1.00	-
Past	1.21 (1.14-1.29)	<0.001	1.18 (1.12-1.26)	<0.001	1.19 (1.13-1.26)	<0.001	1.15 (1.09-1.21)	<0.001
Current	1.39 (1.23-1.57)	<0.001	1.51 (1.34-1.71)	<0.001	1.74 (1.57-1.92)	<0.001	1.78 (1.61-1.96)	<0.001

Notes: Physical impairment measured using the Medical Outcome Scale, SF-36 ten-item physical functioning scale (none/minor=score of 75-100; moderate=score of 50-74; and severe=score of <50

Abbreviations: OR = odds ratios; 95% CI = 95% confidence intervals

[1]Mutually adjusted for other variables listed in table and for education.

Table 7: Sensitivity analysis – adjusted[1] odds ratios of annual weight loss compared to weight maintenance and annual weight gain compared to weight maintenance according to education levels using alternative cut-points of 2kg and 3kg

	OR for annual weight loss >2kg compared to weight maintenance		OR for annual weight loss >3kg compared to weight maintenance		OR for annual weight gain >2kg compared to weight maintenance		OR for annual weight gain >3kg compared to weight maintenance	
	OR (95% CI)[1]	p-value	OR (95% CI)[1]	p-value	OR (95% CI)[1]	p-value	OR (95% CI)[1]	p-value
No school cert	1.00	-	1.00	-	1.00	-	1.00	-
School cert	0.84 (0.72-0.97)	0.017	0.80 (0.65-0.98)	0.031	0.81 (0.71-0.92)	0.002	0.75 (0.62-0.90)	0.002
Trade/cert/dip	0.74 (0.64-0.86)	<0.001	0.71 (0.58-0.87)	0.001	0.79 (0.69-0.90)	<0.001	0.79 (0.66-0.94)	0.009
University degree	0.75 (0.64-0.87)	<0.001	0.77 (0.62-0.95)	0.017	0.64 (0.56-0.74)	<0.001	0.62 (0.51-0.75)	<0.001

Abbreviations: OR = odds ratios; 95% CI = 95% confidence intervals

[1]Adjusted for age group, sex, physical activity, physical impairment and smoking status

Table 8: Sensitivity analysis – adjusted[1] odds ratios of annual weight loss compared to weight maintenance and annual weight gain compared to weight maintenance according to education levels using alternative cut-points of 3% and 5%

	OR for annual weight loss >3% compared to weight maintenance		OR for annual weight loss >5% compared to weight maintenance		OR for annual weight gain >3% compared to weight maintenance		OR for annual weight gain >5% compared to weight maintenance	
	OR (95% CI)[1]	p-value	OR (95% CI)[1]	p-value	OR (95% CI)[1]	p-value	OR (95% CI)[1]	p-value
No school cert	1.00	-	1.00	-	1.00	-	1.00	-
School cert	0.83 (0.71-0.98)	0.032	0.84 (0.63-1.12)	0.235	0.79 (0.69-0.91)	0.001	0.74 (0.59-0.93)	0.010
Trade/cert/dip	0.71 (0.60-0.85)	<0.001	0.67 (0.50-0.89)	0.007	0.81 (0.71-0.94)	0.004	0.84 (0.67-1.04)	0.114
University degree	0.76 (0.63-0.90)	0.002	0.69 (0.50-0.94)	0.019	0.65 (0.56-0.75)	<0.001	0.65 (0.51-0.83)	0.001

Abbreviations: OR = odds ratios; 95% CI = 95% confidence intervals

[1]Adjusted for age group, sex, physical activity, physical impairment and smoking status

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract ✓	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale ✓	2	Explain the scientific background and rationale for the investigation being reported
Objectives ✓	3	State specific objectives, including any prespecified hypotheses
Methods		
Study design ✓	4	Present key elements of study design early in the paper
Setting ✓	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants ✓	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case
Variables ✓	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement ✓	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias ✓	9	Describe any efforts to address potential sources of bias
Study size ✓	10	Explain how the study size was arrived at
Quantitative variables ✓	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods ✓	12	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy
		(*e*) Describe any sensitivity analyses

Continued on next page

Results		
Participants **N/A**	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data ✔	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)
Outcome data ✔	15*	*Cohort study*—Report numbers of outcome events or summary measures over time
		Case-control study—Report numbers in each exposure category, or summary measures of exposure
		Cross-sectional study—Report numbers of outcome events or summary measures
Main results ✔	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses ✔	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
Discussion		
Key results ✔	18	Summarise key results with reference to study objectives
Limitations ✔	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation ✔	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability ✔	21	Discuss the generalisability (external validity) of the study results
Other information		
Funding ✔	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

How weight change is modelled in population studies can affect research findings: empirical results from a large-scale cohort study

Journal:	*BMJ Open*
Manuscript ID:	bmjopen-2014-004860.R1
Article Type:	Research
Date Submitted by the Author:	25-Apr-2014
Complete List of Authors:	Paige, Ellie; Australian National University, National Centre for Epidemiology and Population Health Korda, Rosemary; The Australian National University, National Centre for Epidemiology and Population Health Banks, Emily; The Australian National University, National Centre for Epidemiology and Population Health Rodgers, Bryan; Australian National University, Australian Demographic & Social Research Institute
Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Research methods
Keywords:	EPIDEMIOLOGY, Body weight changes, Education, Cohort studies

How weight change is modelled in population studies can affect research findings: empirical results from a large-scale cohort study

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Key words

Body weight changes, education, cohort studies

Word count

3,616

ABSTRACT

Objectives: The study objective is to investigate how results of the association between education and weight change vary when weight change is defined and modelled in different ways.

Design: Longitudinal cohort study

Participants: 60,404 men and women participating in the Social, Environmental and Economic Factors (SEEF) sub-component of the 45 and Up Study—a population-based cohort study of people aged 45 years and older, residing in New South Wales, Australia.

Outcome measures: The main exposure was self-reported education, categorised into four groups. The outcome was annual weight change, based on change in self-reported weight between the 45 and Up Study baseline questionnaire and SEEF questionnaire (completed an average of 3.3 years later). Weight change was modelled in four different ways: absolute change (kg) modelled as a 1) continuous variable and 2) categorical variable (loss, maintenance and gain); and relative (%) change modelled as a 3) continuous variable and 4) a categorical variable. Different cut-points for defining weight-change categories were also tested.

Results: When weight change was measured categorically, people with higher levels of education (compared to no school certificate) were less likely to lose or to gain weight. When weight change was measured as the average of a continuous measure, a null relationship between education and annual weight change was observed. No material differences in the education and weight-change relationship were found when comparing weight change defined as an absolute (kg) versus a relative (%) measure. Results of the logistic regression were sensitive to different cut-points for defining weight-change categories.

Conclusions: Using average weight change can obscure important directional relationship information and, where possible, categorical outcome measurements should be included in analyses.

ARTICLE SUMMARY

Strengths and limitations of this study

- First study to explore in depth and explicitly demonstrate how study outcomes differ when weight change is defined and modelled in different ways
- Large sample size and heterogeneity across the primary exposure, allowing analysis of multiple education levels
- Weight change calculated from self-reported weight, at two time points

INTRODUCTION

Obesity is a major global health problem.[1] While there are numerous population studies that address the important question of what factors influence weight change, differences in methods, particularly in how weight change is defined and modelled, make it difficult to compare and integrate research results.[2 3]

There is no agreed definition of clinically significant weight change and research studies define and model weight change over time in a variety of ways.[4] These include modelling weight change as either a continuous or categorical variable (or both); defining weight change as an absolute or relative change; and using different cut-points to define weight-change categories. It is unclear whether and, to what extent, these differences in defining and modelling weight change affect research findings.

The aim of our study is to investigate how research results vary when weight change is defined and modelled in different ways. To do this we examine the association between education and weight change, where weight change is modelled in four different ways: absolute change (kg per year) modelled as a continuous variable and as a categorical variable; and relative change (percentage change per year) also modelled as a continuous variable and as a categorical variable. Further, we test the sensitivity of the results to different cut-points for weight-change categories.

Education was chosen as the main sociodemographic factor of interest. While studies have shown education is inversely associated with weight gain, there are inconsistencies in the results across studies.[2] In addition, we explored the relationship of the various weight-change measures to other sociodemographic and behavioural factors.

METHODS

Study population

We used data from the 45 and Up Study baseline questionnaire, linked to data from the Social, Environmental and Economic Factors (SEEF) sub-study questionnaire. The 45 and Up Study is an Australian cohort involving 267,153 men and women aged 45 years and over from New South Wales (NSW), Australia. Participants in the Study were randomly sampled from the database of Medicare Australia, which provides virtually complete coverage of the general population. Approximately 10% of the entire NSW population aged 45 years or older was included. Participants joined the Study by completing a baseline questionnaire—distributed from January 2006 to December 2008—and giving signed consent for follow-up and linkage of their information to a range of health databases. The Study is described in detail elsewhere,[5] and questionnaires can be viewed at http://www.45andup.org.au.

Invitations to the SEEF sub-study were sent to the first 100,000 participants enrolled in the 45 and Up Study. Of those invited to complete the SEEF questionnaire (hereafter referred to as the follow-up questionnaire), 60,404 participants did so, with questionnaires completed in 2010. Only participants who completed both the 45 and Up Study baseline questionnaire and the follow-up questionnaire were included in the present analyses.

Consistent with previous studies on weight change, [6 7] we excluded people with a history of cancer (excluding non-melanoma skin cancer) and those whose physical health severely limited them in walking 100m at baseline. We further excluded participants with implausible values for height (outside the range of 121-213cm[8]) and people with a body mass index (BMI) of <15kg m^{-2} or >50kg m^{-2} at baseline, as measurement error becomes more likely at these extreme values of BMI.[9-11]

Measurements

Exposure

Education was self-reported on the baseline questionnaire. Participants were asked about their highest completed qualification, with options including six categories from 'no school certificate or other qualification' to 'university degree or higher'. For this analysis, education was categorised as: 'no school certificate' (no school certificate or other qualification); 'school certificate' (school or intermediate certificate, or a higher school or leaving certificate, equivalent to completing secondary school); 'apprenticeship/diploma' (trade, apprenticeship, certificate or diploma); and 'university degree' (university degree or higher).

Outcomes

Participants self-reported their weight on the baseline and follow-up questionnaires. Change in weight from baseline to follow-up was the primary outcome and this was calculated as per annum weight change to account for varying follow-up time in the cohort and to enhance comparability with other studies which differ in follow-up length. Specifically, change in weight was calculated as weight (kg) reported on the follow-up questionnaire minus weight (kg) reported on the baseline questionnaire, divided by time (years) between completion of the baseline and follow-up questionnaires. Relative (percentage) change in weight was calculated as change in annual weight divided by weight at baseline, multiplied by 100.

We modelled weight change as four different outcome variables:

i. Absolute annual weight change, modelled as a continuous variable
ii. Absolute annual weight change, modelled as a categorical variable
iii. Percentage annual weight change, modelled as a continuous variable
iv. Percentage annual weight change, modelled as a categorical variable

For the categorical variables, participants were categorised as into groups of 'weight maintenance' (absolute weight change ≤ 1kg; or relative change ≤1.25%), 'weight loss' (weight decrease >1kg or 1.25%) or 'weight gain' (weight increase >1kg or 1.25%). These cut-points were chosen based on those used in previous studies.[6 12 13]

Covariates

Potential covariates in the relationship of education to weight change were identified a priori through a literature review and included age, sex, physical activity, physical impairment and smoking status. Information on these factors was self-reported on the baseline questionnaire. Physical activity was categorised as tertiles based on the weighted number of reported weekly sessions of walking, moderate activity and vigorous activity.[14] Physical impairment was derived from responses to Medical Outcome Scale SF-36 ten-item physical functioning scale (PF-10)[15] and was categorised as: none/minor (score of 100-75); moderate (score of 50-74); and severe (score of <50). Smoking status was categorised as never, past or current. In analyses of a change variable, it is generally considered inappropriate to adjust for the baseline measurement;[16 17] as such baseline weight was not used as a covariate in this study.

Statistical methods

Mean annual absolute and percentage weight change and the proportion of participants in each category of weight change (weight loss, weight maintenance and weight gain) were estimated in relation to the main variables. Differences between groups were compared using analysis of variance tests for mean weight change and chi square tests for categorical weight change.

Multivariable linear and multinomial logistic regression models were used to estimate the strength of the relationship between education and weight change. For each model, unadjusted coefficients, sex- and age-adjusted coefficients and more fully adjusted coefficients (adjusted for covariates defined above) were calculated. We undertook four regression analyses, which differed only in outcome measure, and compared the results. We tested the assumptions of the two linear regression models and used robust standard errors to account for non-normality of the residuals. The exponentiated results of the multinomial logistic regression are reported. Unlike logistic regression which provides an odds ratio, the results of a multinomial logistic regression are estimated as relative risk ratios (RRR).[18] The RRR is interpreted as the relative risk of one outcome in relation to another outcome in the exposed group compared to the unexposed group.

To test the sensitivity to different cut-points, we re-ran the multinomial logistic regression models using cut-points of 2kg, 3kg, 3% and 5% per annum cut-points, which have been previously used in other studies.[4] We then compared the regression coefficients across models using the different cut-points using Wald tests.[18 19] In all analyses, 95% confidence intervals were generated and, in line with previous studies, p-values less than 0.05 were considered as statistically different.

All analyses were performed using Stata version 12.0. Ethics approval for this project was obtained from the University of Sydney Human Research Ethics Committee and the Australian National University Human Research Ethics Committee.

RESULTS

The final sample size was 45,037, after excluding those with: a history of cancer (n=9,411); a severe limitation in the ability to walk 100m (n=964); missing education data (n=673); missing data on weight (n=1,893) or height (n=1,950); implausible height values (n=263); and BMI<15kg m^{-2} or >50kg m^{-2} (n=213). The mean time between the baseline and follow-up questionnaires was 3.3 years (range=1.7-5.1 years).

Characteristics of the sample are presented in Table 1. Just over half the participants had either a university degree (28%) or an apprenticeship/diploma qualification (33%), while about a third (30%) of the participants had a school certificate as their highest qualification and 9% had no school certificate.

[Insert Table 1]

Factors associated with weight change

Mean annual weight gain in the cohort was 0.24kg overall and was higher in women (0.27kg) than in men (0.21kg). Overall, 60% of the sample maintained their weight (≤ 1kg change) while 17% had an annual weight loss of >1kg and 23% (24% of women and 22% of men) had an annual weight gain of >1kg. In the univariate analysis, all factors were statistically associated with weight change, although weight change for physical functioning impairment was only statistically different when weight change was measured categorically (Table 2).

Mean weight gain decreased with increasing age, and those aged 75 years or older had a mean weight loss. Participants with a healthy profile (high levels of physical activity or little to no physical impairment) generally had greater mean weight gain but were also more likely

to have maintained their weight compared to those with less healthy profiles. Similarly, people with an apprenticeship/diploma or a university degree had a greater mean weight gain than those with a school certificate or no school certificate, but also had higher proportions of people maintaining their weight.

[Insert Table 2]

Continuous versus categorical modelling of weight change

The results of the linear regression analyses are shown in Table 3. The unadjusted results show that, compared to people without a school certificate, those with a higher qualification gained slightly more weight annually. However, after adjusting for covariates, there was no statistical association between education level and annual weight change.

When weight change was modelled categorically, both the unadjusted and adjusted associations between education and weight change were statistically different (Table 4). Compared to people with no school certificate, those with a school certificate, apprenticeship/diploma or a university degree were less likely to lose weight and were less likely to gain weight, i.e. they were more likely to have maintained their annual weight.

Results for the other variables included in the analyses also statistically differed when modelling weight change using continuous versus categorical variables (Table 5 and Table 6). Where a variable was both associated with weight loss and weight gain, the results between the categorical and continuous outcomes differed. For example, participants with moderate or severe physical impairment (compared to none/minor physical impairment) and those who were past or current smokers (compared to never smokers) were more likely to

gain weight and were more likely to lose weight. However, when weight change was modelled as a continuous variable, no relationship between weight change and physical impairment and smoking was found.

[Insert Tables 3, 4, 5 and 6]

Absolute versus relative weight change measures

The overall association between education and weight change did not differ materially when weight change was measured as a relative (%/year) variable rather than as an absolute variable (kg/year) (Tables 5 and 6), with one exception. When modelled as a categorical variable (Table 6), the direction and magnitude of the effect size for sex changed between the absolute and relative weight measures. For weight loss, when measured as an absolute change, females were less likely to have lost weight than males, but when measured as a relative change they were more likely to have lost weight. For weight gain, there was no significant sex effect when measured as an absolute change, but when measured as a relative change, females were more 50% more likely to gain weight than males. Notably, females had a lower mean starting weight compared to males (69.7kg compared to 83.9kg); thus for a given value of absolute weight change, the percentage change in weight was higher in females compared to males. For all other variables, mean baseline weight was similar between groups and there were no material differences observed between absolute and relative measures.

Sensitivity of categorical cut-points

The results of the logistic regression using different cut-points to define weight-change categories are presented in Table 7 and Table 8. Using the 2kg cut-point, 6.57% (n=2,959) of

participants were in the weight-loss category and 8.98% (n=4,043) were in the weight-gain category, while a 3kg cut-point decreased the proportions to 3.21% (n=1,446) and 4.29% (n=1,933), respectively. When a 3% cut-point was used to categorise weight change, 4.89% (n=2,203) of participants were in the weight-loss group and 7.49% (n=3,374) were in the weight-gain group, while the corresponding proportions for a cut-point of 5% were 1.49% (n=669) and 2.63% (1,186). Those with a school certificate, apprenticeship/diploma or university degree were still more likely to maintain their annual weight than those with no school certificate, but this was no longer statistically different for some education levels based on the 5% cut-point, possibly due to smaller numbers in these groups (<5% of the sample were in the weight-loss and weight-gain groups). Formal testing of the differences in effects sizes using different cut-points showed they statistically differed in magnitude, but not direction, from the results of the main logistic regression analyses ($p<0.001$), except for weight loss using the 2kg cut-point ($p=0.097$).

[Insert Tables 7 and 8]

DISCUSSION

Principal findings

Weight change in this middle-aged cohort of Australians was common, with 23% of people gaining weight and 17% losing weight during the follow up period. This study shows that observed relationships of exposures to weight change can vary according to how weight change is defined and modelled. Specifically, when weight change was measured as the average of a continuous variable, we found no statistical association between education and weight change. However, when weight change was modelled as a categorical variable, we found that people with higher levels of education (compared to no school certificate) were more likely to maintain their weight annually within 1kg or 1.25% of their baseline weight — they were less likely to lose weight and less likely to gain weight. For other factors where participants were both more likely to lose and gain weight, we found similar differences in results when weight change was modelled as a continuous rather than categorical variable. Further, we found that the results of the logistic regression were also sensitive to different cut-points for defining weight-change categories.

Strengths and weakness of this study

The main strength of this study is the large sample size and heterogeneity across the primary exposure allowing different levels of education to be examined. There are three important limitations to our study. First, weight change was calculated from self-report weight at baseline and follow-up. It is well established that people tend to underestimate their weight when self-reporting.[20] A validation study using participants from the 45 and Up Study found a high correlation between self-reported and measured weight of 0.99,[21] suggesting the effect estimates calculated from this self-reported data are still likely to be valid. Unpublished data from the weight validation study [21] within the 45 and Up Study

demonstrated that while people on average under-report their weight, there was no significant difference in the mean discrepancy between measured and self-reported weight according to education level. Further, if people underestimated their weight by approximately the same amount at both time points there will be minimal to no bias in the change measurement. However, it is acknowledged that if precision in reporting weight change, and hence variance, varies by education level, this itself could at least partly account for the observed differences between the categorical versus continuous weight change measures. This is because the greater the variation, the higher the probability there is of crossing the upper- and lower-thresholds for defining weight change, while mean weight change remains unaffected.

We further note the overall mean weight change observed in the participants (0.24kg per year) is small and falls within expected error margins. Second, weight was reported at only two time points; thus the observed weight change may be due to regression to the mean. However, the majority of previous studies also analysed data from two time points only and the purpose of this study was to use similar techniques to previous studies in order to compare results when using different outcome measures, not to estimate the actual strength of the association between education and weight change. Third, height was only recorded at baseline and as such we could not examine change in BMI. While height at follow-up was not reported, the short follow-up time (mean 3.3 years) means that no material change in height would be expected in the cohort as height generally remains stable in adults over this time period (except in the very elderly). Given this, and the fact that weight change and BMI change are mathematically equivalent when height is constant,[4] these findings can be applied to studies examining change in BMI in situations where height remains constant over time.

Strengths and weakness of the study in relation to other studies

We are not aware of any studies that have explicitly tested whether differences in the modelling of weight change can affect research findings. However, two previous studies[22 23] used data from the United States (US) National Health and Nutrition Examination Survey to examine the association between education and weight change where weight change was measured as both a continuous and as a categorical outcome. While the authors did not specifically look at the impact of different weight change modelling on research findings, the results of their study showed slight differences in findings when weight change was modeled as a continuous versus categorical outcome. In contrast to our study where we found no clear pattern between education level and average weight change after adjusting for covariates, the two US studies found that, after adjusting for multiple covariates, mean weight gain was slightly higher in men and women with a lower education level (12^{th} grade or below) than in those with higher education (above 12^{th} grade). When the authors modelled weight change in categories (major weight gain and major weight loss based on change in BMI points), they found no statistical association between education and weight change. While the US studies used weight change based on measured rather than self-reported weight, their sample sizes were relatively small (n=1552 and 4836, respectively) and it is not clear whether the study was sufficiently powered to detect effects particularly in analyses using weight change categories. In contrast to the US studies, our study sought to test the effect of different modelling of weight change on research findings and within this we examined use of different cut-points to define categories and the use of absolute versus weight change measures; aspects which were not included in the US study designs.

What does this study mean?

Our results indicate that findings from studies examining factors associated with weight change can vary depending on how weight change is modelled and defined. This limits comparability across study results where different measures have been used and may affect interpretation of individual study results, contributing to inconsistences in the literature.

Based on our results we suggest, where sample sizes allow, weight change should be modelled as both a continuous and categorical variable. The common statistical viewpoint is that reducing continuous variables into categories can obscure linear relationships [24 25] and result in a loss of information and statistical power.[24-26] We counter that, in research studies where both weight gain and weight loss are of interest, use of mean weight change alone can obscure important directional information where high proportions of people are either losing or gaining weight within the same exposure group. Modelling weight change as both as continuous and categorical variable is likely to avoid this loss of directional information and increase comparability across studies.

Further, during the planning of analyses, consideration should be given to whether weight change is modelled as an absolute or relative measure and to the cut-points used to define categories. Unless baseline weight differs substantially between exposure levels, the relative and absolute weight-change measures are likely to give similar results; however, the two different measures lend themselves to different research questions and purposes, whether it be for clinical use or for a public health message.[4]

This study was intended to compare results of the association between education and other exposures and weight change, when the definition and modelling of the outcome measure

was varied. We did not aim to investigate causal relationships between weight change and other factors and we caution against such interpretation.

Unanswered questions and future research

The results and conclusions of this paper should be tested by replication, particularly in different datasets and in studies where weight is measured at multiple time points. Further, we did not examine whether inconsistencies between research studies may also be due to differences in how exposure variables were modelled and defined.

CONCLUSIONS

To our knowledge, this is the first empirical study to directly test whether research results of factors associated with weight change differ according to how weight change is defined and modelled. Specifically, where factors are both associated with weight loss and weight gain, continuous measurement of weight gain obscures the direction of the weight change. To build a more complete picture of the relationship between weight change and various factors, we suggest, where possible, weight change should be modelled as both a continuous and a categorical variable. Further, consideration should be given to the cut-points used to define categories, as these can result in changes in the magnitude of the effect size; and, when baseline weight substantially differs between exposure groups, consideration should also be given to whether absolute or relative change is used. Above and beyond this, agreed definitions for clinically significant weight loss, weight maintenance and weight gain, would greatly improve both the practical application of research and comparability between studies.

ACKNOWLEDGEMENTS AND FUNDING

This research was completed using data collected through the 45 and Up Study (www.saxinstitute.org.au). The 45 and Up Study is managed by the Sax Institute in collaboration with major partner Cancer Council NSW; and partners: the National Heart Foundation of Australia (NSW Division); NSW Ministry of Health; beyondblue; Ageing, Disability and Home Care, Department of Family and Community Services; the Australian Red Cross Blood Service; and UnitingCare Ageing. We thank the many thousands of people participating in the 45 and Up Study. This specific project was part of the Study of Economic and Environmental Factors in health program funded by the National Health and Medical Research Council of Australia (NHMRC) Strategic Award for Preventive Healthcare and Strengthening Australia's Social and Economic Fabric (grant reference: 402810). Emily Banks and Bryan Rodgers are supported by the NHMRC (Fellowship No. 1042717 and 471429, respectively).

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

EP primarily designed the study, carried out the statistical analysis and drafted the manuscript. RK, EB and BR participated in the design of the study and interpretation of results and provided advice on drafting of the manuscript. All authors read and approved the final manuscript.

DATA SHARING

No additional data available.

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TABLES

Table 1: Characteristics of participants by education categories

	Education level			
	No school certificate 9% (n=3857)	School certificate 30% (n=13635)	Trade/certificate/diploma 33% (n=15059)	University degree or higher 28% (n=12486)
	% (n)	% (n)	% (n)	% (n)
Sex				
Male	43 (1673)	36 (4951)	54 (8110)	49 (6177)
Female	57 (2184)	64 (8684)	46 (6949)	51 (6309)
Age				
45-54	19 (722)	27 (3627)	34 (5104)	45 (5578)
55-64	31 (1178)	36 (4891)	33 (5004)	33 (4134)
65-74	32 (1228)	24 (3263)	22 (3282)	15 (1846)
75-84	17 (639)	12 (1624)	10 (1481)	6 (805)
85plus	2 (90)	2 (230)	1 (188)	1 (123)
Physical activity tertile				
Low	33 (1235)	28 (3736)	27 (3994)	24 (2931)
Moderate	34 (1274)	37 (4969)	35 (5261)	36 (4414)
High	33 (1248)	35 (4755)	38 (5667)	41 (5081)
Physical impairment				
None/minor	75 (2352)	84 (10058)	86 (11688)	92 (10715)
Moderate	15 (459)	11 (1303)	9 (1264)	5 (636)
Severe	11 (335)	5 (641)	5 (622)	2 (250)
Smoking status				
Never	51 (1960)	59 (8085)	55 (8191)	65 (8079)
Past	40 (1532)	34 (4591)	39 (5910)	32 (3920)
Current	9 (347)	7 (923)	6 (919)	4 (445)

Notes: Physical impairment measured using the Medical Outcome Scale, SF-36 ten-item physical functioning scale (none/minor=score of 75-100; moderate=score of 50-74; and severe=score of <50). Percentage missing: physical activity = 1.05%; physical functioning = 10.47%; smoking status = 0.30%.

Table 2: Mean annual weight change and proportion of participants by weight change categories according to sample characteristics

	N	Mean annual weight change (kg)	p-value[1]	Annual weight change category			p-value[2]
				Loss (%) n= 7685 (17%)	Maintenance (%) n=26922 (60%)	Gain (%) n= 10430 (23%)	
Sex							
Male	20911	0.21	0.019	18	60	22	<0.001
Female	24126	0.27		16	60	24	
Age							
45-54	15031	0.41	<0.001	14	57	28	<0.001
55-64	15207	0.26		16	60	24	
65-74	9619	0.14		18	63	19	
75-84	4549	-0.07		24	61	15	
85plus	631	-0.26		32	56	13	
Education							
No school cert	3857	0.14	0.016	22	54	25	<0.001
School cert	13635	0.23		18	58	24	
Trade/cert/dip	15059	0.28		16	60	23	
University degree	12486	0.24		16	63	22	
Physical activity tertile							
Low	11896	0.19	0.025	19	56	25	<0.001
Moderate	15918	0.25		17	60	23	
High	16751	0.27		15	62	22	
Physical impairment							
None/minor	34813	0.25	0.080	16	62	23	<0.001
Moderate	3662	0.21		22	53	25	
Severe	1848	0.13		26	46	28	
Smoking status							
Never	26315	0.21	<0.001	16	62	22	<0.001
Past	15953	0.25		18	58	24	
Current	2634	0.50		18	49	33	

Notes: Physical impairment measured using the Medical Outcome Scale, SF-36 ten-item physical functioning scale (none/minor=score of 75-100; moderate=score of 50-74; and severe=score of <50). No weight change is defined as an annual weight change of between -1kg and 1kg. Weight loss is defined as >-1kg annual weight change. Weight gain is defined as >1kg weight change.

[1] p-value of analysis of variance tests

[2] p-value of chi square tests

Table 3: Relationship of education level to annual change in weight, measured as a continuous variable

	Annual weight change (kg)			Annual weight change (%)		
	β	95% CI	p-value	β	95% CI	p-value
Unadjusted						
No school cert	0.00	-	-	0.00	-	-
School cert	0.08	-0.01-0.17	0.076	0.08	-0.04-0.20	0.179
Trade/cert/dip	0.14	0.05-0.23	0.003	0.16	0.04-0.27	0.011
University degree	0.09	0.00-0.18	0.048	0.09	-0.03-0.21	0.128
Adjusted[1]						
No school cert	0.00	-	-	0.00	-	-
School cert	0.04	-0.05-0.13	0.387	0.02	-0.10-0.14	0.717
Trade/cert/dip	0.08	-0.02-0.17	0.103	0.08	-0.04-0.20	0.190
University degree	-0.01	-0.10-0.09	0.874	-0.04	-0.16-0.09	0.572
Adjusted[2]						
No school cert	0.00	-	-	0.00	-	-
School cert	0.02	-0.08-0.11	0.753	-0.01	-0.14-0.11	0.846
Trade/cert/dip	0.07	-0.02-0.17	0.141	0.07	-0.06-0.20	0.264
University degree	-0.01	-0.11-0.09	0.814	-0.04	-0.17-0.09	0.567

Abbreviations: 95% CI = 95% confidence intervals

[1]Sex- and age-adjusted only

[2]Adjusted for age group, sex, physical activity, physical impairment and smoking status

Table 4: Relative risk ratios of annual weight loss compared to weight maintenance, and annual weight gain compared to weight maintenance, according to education levels

	RRR for annual weight loss >1kg compared to weight maintenance		RRR for annual weight loss >1.25% compared to weight maintenance		RRR for annual weight gain >1kg compared to weight maintenance		RRR for annual weight gain >1.25% compared to weight maintenance	
	RRR (95% CI)	p-value	RRR (95% CI)	p-value	RRR (95% CI)	p-value	RRR (95% CI)	p-value
Unadjusted								
No school cert	1.00	-	1.00	-	1.00	-	1.00	-
School cert	0.75 (0.68-0.82)	<0.001	0.75 (0.69-0.83)	<0.001	0.90 (0.82-0.98)	0.014	0.92 (0.84-1.00)	0.053
Trade/cert/dip	0.68 (0.62-0.74)	<0.001	0.65 (0.60-0.72)	<0.001	0.85 (0.78-0.93)	<0.001	0.84 (0.77-0.92)	<0.001
University degree	0.62 (0.56-0.68)	<0.001	0.61 (0.56-0.67)	<0.001	0.76 (0.69-0.83)	<0.001	0.77 (0.71-0.85)	<0.001
Adjusted[1]								
No school cert	1.00	-	1.00	-	1.00	-	1.00	-
School cert	0.77 (0.71-0.85)	<0.001	0.77 (0.70-0.85)	<0.001	0.83 (0.76-0.91)	<0.001	0.84 (0.77-0.92)	<0.001
Trade/cert/dip	0.70 (0.64-0.77)	<0.001	0.72 (0.65-0.79)	<0.001	0.76 (0.70-0.83)	<0.001	0.80 (0.73-0.87)	<0.001
University degree	0.66 (0.60-0.73)	<0.001	0.68 (0.62-0.75)	<0.001	0.64 (0.58-0.70)	<0.001	0.68 (0.62-0.74)	<0.001
Adjusted[2]								
No school cert	1.00	-	1.00	-	1.00	-	1.00	-
School cert	0.84 (0.76-0.93)	0.001	0.82 (0.73-0.91)	<0.001	0.88 (0.80-0.97)	0.014	0.87 (0.79-0.96)	0.005
Trade/cert/dip	0.76 (0.68-0.84)	<0.001	0.76 (0.69-0.84)	<0.001	0.80 (0.73-0.89)	<0.001	0.82 (0.75-0.91)	<0.001
University degree	0.76 (0.68-0.85)	<0.001	0.76 (0.69-0.85)	<0.001	0.72 (0.65-0.80)	<0.001	0.74 (0.67-0.82)	<0.001

Abbreviations: RRR = relative risk ratio; 95% CI = 95% confidence intervals

[1] Sex- and age-adjusted only

[2] Adjusted for age group, sex, physical activity, physical impairment and smoking status.

Table 5: Relationship of baseline characteristics (excluding education) to annual change in weight, measured as a continuous variable

	Annual weight change (kg)			Annual weight change (%)		
	B[1]	95% CI	p-value	β[1]	95% CI	p-value
Sex						
Male	0.00	-	-	0.00	-	-
Female	0.02	-0.03-0.07	0.498	0.09	0.03-0.16	0.004
Age						
45-54	0 .00	-	-	0.00	-	-
55-64	-0.14	-0.20--0.09	<0.001	-0.19	-0.26--0.12	<0.001
65-74	-0.28	-0.35--0.21	<0.001	-0.36	-0.45--0.27	<0.001
75-84	-0.47	-0.57--0.36	<0.001	-0.62	-0.76--0.48	<0.001
85plus	-0.83	-1.00--0.66	<0.001	-1.14	-1.40--0.88	<0.001
Physical activity tertile						
Low	0.00	-	-	0.00	-	-
Moderate	0.06	0.00-0.12	0.053	0.06	-0.02-0.14	0.128
High	0.06	0.00-0.12	0.038	0.07	0.00-0.15	0.066
Physical impairment						
None/minor	0.00	-	-	0.00	-	-
Moderate	0.05	-0.05-0.15	0.290	0.04	-0.08-0.16	0.534
Severe	0.00	-0.13-0.13	0.959	0.00	-0.17-0.16	0.956
Smoking status						
Never	0.00	-	-	0.00	-	-
Past	0.03	-0.02-0.08	0.278	0.04	-0.03-0.11	0.250
Current	0.26	0.14-0.38	<0.001	0.40	0.23-0.56	<0.001

Notes: Physical impairment measured using the Medical Outcome Scale, SF-36 ten-item physical functioning scale (none/minor=score of 75-100; moderate=score of 50-74; and severe=score of <50

Abbreviations: 95% CI = 95% confidence intervals

[1] Mutually adjusted for other variables listed in table and education.

Table 6: Adjusted[1] relative risk ratios of annual weight loss compared to weight maintenance and annual weight gain compared to weight maintenance according to other sample characteristics

	RRR for annual weight loss >1kg compared to weight maintenance		RRR for annual weight loss >1.25% compared to weight maintenance		RRR for annual weight gain >1kg compared to weight maintenance		RRR for annual weight gain >1.25% compared to weight maintenance	
	RRR (95% CI)[1]	p-value	RRR (95% CI) [1]	p-value	RRR (95% CI) [1]	p-value	RRR (95% CI) [1]	p-value
Sex								
Male	1.00	-	1.00	-	1.00	-	1.00	-
Female	0.92 (0.87-0.98)	0.007	1.31 (1.24-1.39)	<0.001	1.03 (0.98-1.09)	0.216	1.48 (1.41-1.56)	<0.001
Age								
45-54	1.00	-	1.00	-	1.00	-	1.00	-
55-64	1.05 (0.98-1.13)	0.133	1.03 (0.97-1.11)	0.331	0.79 (0.74-0.83)	<0.001	0.76 (0.72-0.81)	<0.001
65-74	1.05 (0.97-1.13)	0.236	1.09 (1.01-1.18)	0.030	0.56 (0.52-0.60)	<0.001	0.58 (0.54-0.62)	<0.001
75-84	1.23 (1.11-1.36)	<0.001	1.50 (1.36-1.66)	<0.001	0.39 (0.35-0.44)	<0.001	0.48 (0.43-0.53)	<0.001
85plus	1.54 (1.24-1.92)	<0.001	2.23 (1.80-2.76)	<0.001	0.29 (0.21-0.40)	<0.001	0.44 (0.33-0.59)	<0.001
Physical activity tertile								
Low	1.00	-	1.00	-	1.00	-	1.00	-
Moderate	0.86 (0.80-0.92)	<0.001	0.89 (0.83-0.96)	0.001	0.88 (0.83-0.94)	<0.001	0.91 (0.86-0.97)	0.004
High	0.77 (0.72-0.83)	<0.001	0.85 (0.79-0.91)	<0.001	0.84 (0.79-0.89)	<0.001	0.93 (0.87-0.99)	0.015
Physical impairment								
None/minor	1.00	-	1.00	-	1.00	-	1.00	-
Moderate	1.49 (1.36-1.64)	<0.001	1.33 (1.21-1.45)	<0.001	1.44 (1.32-1.57)	<0.001	1.25 (1.14-1.36)	<0.001
Severe	1.88 (1.67-2.12)	<0.001	1.69 (1.49-1.90)	<0.001	1.82 (1.62-2.05)	<0.001	1.60 (1.42-1.80)	<0.001
Smoking status								
Never	1.00	-	1.00	-	1.00	-	1.00	-
Past	1.21 (1.14-1.29)	<0.001	1.18 (1.12-1.26)	<0.001	1.19 (1.13-1.26)	<0.001	1.15 (1.09-1.21)	<0.001
Current	1.39 (1.23-1.57)	<0.001	1.51 (1.34-1.71)	<0.001	1.74 (1.57-1.92)	<0.001	1.78 (1.61-1.96)	<0.001

Notes: Physical impairment measured using the Medical Outcome Scale, SF-36 ten-item physical functioning scale (none/minor=score of 75-100; moderate=score of 50-74; and severe=score of <50

Abbreviations: RRR = relative risk ratio; 95% CI = 95% confidence intervals

[1]Mutually adjusted for other variables listed in table and for education.

Table 7: Sensitivity analysis – adjusted[1] relative risk ratios of annual weight loss compared to weight maintenance and annual weight gain compared to weight maintenance according to education levels using alternative cut-points of 2kg and 3kg

	RRR for annual weight loss >2kg compared to weight maintenance		RRR for annual weight loss >3kg compared to weight maintenance		RRR for annual weight gain >2kg compared to weight maintenance		RRR for annual weight gain >3kg compared to weight maintenance	
	RRR (95% CI)[1]	p-value	RRR (95% CI)[1]	p-value	RRR (95% CI)[1]	p-value	RRR (95% CI)[1]	p-value
No school cert	1.00	-	1.00	-	1.00	-	1.00	-
School cert	0.84 (0.72-0.97)	0.017	0.80 (0.65-0.98)	0.031	0.81 (0.71-0.92)	0.002	0.75 (0.62-0.90)	0.002
Trade/cert/dip	0.74 (0.64-0.86)	<0.001	0.71 (0.58-0.87)	0.001	0.79 (0.69-0.90)	<0.001	0.79 (0.66-0.94)	0.009
University degree	0.75 (0.64-0.87)	<0.001	0.77 (0.62-0.95)	0.017	0.64 (0.56-0.74)	<0.001	0.62 (0.51-0.75)	<0.001

Abbreviations: RR = relative risk ratio; 95% CI = 95% confidence intervals
[1]Adjusted for age group, sex, physical activity, physical impairment and smoking status

Table 8: Sensitivity analysis – adjusted[1] relative risk ratios of annual weight loss compared to weight maintenance and annual weight gain compared to weight maintenance according to education levels using alternative cut-points of 3% and 5%

	RRR for annual weight loss >3% compared to weight maintenance		RRR for annual weight loss >5% compared to weight maintenance		RRR for annual weight gain >3% compared to weight maintenance		RRR for annual weight gain >5% compared to weight maintenance	
	RRR (95% CI)[1]	p-value	RRR (95% CI)[1]	p-value	RRR (95% CI)[1]	p-value	RRR (95% CI)[1]	p-value
No school cert	1.00	-	1.00	-	1.00	-	1.00	-
School cert	0.83 (0.71-0.98)	0.032	0.84 (0.63-1.12)	0.235	0.79 (0.69-0.91)	0.001	0.74 (0.59-0.93)	0.010
Trade/cert/dip	0.71 (0.60-0.85)	<0.001	0.67 (0.50-0.89)	0.007	0.81 (0.71-0.94)	0.004	0.84 (0.67-1.04)	0.114
University degree	0.76 (0.63-0.90)	0.002	0.69 (0.50-0.94)	0.019	0.65 (0.56-0.75)	<0.001	0.65 (0.51-0.83)	0.001

Abbreviations: RR = relative risk ratio; 95% CI = 95% confidence intervals
[1]Adjusted for age group, sex, physical activity, physical impairment and smoking status

How weight change is modelled in population studies can affect research findings: empirical results from a large-scale cohort study

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Key words

Body weight changes, education, cohort studies

Word count

3,616~~418~~

ABSTRACT

Objectives: The study objective is to investigate how results of the association between education and weight change vary when weight change is defined and modelled in different ways.

Design: Longitudinal cohort study

Participants: 60,404 men and women participating in the Social, Environmental and Economic Factors (SEEF) sub-component of the 45 and Up Study—a population-based cohort study of people aged 45 years and older, residing in New South Wales, Australia.

Outcome measures: The main exposure was self-reported education, categorised into four groups. The outcome was annual weight change, based on change in self-reported weight between the 45 and Up Study baseline questionnaire and SEEF questionnaire (completed an average of 3.3 years later). Weight change was modelled in four different ways: absolute change (kg) modelled as a 1) continuous variable and 2) categorical variable (loss, maintenance and gain); and relative (%) change modelled as a 3) continuous variable and 4) a categorical variable. Different cut-points for defining weight-change categories were also tested.

Results: When weight change was measured categorically, people with higher levels of education (compared to no school certificate) were less likely to lose or to gain weight. When weight change was measured as the average of a continuous measure, a null relationship between education and annual weight change was observed. No material differences in the education and weight-change relationship were found when comparing weight change defined as an absolute (kg) versus a relative (%) measure. Results of the logistic regression were sensitive to different cut-points for defining weight-change categories.

Conclusions: Using average weight change can obscure important directional relationship information and, where possible, categorical outcome measurements should be included in analyses.

ARTICLE SUMMARY

Strengths and limitations of this study

- First study to explore in depth and explicitly demonstrate how study outcomes differ when weight change is defined and modelled in different ways
- Large sample size and heterogeneity across the primary exposure, allowing analysis of multiple education levels
- Weight change calculated from self-reported weight, at two time points

INTRODUCTION

Obesity is a major global health problem.[1] While there are numerous population studies that address the important question of what factors influence weight change, differences in methods, particularly in how weight change is defined and modelled, make it difficult to compare and integrate research results.[2 3]

There is no agreed definition of clinically significant weight change and research studies define and model weight change over time in a variety of ways.[4] These include modelling weight change as either a continuous or categorical variable (or both); defining weight change as an absolute or relative change; and using different cut-points to define weight-change categories. It is unclear whether and, to what extent, these differences in defining and modelling weight change affect research findings.

The aim of our study is to investigate how research results vary when weight change is defined and modelled in different ways. To do this we examine the association between education and weight change, where weight change is modelled in four different ways: absolute change (kg per year) modelled as a continuous variable and as a categorical variable; and relative change (percentage change per year) also modelled as a continuous variable and as a categorical variable. Further, we test the sensitivity of the results to different cut-points for weight-change categories.

Education was chosen as the main sociodemographic factor of interest. While studies have shown education is inversely associated with weight gain, there are inconsistencies in the results across studies.[2] In addition, we explored the relationship of the various weight-change measures to other sociodemographic and behavioural factors.

METHODS

Study population

We used data from the 45 and Up Study baseline questionnaire, linked to data from the Social, Environmental and Economic Factors (SEEF) sub-study questionnaire. The 45 and Up Study is an Australian cohort involving 267,153 men and women aged 45 years and over from New South Wales (NSW), Australia. Participants in the Study were randomly sampled from the database of Medicare Australia, which provides virtually complete coverage of the general population. Approximately 10% of the entire NSW population aged 45 years or older was included. Participants joined the Study by completing a baseline questionnaire—distributed from January 2006 to December 2008—and giving signed consent for follow-up and linkage of their information to a range of health databases. The Study is described in detail elsewhere,[5] and questionnaires can be viewed at http://www.45andup.org.au.

Invitations to the SEEF sub-study were sent to the first 100,000 participants enrolled in the 45 and Up Study. Of those invited to complete the SEEF questionnaire (hereafter referred to as the follow-up questionnaire), 60,404 participants did so, with questionnaires completed in 2010. Only participants who completed both the 45 and Up Study baseline questionnaire and the follow-up questionnaire were included in the present analyses.

Consistent with previous studies on weight change, [6 7] we excluded people with a history of cancer (excluding non-melanoma skin cancer) and those whose physical health severely limited them in walking 100m at baseline. We further excluded participants with implausible values for height (outside the range of 121-213cm[8]) and people with a body mass index (BMI) of <15kg m^{-2} or >50kg m^{-2} at baseline, as measurement error becomes more likely at these extreme values of BMI.[9-11]

Measurements

Exposure

Education was self-reported on the baseline questionnaire. Participants were asked about their highest completed qualification, with options including six categories from 'no school certificate or other qualification' to 'university degree or higher'. For this analysis, education was categorised as: 'no school certificate' (no school certificate or other qualification); 'school certificate' (school or intermediate certificate, or a higher school or leaving certificate, equivalent to completing secondary school); 'apprenticeship/diploma' (trade, apprenticeship, certificate or diploma); and 'university degree' (university degree or higher).

Outcomes

Participants self-reported their weight on the baseline and follow-up questionnaires. Change in weight from baseline to follow-up was the primary outcome and this was calculated as per annum weight change to account for varying follow-up time in the cohort and to enhance comparability with other studies which differ in follow-up length. Specifically, change in weight was calculated as weight (kg) reported on the follow-up questionnaire minus weight (kg) reported on the baseline questionnaire, divided by time (years) between completion of the baseline and follow-up questionnaires. Relative (percentage) change in weight was calculated as change in annual weight divided by weight at baseline, multiplied by 100.

We modelled weight change as four different outcome variables:

i. Absolute annual weight change, modelled as a continuous variable
ii. Absolute annual weight change, modelled as a categorical variable
iii. Percentage annual weight change, modelled as a continuous variable
iv. Percentage annual weight change, modelled as a categorical variable

For the categorical variables, participants were categorised as into groups of 'weight maintenance' (absolute weight change ≤ 1kg; or relative change ≤1.25%), 'weight loss' (weight decrease >1kg or 1.25%) or 'weight gain' (weight increase >1kg or 1.25%). These cut-points were chosen based on those used in previous studies.[6 12 13]

Covariates

Potential covariates in the relationship of education to weight change were identified a priori through a literature review and included age, sex, physical activity, physical impairment and smoking status. Information on these factors was self-reported on the baseline questionnaire. Physical activity was categorised as tertiles based on the weighted number of reported weekly sessions of walking, moderate activity and vigorous activity.[14] Physical impairment was derived from responses to Medical Outcome Scale SF-36 ten-item physical functioning scale (PF-10)[15] and was categorised as: none/minor (score of 100-75); moderate (score of 50-74); and severe (score of <50). Smoking status was categorised as never, past or current. In analyses of a change variable, it is generally considered inappropriate to adjust for the baseline measurement;[16 17] as such baseline weight was not used as a covariate in this study.

Statistical methods

Mean annual absolute and percentage weight change and the proportion of participants in each category of weight change (weight loss, weight maintenance and weight gain) were estimated in relation to the main variables. Differences between groups were compared using analysis of variance tests for mean weight change and chi square tests for categorical weight change.

Multivariable linear and multinomial logistic regression models were used to estimate the strength of the relationship between education and weight change. For each model, unadjusted coefficients, sex- and age-adjusted coefficients and more fully adjusted coefficients (adjusted for covariates defined above) were calculated. We undertook four regression analyses, which differed only in outcome measure, and compared the results. We tested the assumptions of the two linear regression models and used robust standard errors to account for non-normality of the residuals. The exponentiated results of the multinomial logistic regression are reported. Unlike logistic regression which provides an odds ratio, the results of a multinomial logistic regression are estimated as relative risk ratios (RRR).[18] The RRR is interpreted as the relative risk of one outcome in relation to another outcome in the exposed group compared to the unexposed group.

To test the sensitivity to different cut-points, we re-ran the multinomial logistic regression models using cut-points of 2kg, 3kg, 3% and 5% per annum cut-points, which have been previously used in other studies.[4] We then compared the regression coefficients across models using the different cut-points using ~~Hausman-type~~Wald tests.[18 19] In all analyses, 95% confidence intervals were generated and, in line with previous studies, p-values less than 0.05 were considered as statistically different.

All analyses were performed using Stata version 12.0. Ethics approval for this project was obtained from the University of Sydney Human Research Ethics Committee and the Australian National University Human Research Ethics Committee.

RESULTS

The final sample size was 45,037, after excluding those with: a history of cancer (n=9,411); a severe limitation in the ability to walk 100m (n=964); missing education data (n=673); missing data on weight (n=1,893) or height (n=1,950); implausible height values (n=263); and BMI<15kg m^{-2} or >50kg m^{-2} (n=213). The mean time between the baseline and follow-up questionnaires was 3.3 years (range=1.7-5.1 years).

Characteristics of the sample are presented in Table 1. Just over half the participants had either a university degree (28%) or an apprenticeship/diploma qualification (33%), while about a third (30%) of the participants had a school certificate as their highest qualification and 9% had no school certificate.

[Insert Table 1]

Factors associated with weight change

Mean annual weight gain in the cohort was 0.24kg overall and was higher in women (0.27kg) than in men (0.21kg). Overall, 60% of the sample maintained their weight (≤ 1kg change) while 17% had an annual weight loss of >1kg and 23% (24% of women and 22% of men) had an annual weight gain of >1kg. In the univariate analysis, all factors were statistically associated with weight change, although weight change for physical functioning impairment was only statistically different when weight change was measured categorically (Table 2).

Mean weight gain decreased with increasing age, and those aged 75 years or older had a mean weight loss. Participants with a healthy profile (high levels of physical activity or little to no physical impairment) generally had greater mean weight gain but were also more likely

to have maintained their weight compared to those with less healthy profiles. Similarly, people with an apprenticeship/diploma or a university degree had a greater mean weight gain than those with a school certificate or no school certificate, but also had higher proportions of people maintaining their weight.

[Insert Table 2]

Continuous versus categorical modelling of weight change

The results of the linear regression analyses are shown in Table 3. The unadjusted results show that, compared to people without a school certificate, those with a higher qualification gained slightly more weight annually. However, after adjusting for covariates, there was no statistical association between education level and annual weight change.

When weight change was modelled categorically, both the unadjusted and adjusted associations between education and weight change were statistically different (Table 4). Compared to people with no school certificate, those with a school certificate, apprenticeship/diploma or a university degree were less likely to lose weight and were less likely to gain weight, i.e. they were more likely to have maintained their annual weight.

Results for the other variables included in the analyses also statistically differed when modelling weight change using continuous versus categorical variables (Table 5 and Table 6). Where a variable was both associated with weight loss and weight gain, the results between the categorical and continuous outcomes differed. For example, participants with moderate or severe physical impairment (compared to none/minor physical impairment) and those who were past or current smokers (compared to never smokers) were more likely to

gain weight and were more likely to lose weight. However, when weight change was modelled as a continuous variable, no relationship between weight change and physical impairment and smoking was found.

[Insert Tables 3, 4, 5 and 6]

Absolute versus relative weight change measures

The overall association between education and weight change did not differ materially when weight change was measured as a relative (%/year) variable rather than as an absolute variable (kg/year) (Tables 5 and 6), with one exception. When modelled as a categorical variable (Table 6), the direction and magnitude of the effect size for sex changed between the absolute and relative weight measures. For weight loss, when measured as an absolute change, females were less likely to have lost weight than males, but when measured as a relative change they were more likely to have lost weight. For weight gain, there was no significant sex effect when measured as an absolute change, but when measured as a relative change, females were more 50% more likely to gain weight than males. Notably, females had a lower mean starting weight compared to males (69.7kg compared to 83.9kg); thus for a given value of absolute weight change, the percentage change in weight was higher in females compared to males. For all other variables, mean baseline weight was similar between groups and there were no material differences observed between absolute and relative measures.

Sensitivity of categorical cut-points

The results of the logistic regression using different cut-points to define weight-change categories are presented in Table 7 and Table 8. Using the 2kg cut-point, 6.57% (n=2,959) of

participants were in the weight-loss category and 8.98% (n=4,043) were in the weight-gain category, while a 3kg cut-point decreased the proportions to 3.21% (n=1,446) and 4.29% (n=1,933), respectively. When a 3% cut-point was used to categorise weight change, 4.89% (n=2,203) of participants were in the weight-loss group and 7.49% (n=3,374) were in the weight-gain group, while the corresponding proportions for a cut-point of 5% were 1.49% (n=669) and 2.63% (1,186). Those with a school certificate, apprenticeship/diploma or university degree were still more likely to maintain their annual weight than those with no school certificate, but this was no longer statistically different for some education levels based on the 5% cut-point, possibly due to smaller numbers in these groups (<5% of the sample were in the weight-loss and weight-gain groups). Formal testing of the differences in effects sizes using different cut-points showed they statistically differed in magnitude, but not direction, from the results of the main logistic regression analyses ($p<0.001$), except for weight loss using the 2kg cut-point ($p=0.097$).

[Insert Tables 7 and 8]

DISCUSSION

Principal findings

Weight change in this middle-aged cohort of Australians was common, with 23% of people gaining weight and 17% losing weight during the follow up period. This study shows that observed relationships of exposures to weight change can vary according to how weight change is defined and modelled. Specifically, when weight change was measured as the average of a continuous variable, we found no statistical association between education and weight change. However, when weight change was modelled as a categorical variable, we found that people with higher levels of education (compared to no school certificate) were more likely to maintain their weight annually within 1kg or 1.25% of their baseline weight — they were less likely to lose weight and less likely to gain weight. For other factors where participants were both more likely to lose and gain weight, we found similar differences in results when weight change was modelled as a continuous rather than categorical variable. Further, we found that the results of the logistic regression were also sensitive to different cut-points for defining weight-change categories.

Strengths and weakness of this study

The main strength of this study is the large sample size and heterogeneity across the primary exposure allowing different levels of education to be examined. There are three important limitations to our study. First, weight change was calculated from self-report weight at baseline and follow-up. It is well established that people tend to underestimate their weight when self-reporting.[20] A validation study using participants from the 45 and Up Study found a high correlation between self-reported and measured weight of 0.99,[21] suggesting the effect estimates calculated from this self-reported data are still likely to be valid. Unpublished data from the weight validation study [21] within the 45 and Up Study

demonstrated that while people on average under-report their weight, there was no significant difference in the mean discrepancy between measured and self-reported weight according to education level. Further, if people underestimated their weight by approximately the same amount at both time points there will be minimal to no bias in the change measurement. However, it is acknowledged that if precision in reporting weight change, and hence variance, varies by education level, this itself could at least partly account for the observed differences between the categorical versus continuous weight change measures. This is because the greater the variation, the higher the probability there is of crossing the upper- and lower-thresholds for defining weight change, while mean weight change remains unaffected. ~~However,~~ W~~w~~e ~~do~~ further note the overall mean weight change observed in the participants (0.24kg per year) is small and falls within expected error margins. Second, weight was reported at only two time points; thus the observed weight change may be due to regression to the mean. However, the majority of previous studies also analysed data from two time points only and the purpose of this study was to use similar techniques to previous studies in order to compare results when using different outcome measures, not to estimate the actual strength of the association between education and weight change. Third, height was only recorded at baseline and as such we could not examine change in BMI. While height at follow-up was not reported, the short follow-up time (mean 3.3 years) means that no material change in height would be expected in the cohort as height generally remains stable in adults over this time period (except in the very elderly). Given this, and the fact that weight change and BMI change are mathematically equivalent when height is constant,[4] these findings can be applied to studies examining change in BMI in situations where height remains constant over time.

Strengths and weakness of the study in relation to other studies

We are not aware of any studies that have explicitly tested whether differences in the modelling of weight change can affect research findings. However, two previous studies[22 23] used data from the United States (US) National Health and Nutrition Examination Survey to examine the association between education and weight change where weight change was measured as both a continuous and as a categorical outcome. While the authors did not specifically look at the impact of different weight change modelling on research findings, the results of their study showed slight differences in findings when weight change was modeled as a continuous versus categorical outcome. In contrast to our study where we found no clear pattern between education level and average weight change after adjusting for covariates, the two US studies found that, after adjusting for multiple covariates, mean weight gain was slightly higher in men and women with a lower education level (12^{th} grade or below) than in those with higher education (above 12^{th} grade). When the authors modelled weight change in categories (major weight gain and major weight loss based on change in BMI points), they found no statistical association between education and weight change. While the US studies used weight change based on measured rather than self-reported weight, their sample sizes were relatively small (n=1552 and 4836, respectively) and it is not clear whether the study was sufficiently powered to detect effects particularly in analyses using weight change categories. In contrast to the US studies, our study sought to test the effect of different modelling of weight change on research findings and within this we examined use of different cut-points to define categories and the use of absolute versus weight change measures; aspects which were not included in the US study designs.

What does this study mean?

Our results indicate that findings from studies examining factors associated with weight change can vary depending on how weight change is modelled and defined. This limits comparability across study results where different measures have been used and may affect interpretation of individual study results, contributing to inconsistences in the literature.

Based on our results we suggest, where sample sizes allow, weight change should be modelled as both a continuous and categorical variable. The common statistical viewpoint is that reducing continuous variables into categories can obscure linear relationships [24 25] and result in a loss of information and statistical power.[24-26] We counter that, in research studies where both weight gain and weight loss are of interest, use of mean weight change alone can obscure important directional information where high proportions of people are either losing or gaining weight within the same exposure group. Modelling weight change as both as continuous and categorical variable is likely to avoid this loss of directional information and increase comparability across studies.

Further, during the planning of analyses, consideration should be given to whether weight change is modelled as an absolute or relative measure and to the cut-points used to define categories. Unless baseline weight differs substantially between exposure levels, the relative and absolute weight-change measures are likely to give similar results; however, the two different measures lend themselves to different research questions and purposes, whether it be for clinical use or for a public health message.[4]

This study was intended to compare results of the association between education and other exposures and weight change, when the definition and modelling of the outcome measure

was varied. We did not aim to investigate causal relationships between weight change and other factors and we caution against such interpretation.

Unanswered questions and future research

The results and conclusions of this paper should be tested by replication, particularly in different datasets and in studies where weight is measured at multiple time points. Further, we did not examine whether inconsistencies between research studies may also be due to differences in how exposure variables were modelled and defined.

CONCLUSIONS

To our knowledge, this is the first empirical study to directly test whether research results of factors associated with weight change differ according to how weight change is defined and modelled. Specifically, where factors are both associated with weight loss and weight gain, continuous measurement of weight gain obscures the direction of the weight change. To build a more complete picture of the relationship between weight change and various factors, we suggest, where possible, weight change should be modelled as both a continuous and a categorical variable. Further, consideration should be given to the cut-points used to define categories, as these can result in changes in the magnitude of the effect size; and, when baseline weight substantially differs between exposure groups, consideration should also be given to whether absolute or relative change is used. Above and beyond this, agreed definitions for clinically significant weight loss, weight maintenance and weight gain, would greatly improve both the practical application of research and comparability between studies.

~~COMPETING INTERESTS~~

~~The authors declare that they have no competing interests.~~

~~AUTHORS' CONTRIBUTIONS~~

~~EP primarily designed the study, carried out the statistical analysis and drafted the manuscript. RK, EB and BR participated in the design of the study and interpretation of results and provided advice on drafting of the manuscript. All authors read and approved the final manuscript.~~

ACKNOWLEDGEMENTS AND FUNDING

This research was completed using data collected through the 45 and Up Study (www.saxinstitute.org.au). The 45 and Up Study is managed by the Sax Institute in collaboration with major partner Cancer Council NSW; and partners: the National Heart Foundation of Australia (NSW Division); NSW Ministry of Health; beyondblue; Ageing, Disability and Home Care, Department of Family and Community Services; the Australian Red Cross Blood Service; and UnitingCare Ageing. We thank the many thousands of people participating in the 45 and Up Study. This specific project was part of the Study of Economic and Environmental Factors in health program funded by the National Health and Medical Research Council of Australia (NHMRC) Strategic Award for Preventive Healthcare and Strengthening Australia's Social and Economic Fabric (grant reference: 402810). Emily Banks and Bryan Rodgers are supported by the NHMRC (Fellowship No. 1042717 and 471429, respectively).

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DATA SHARING

No additional data available.

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TABLES

Table 1: Characteristics of participants by education categories

	Education level			
	No school certificate 9% (n=3857)	School certificate 30% (n=13635)	Trade/certificate/diploma 33% (n=15059)	University degree or higher 28% (n=12486)
	% (n)	% (n)	% (n)	% (n)
Sex				
Male	43 (1673)	36 (4951)	54 (8110)	49 (6177)
Female	57 (2184)	64 (8684)	46 (6949)	51 (6309)
Age				
45-54	19 (722)	27 (3627)	34 (5104)	45 (5578)
55-64	31 (1178)	36 (4891)	33 (5004)	33 (4134)
65-74	32 (1228)	24 (3263)	22 (3282)	15 (1846)
75-84	17 (639)	12 (1624)	10 (1481)	6 (805)
85plus	2 (90)	2 (230)	1 (188)	1 (123)
Physical activity tertile				
Low	33 (1235)	28 (3736)	27 (3994)	24 (2931)
Moderate	34 (1274)	37 (4969)	35 (5261)	36 (4414)
High	33 (1248)	35 (4755)	38 (5667)	41 (5081)
Physical impairment				
None/minor	75 (2352)	84 (10058)	86 (11688)	92 (10715)
Moderate	15 (459)	11 (1303)	9 (1264)	5 (636)
Severe	11 (335)	5 (641)	5 (622)	2 (250)
Smoking status				
Never	51 (1960)	59 (8085)	55 (8191)	65 (8079)
Past	40 (1532)	34 (4591)	39 (5910)	32 (3920)
Current	9 (347)	7 (923)	6 (919)	4 (445)

Notes: Physical impairment measured using the Medical Outcome Scale, SF-36 ten-item physical functioning scale (none/minor=score of 75-100; moderate=score of 50-74; and severe=score of <50). Percentage missing: physical activity = 1.05%; physical functioning = 10.47%; smoking status = 0.30%.

Table 2: Mean annual weight change and proportion of participants by weight change categories according to sample characteristics

	N	Mean annual weight change (kg)	p-value[1]	Annual weight change category			p-value[2]
				Loss (%) n= 7685 (17%)	Maintenance (%) n=26922 (60%)	Gain (%) n= 10430 (23%)	
Sex							
Male	20911	0.21	0.019	18	60	22	<0.001
Female	24126	0.27		16	60	24	
Age							
45-54	15031	0.41	<0.001	14	57	28	<0.001
55-64	15207	0.26		16	60	24	
65-74	9619	0.14		18	63	19	
75-84	4549	-0.07		24	61	15	
85plus	631	-0.26		32	56	13	
Education							
No school cert	3857	0.14	0.016	22	54	25	<0.001
School cert	13635	0.23		18	58	24	
Trade/cert/dip	15059	0.28		16	60	23	
University degree	12486	0.24		16	63	22	
Physical activity tertile							
Low	11896	0.19	0.025	19	56	25	<0.001
Moderate	15918	0.25		17	60	23	
High	16751	0.27		15	62	22	
Physical impairment							
None/minor	34813	0.25	0.080	16	62	23	<0.001
Moderate	3662	0.21		22	53	25	
Severe	1848	0.13		26	46	28	
Smoking status							
Never	26315	0.21	<0.001	16	62	22	<0.001
Past	15953	0.25		18	58	24	
Current	2634	0.50		18	49	33	

Notes: Physical impairment measured using the Medical Outcome Scale, SF-36 ten-item physical functioning scale (none/minor=score of 75-100; moderate=score of 50-74; and severe=score of <50). No weight change is defined as an annual weight change of between -1kg and 1kg. Weight loss is defined as >-1kg annual weight change. Weight gain is defined as >1kg weight change.

[1] p-value of analysis of variance tests

[2] p-value of chi square tests

Table 3: Relationship of education level to annual change in weight, measured as a continuous variable

	Annual weight change (kg)			Annual weight change (%)		
	β	95% CI	p-value	β	95% CI	p-value
Unadjusted						
No school cert	0.00	-	-	0.00	-	-
School cert	0.08	-0.01-0.17	0.076	0.08	-0.04-0.20	0.179
Trade/cert/dip	0.14	0.05-0.23	0.003	0.16	0.04-0.27	0.011
University degree	0.09	0.00-0.18	0.048	0.09	-0.03-0.21	0.128
Adjusted[1]						
No school cert	0.00	-	-	0.00	-	-
School cert	0.04	-0.05-0.13	0.387	0.02	-0.10-0.14	0.717
Trade/cert/dip	0.08	-0.02-0.17	0.103	0.08	-0.04-0.20	0.190
University degree	-0.01	-0.10-0.09	0.874	-0.04	-0.16-0.09	0.572
Adjusted[2]						
No school cert	0.00	-	-	0.00	-	-
School cert	0.02	-0.08-0.11	0.753	-0.01	-0.14-0.11	0.846
Trade/cert/dip	0.07	-0.02-0.17	0.141	0.07	-0.06-0.20	0.264
University degree	-0.01	-0.11-0.09	0.814	-0.04	-0.17-0.09	0.567

Abbreviations: 95% CI = 95% confidence intervals

[1]Sex- and age-adjusted only

[2]Adjusted for age group, sex, physical activity, physical impairment and smoking status

Table 4: ~~Odds~~ Relative risk ratios of annual weight loss compared to weight maintenance, and annual weight gain compared to weight maintenance, according to education levels

	~~OR~~ RRR for annual weight loss >1kg compared to weight maintenance		~~OR~~ RRR for annual weight loss >1.25% compared to weight maintenance		~~OR~~ RRR for annual weight gain >1kg compared to weight maintenance		~~OR~~ RRR for annual weight gain >1.25% compared to weight maintenance	
	~~OR~~ RRR (95% CI)	p-value	~~OR~~ RRR (95% CI)	p-value	~~OR~~ RRR (95% CI)	p-value	~~OR~~ RRR (95% CI)	p-value
Unadjusted								
No school cert	1.00	-	1.00	-	1.00	-	1.00	-
School cert	0.75 (0.68-0.82)	<0.001	0.75 (0.69-0.83)	<0.001	0.90 (0.82-0.98)	0.014	0.92 (0.84-1.00)	0.053
Trade/cert/dip	0.68 (0.62-0.74)	<0.001	0.65 (0.60-0.72)	<0.001	0.85 (0.78-0.93)	<0.001	0.84 (0.77-0.92)	<0.001
University degree	0.62 (0.56-0.68)	<0.001	0.61 (0.56-0.67)	<0.001	0.76 (0.69-0.83)	<0.001	0.77 (0.71-0.85)	<0.001
Adjusted[1]								
No school cert	1.00	-	1.00	-	1.00	-	1.00	-
School cert	0.77 (0.71-0.85)	<0.001	0.77 (0.70-0.85)	<0.001	0.83 (0.76-0.91)	<0.001	0.84 (0.77-0.92)	<0.001
Trade/cert/dip	0.70 (0.64-0.77)	<0.001	0.72 (0.65-0.79)	<0.001	0.76 (0.70-0.83)	<0.001	0.80 (0.73-0.87)	<0.001
University degree	0.66 (0.60-0.73)	<0.001	0.68 (0.62-0.75)	<0.001	0.64 (0.58-0.70)	<0.001	0.68 (0.62-0.74)	<0.001
Adjusted[2]								
No school cert	1.00	-	1.00	-	1.00	-	1.00	-
School cert	0.84 (0.76-0.93)	0.001	0.82 (0.73-0.91)	<0.001	0.88 (0.80-0.97)	0.014	0.87 (0.79-0.96)	0.005
Trade/cert/dip	0.76 (0.68-0.84)	<0.001	0.76 (0.69-0.84)	<0.001	0.80 (0.73-0.89)	<0.001	0.82 (0.75-0.91)	<0.001
University degree	0.76 (0.68-0.85)	<0.001	0.76 (0.69-0.85)	<0.001	0.72 (0.65-0.80)	<0.001	0.74 (0.67-0.82)	<0.001

Abbreviations: ~~OR~~ RRR = ~~odds ratios~~relative risk ratio; 95% CI = 95% confidence intervals

[1] Sex- and age-adjusted only

[2]Adjusted for age group, sex, physical activity, physical impairment and smoking status.

Table 5: Relationship of baseline characteristics (excluding education) to annual change in weight, measured as a continuous variable

	Annual weight change (kg)			Annual weight change (%)		
	B[1]	95% CI	p-value	β[1]	95% CI	p-value
Sex						
Male	0.00	-	-	0.00	-	-
Female	0.02	-0.03-0.07	0.498	0.09	0.03-0.16	0.004
Age						
45-54	0 .00	-	-	0.00	-	-
55-64	-0.14	-0.20--0.09	<0.001	-0.19	-0.26--0.12	<0.001
65-74	-0.28	-0.35--0.21	<0.001	-0.36	-0.45--0.27	<0.001
75-84	-0.47	-0.57--0.36	<0.001	-0.62	-0.76--0.48	<0.001
85plus	-0.83	-1.00--0.66	<0.001	-1.14	-1.40--0.88	<0.001
Physical activity tertile						
Low	0.00	-	-	0.00	-	-
Moderate	0.06	0.00-0.12	0.053	0.06	-0.02-0.14	0.128
High	0.06	0.00-0.12	0.038	0.07	0.00-0.15	0.066
Physical impairment						
None/minor	0.00	-	-	0.00	-	-
Moderate	0.05	-0.05-0.15	0.290	0.04	-0.08-0.16	0.534
Severe	0.00	-0.13-0.13	0.959	0.00	-0.17-0.16	0.956
Smoking status						
Never	0.00	-	-	0.00	-	-
Past	0.03	-0.02-0.08	0.278	0.04	-0.03-0.11	0.250
Current	0.26	0.14-0.38	<0.001	0.40	0.23-0.56	<0.001

Notes: Physical impairment measured using the Medical Outcome Scale, SF-36 ten-item physical functioning scale (none/minor=score of 75-100; moderate=score of 50-74; and severe=score of <50

Abbreviations: 95% CI = 95% confidence intervals

[1] Mutually adjusted for other variables listed in table and education.

Table 6: Adjusted[1] ~~odds~~ relative risk ratios of annual weight loss compared to weight maintenance and annual weight gain compared to weight maintenance according to other sample characteristics

	~~OR~~ RRR for annual weight loss >1kg compared to weight maintenance		~~OR~~ RRR for annual weight loss >1.25% compared to weight maintenance		~~OR~~ RRR for annual weight gain >1kg compared to weight maintenance		~~OR~~ RRR for annual weight gain >1.25% compared to weight maintenance	
	~~OR~~ RRR (95% CI)[1]	p-value	~~OR~~ RRR (95% CI)[1]	p-value	~~OR~~ RRR (95% CI)[1]	p-value	~~OR~~ RRR (95% CI)[1]	p-value
Sex								
Male	1.00	-	1.00	-	1.00	-	1.00	-
Female	0.92 (0.87-0.98)	0.007	1.31 (1.24-1.39)	<0.001	1.03 (0.98-1.09)	0.216	1.48 (1.41-1.56)	<0.001
Age								
45-54	1.00	-	1.00	-	1.00	-	1.00	-
55-64	1.05 (0.98-1.13)	0.133	1.03 (0.97-1.11)	0.331	0.79 (0.74-0.83)	<0.001	0.76 (0.72-0.81)	<0.001
65-74	1.05 (0.97-1.13)	0.236	1.09 (1.01-1.18)	0.030	0.56 (0.52-0.60)	<0.001	0.58 (0.54-0.62)	<0.001
75-84	1.23 (1.11-1.36)	<0.001	1.50 (1.36-1.66)	<0.001	0.39 (0.35-0.44)	<0.001	0.48 (0.43-0.53)	<0.001
85plus	1.54 (1.24-1.92)	<0.001	2.23 (1.80-2.76)	<0.001	0.29 (0.21-0.40)	<0.001	0.44 (0.33-0.59)	<0.001
Physical activity tertile								
Low	1.00	-	1.00	-	1.00	-	1.00	-
Moderate	0.86 (0.80-0.92)	<0.001	0.89 (0.83-0.96)	0.001	0.88 (0.83-0.94)	<0.001	0.91 (0.86-0.97)	0.004
High	0.77 (0.72-0.83)	<0.001	0.85 (0.79-0.91)	<0.001	0.84 (0.79-0.89)	<0.001	0.93 (0.87-0.99)	0.015
Physical impairment								
None/minor	1.00	-	1.00	-	1.00	-	1.00	-
Moderate	1.49 (1.36-1.64)	<0.001	1.33 (1.21-1.45)	<0.001	1.44 (1.32-1.57)	<0.001	1.25 (1.14-1.36)	<0.001
Severe	1.88 (1.67-2.12)	<0.001	1.69 (1.49-1.90)	<0.001	1.82 (1.62-2.05)	<0.001	1.60 (1.42-1.80)	<0.001
Smoking status								
Never	1.00	-	1.00	-	1.00	-	1.00	-
Past	1.21 (1.14-1.29)	<0.001	1.18 (1.12-1.26)	<0.001	1.19 (1.13-1.26)	<0.001	1.15 (1.09-1.21)	<0.001
Current	1.39 (1.23-1.57)	<0.001	1.51 (1.34-1.71)	<0.001	1.74 (1.57-1.92)	<0.001	1.78 (1.61-1.96)	<0.001

Notes: Physical impairment measured using the Medical Outcome Scale, SF-36 ten-item physical functioning scale (none/minor=score of 75-100; moderate=score of 50-74; and severe=score of <50

Abbreviations: ~~OR = odds ratios~~RRR = relative risk ratio; 95% CI = 95% confidence intervals

[1]Mutually adjusted for other variables listed in table and for education.

Table 7: Sensitivity analysis – adjusted[1] relative risk~~odds~~ ratios of annual weight loss compared to weight maintenance and annual weight gain compared to weight maintenance according to education levels using alternative cut-points of 2kg and 3kg

	~~OR~~ RRR for annual weight loss >2kg compared to weight maintenance		~~OR~~ RRR for annual weight loss >3kg compared to weight maintenance		~~OR~~ RRR for annual weight gain >2kg compared to weight maintenance		~~OR~~ RRR for annual weight gain >3kg compared to weight maintenance	
	~~OR~~ RRR (95% CI)[1]	p-value	~~OR~~ RRR (95% CI)[1]	p-value	~~OR~~ RRR (95% CI)[1]	p-value	~~OR~~ RRR (95% CI)[1]	p-value
No school cert	1.00	-	1.00	-	1.00	-	1.00	-
School cert	0.84 (0.72-0.97)	0.017	0.80 (0.65-0.98)	0.031	0.81 (0.71-0.92)	0.002	0.75 (0.62-0.90)	0.002
Trade/cert/dip	0.74 (0.64-0.86)	<0.001	0.71 (0.58-0.87)	0.001	0.79 (0.69-0.90)	<0.001	0.79 (0.66-0.94)	0.009
University degree	0.75 (0.64-0.87)	<0.001	0.77 (0.62-0.95)	0.017	0.64 (0.56-0.74)	<0.001	0.62 (0.51-0.75)	<0.001

Abbreviations: ~~OR = odds ratios~~RR = relative risk ratio; 95% CI = 95% confidence intervals
[1]Adjusted for age group, sex, physical activity, physical impairment and smoking status

Table 8: Sensitivity analysis – adjusted[1] ~~odds~~ relative risk ratios of annual weight loss compared to weight maintenance and annual weight gain compared to weight maintenance according to education levels using alternative cut-points of 3% and 5%

	~~OR~~ RRR for annual weight loss >3% compared to weight maintenance		~~OR~~ RRR for annual weight loss >5% compared to weight maintenance		~~OR~~ RRR for annual weight gain >3% compared to weight maintenance		~~OR~~ RRR for annual weight gain >5% compared to weight maintenance	
	~~OR~~ RRR (95% CI)[1]	p-value	~~OR~~ RRR (95% CI)[1]	p-value	~~OR~~ RRR (95% CI)[1]	p-value	~~OR~~ RRR (95% CI)[1]	p-value
No school cert	1.00	-	1.00	-	1.00	-	1.00	-
School cert	0.83 (0.71-0.98)	0.032	0.84 (0.63-1.12)	0.235	0.79 (0.69-0.91)	0.001	0.74 (0.59-0.93)	0.010
Trade/cert/dip	0.71 (0.60-0.85)	<0.001	0.67 (0.50-0.89)	0.007	0.81 (0.71-0.94)	0.004	0.84 (0.67-1.04)	0.114
University degree	0.76 (0.63-0.90)	0.002	0.69 (0.50-0.94)	0.019	0.65 (0.56-0.75)	<0.001	0.65 (0.51-0.83)	0.001

Abbreviations: ~~OR = odds ratios~~RR = relative risk ratio; 95% CI = 95% confidence intervals
[1]Adjusted for age group, sex, physical activity, physical impairment and smoking status

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract ✓	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale ✓	2	Explain the scientific background and rationale for the investigation being reported
Objectives ✓	3	State specific objectives, including any prespecified hypotheses
Methods		
Study design ✓	4	Present key elements of study design early in the paper
Setting ✓	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants ✓	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case
Variables ✓	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement ✓	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias ✓	9	Describe any efforts to address potential sources of bias
Study size ✓	10	Explain how the study size was arrived at
Quantitative variables ✓	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods ✓	12	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy
		(*e*) Describe any sensitivity analyses

Continued on next page

Results		
Participants **N/A**	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data ✔	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)
Outcome data ✔	15*	*Cohort study*—Report numbers of outcome events or summary measures over time
		Case-control study—Report numbers in each exposure category, or summary measures of exposure
		Cross-sectional study—Report numbers of outcome events or summary measures
Main results ✔	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses ✔	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
Discussion		
Key results ✔	18	Summarise key results with reference to study objectives
Limitations ✔	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation ✔	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability ✔	21	Discuss the generalisability (external validity) of the study results
Other information		
Funding ✔	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.