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

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ABSTRACT

Objectives: 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) subcomponent of the 45 and Up Study—a population-based cohort study of people aged 45 years or 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 (1) a continuous variable and (2) a categorical variable (loss, maintenance and gain), and relative (%) change modelled as (3) a 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 with 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.

INTRODUCTION

Obesity is a major global health problem.[1] While there are numerous population studies that address the important question of what

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.

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/year) modelled as a continuous variable and as a categorical variable, and relative change (percentage change/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 that 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) substudy questionnaire. The 45 and Up Study is an Australian cohort involving 267 153 men and women aged 45 years and older from New South Wales, 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 New South Wales 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 substudy 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 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 100 m at baseline. We further excluded participants with implausible values for height (outside the range of 121–213 cm[8]) and people with a body mass index (BMI) of <15 $kg\,m^{-2}$ or >50 $kg\,m^{-2}$ 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. 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:
1. Absolute annual weight change, modelled as a continuous variable
2. Absolute annual weight change, modelled as a categorical variable
3. Percentage annual weight change, modelled as a continuous variable
4. 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 ≤1 kg; or relative change ≤1.25%), 'weight loss' (weight decrease >1 kg or 1.25%) or 'weight gain' (weight increase >1 kg 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 the Medical Outcomes Score-Physical Functioning (MOS-PF), which is equivalent to items from the physical functioning scale of the SF-36 health survey[15] and was categorised as none/minor (score of 75–100), 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 proportions 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 χ^2 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 (RRRs).[18] The RRR is interpreted as the relative risk of one outcome in relation to another outcome in the exposed group compared with the unexposed group.

To test the sensitivity to different cut-points, we re-ran the multinomial logistic regression models using cut-points of 2 kg, 3 kg, 3% and 5% per annum, 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 (CIs) were generated and, in line with previous studies, p values less than 0.05 were considered statistically different.

All analyses were performed using Stata V.12.0.

RESULTS

The final sample size was 45 037, after excluding those with a history of cancer (n=9411), a severe limitation in the ability to walk 100 m (n=964), missing education data (n=673), missing data on weight (n=1893) or height (n=1950), implausible height values (n=263) and BMI <15 or >50 kg/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.

Factors associated with weight change

Mean annual weight gain in the cohort was 0.24 kg overall and was higher in women (0.27 kg) than in men (0.21 kg). Overall, 60% of the sample maintained their weight (≤1 kg change), while 17% had an annual weight loss of >1 kg and 23% (24% of women and 22% of men) had an annual weight gain of >1 kg. 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).

Table 1 Characteristics of participants by education categories

	Education level, % (n)			
	No school certificate 9% (n=3857)	School certificate 30% (n=13 635)	Trade/certificate/diploma 33% (n=15 059)	University degree or higher 28% (n=12 486)
Sex				
Male	43 (1673)	36 (4951)	54 (8110)	49 (6177)
Female	57 (2184)	64 (8684)	46 (6949)	51 (6309)
Age (years)				
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)
85 plus	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 (10 058)	86 (11 688)	92 (10 715)
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)

Physical impairment was measured using the Medical Outcomes Score-Physical Functioning (MOS-PF), which is equivalent to items from the physical functioning scale of the SF-36 health survey (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%.

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 with 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 they also had a higher proportion of people maintaining their weight.

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 with 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 with 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, that is, 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 (tables 5 and 6). Where a variable was 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 with no/minor physical impairment) and those who were past or current smokers (compared with never smokers) were statistically less likely to maintain their weight. However, when weight change was modelled as a continuous variable, no relationship between weight change and physical impairment and smoking was found.

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

| | | Mean annual weight change (kg) | p Value* | Annual weight-change category | | | p Value† |
	N			Loss (%) n=7685 (17%)	Maintenance (%) n=26 922 (60%)	Gain (%) n=10 430 (23%)	
Sex							
Male	20 911	0.21	0.019	18	60	22	<0.001
Female	24 126	0.27		16	60	24	
Age (years)							
45–54	15 031	0.41	<0.001	14	57	28	<0.001
55–64	15 207	0.26		16	60	24	
65–74	9619	0.14		18	63	19	
75–84	4549	−0.07		24	61	15	
85 plus	631	−0.26		32	56	13	
Education							
No school cert	3857	0.14	0.016	22	54	25	<0.001
School cert	13 635	0.23		18	58	24	
Trade/cert/dip	15 059	0.28		16	60	23	
University degree	12 486	0.24		16	63	22	
Physical activity tertile							
Low	11 896	0.19	0.025	19	56	25	<0.001
Moderate	15 918	0.25		17	60	23	
High	16 751	0.27		15	62	22	
Physical impairment							
None/minor	34 813	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	26 315	0.21	<0.001	16	62	22	<0.001
Past	15 953	0.25		18	58	24	
Current	2634	0.50		18	49	33	

*p Value of analysis of variance tests.
†p Value of χ^2 tests.
Physical impairment was measured using the Medical Outcomes Score-Physical Functioning (MOS-PF), which is equivalent to items from the physical functioning scale of the SF-36 health survey (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 −1 and 1 kg. Weight loss is defined as >−1 kg annual weight change. Weight gain is defined as >1 kg weight change.

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 to 0.17	0.076	0.08	−0.04 to 0.20	0.179
Trade/cert/dip	0.14	0.05 to 0.23	0.003	0.16	0.04 to 0.27	0.011
University degree	0.09	0.00 to 0.18	0.048	0.09	−0.03 to 0.21	0.128
Adjusted*						
No school cert	0.00	–	–	0.00	–	–
School cert	0.04	−0.05 to 0.13	0.387	0.02	−0.10 to 0.14	0.717
Trade/cert/dip	0.08	−0.02 to 0.17	0.103	0.08	−0.04 to 0.20	0.190
University degree	−0.01	−0.10 to 0.09	0.874	−0.04	−0.16 to 0.09	0.572
Adjusted†						
No school cert	0.00	–	–	0.00	–	–
School cert	0.02	−0.08 to 0.11	0.753	−0.01	−0.14 to 0.11	0.846
Trade/cert/dip	0.07	−0.02 to 0.17	0.141	0.07	−0.06 to 0.20	0.264
University degree	−0.01	−0.11 to 0.09	0.814	−0.04	−0.17 to 0.09	0.567

*Sex-adjusted and age-adjusted only.
†Adjusted for age group, sex, physical activity, physical impairment and smoking status.

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 weight and relative weight measures. For weight loss, when measured as an absolute change, women were less likely to have lost weight than men, 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, women were more 50% more likely to gain weight than men. Notably, women had a lower mean starting weight compared with men (69.7 kg compared with 83.9 kg); thus, for a given value of absolute weight change, the percentage change in weight was higher in women compared with men. 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 tables 7 and 8. Using the 2 kg cut-point, 6.57% (n=2959) of participants were in the weight-loss category and 8.98% (n=4043) were in the weight-gain category, while a 3 kg cut-point decreased the proportions to 3.21% (n=1446) and 4.29% (n=1933), respectively. When a 3% cut-point was used to categorise weight change, 4.89% (n=2203) of participants were in the weight-loss group and 7.49% (n=3374) were in the weight-gain group, while the corresponding proportions

for a cut-point of 5% were 1.49% (n=669) and 2.63% (1186). 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 effect sizes using different cut-points showed that 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 2 kg cut-point (p=0.097).

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 with no school certificate) were more likely to maintain their weight annually within 1 kg or 1.25% of their baseline weight—they were less likely to lose weight or 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

Table 4 Relative risk ratios (RRRs) 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 >1 kg compared to weight maintenance		RRR for annual weight loss >1.25% compared to weight maintenance		RRR for annual weight gain >1 kg 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 to 0.82)	<0.001	0.75 (0.69 to 0.83)	<0.001	0.90 (0.82 to 0.98)	0.014	0.92 (0.84 to 1.00)	0.053
Trade/cert/dip	0.68 (0.62 to 0.74)	<0.001	0.65 (0.60 to 0.72)	<0.001	0.85 (0.78 to 0.93)	<0.001	0.84 (0.77 to 0.92)	<0.001
University degree	0.62 (0.56 to 0.68)	<0.001	0.61 (0.56 to 0.67)	<0.001	0.76 (0.69 to 0.83)	<0.001	0.77 (0.71 to 0.85)	<0.001
Adjusted*								
No school cert	1.00	–	1.00	–	1.00	–	1.00	–
School cert	0.77 (0.71 to 0.85)	<0.001	0.77 (0.70 to 0.85)	<0.001	0.83 (0.76 to 0.91)	<0.001	0.84 (0.77 to 0.92)	<0.001
Trade/cert/dip	0.70 (0.64 to 0.77)	<0.001	0.72 (0.65 to 0.79)	<0.001	0.76 (0.70 to 0.83)	<0.001	0.80 (0.73 to 0.87)	<0.001
University degree	0.66 (0.60 to 0.73)	<0.001	0.68 (0.62 to 0.75)	<0.001	0.64 (0.58 to 0.70)	<0.001	0.68 (0.62 to 0.74)	<0.001
Adjusted†								
No school cert	1.00	–	1.00	–	1.00	–	1.00	–
School cert	0.84 (0.76 to 0.93)	0.001	0.82 (0.73 to 0.91)	<0.001	0.88 (0.80 to 0.97)	0.014	0.87 (0.79 to 0.96)	0.005
Trade/cert/dip	0.76 (0.68 to 0.84)	<0.001	0.76 (0.69 to 0.84)	<0.001	0.80 (0.73 to 0.89)	<0.001	0.82 (0.75 to 0.91)	<0.001
University degree	0.76 (0.68 to 0.85)	<0.001	0.76 (0.69 to 0.85)	<0.001	0.72 (0.65 to 0.80)	<0.001	0.74 (0.67 to 0.82)	<0.001

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

*Mutually adjusted for other variables listed in table and education.
Physical impairment was measured using the Medical Outcomes Score-Physical Functioning (MOS-PF), which is equivalent to items from the physical functioning scale of the SF-36 health survey (none/minor=score of 75–100; moderate=score of 50–74; and severe=score of <50).

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 weaknesses 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-reported 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 the self-reported and measured weight (r=0.99),[21] suggesting that the effect estimates calculated from these 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 that the overall mean weight change observed in the participants (0.24 kg/year) is small and falls within the 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.

Table 6 Adjusted* relative risk ratios (RRRs) 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 >1 kg compared to weight maintenance		RRR for annual weight loss >1.25% compared to weight maintenance		RRR for annual weight gain >1 kg 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
Sex								
Male	1.00	–	1.00	–	1.00	–	1.00	–
Female	0.92 (0.87 to 0.98)	0.007	1.31 (1.24 to 1.39)	<0.001	1.03 (0.98 to 1.09)	0.216	1.48 (1.41 to 1.56)	<0.001
Age								
45–54	1.00	–	1.00	–	1.00	–	1.00	–
55–64	1.05 (0.98 to 1.13)	0.133	1.03 (0.97 to 1.11)	0.331	0.79 (0.74 to 0.83)	<0.001	0.76 (0.72 to 0.81)	<0.001
65–74	1.05 (0.97 to 1.13)	0.236	1.09 (1.01 to 1.18)	0.030	0.56 (0.52 to 0.60)	<0.001	0.58 (0.54 to 0.62)	<0.001
75–84	1.23 (1.11 to 1.36)	<0.001	1.50 (1.36 to 1.66)	<0.001	0.39 (0.35 to 0.44)	<0.001	0.48 (0.43 to 0.53)	<0.001
85plus	1.54 (1.24 to 1.92)	<0.001	2.23 (1.80 to 2.76)	<0.001	0.29 (0.21 to 0.40)	<0.001	0.44 (0.33 to 0.59)	<0.001
Physical activity tertile								
Low	1.00	–	1.00	–	1.00	–	1.00	–
Moderate	0.86 (0.80 to 0.92)	<0.001	0.89 (0.83 to 0.96)	0.001	0.88 (0.83 to 0.94)	<0.001	0.91 (0.86 to 0.97)	0.004
High	0.77 (0.72 to 0.83)	<0.001	0.85 (0.79 to 0.91)	<0.001	0.84 (0.79 to 0.89)	<0.001	0.93 (0.87 to 0.99)	0.015
Physical impairment								
None/minor	1.00	–	1.00	–	1.00	–	1.00	–
Moderate	1.49 (1.36 to 1.64)	<0.001	1.33 (1.21 to 1.45)	<0.001	1.44 (1.32 to 1.57)	<0.001	1.25 (1.14 to 1.36)	<0.001
Severe	1.88 (1.67 to 2.12)	<0.001	1.69 (1.49 to 1.90)	<0.001	1.82 (1.62 to 2.05)	<0.001	1.60 (1.42 to 1.80)	<0.001
Smoking status								
Never	1.00	–	1.00	–	1.00	–	1.00	–
Past	1.21 (1.14 to 1.29)	<0.001	1.18 (1.12 to 1.26)	<0.001	1.19 (1.13 to 1.26)	<0.001	1.15 (1.09 to 1.21)	<0.001
Current	1.39 (1.23 to 1.57)	<0.001	1.51 (1.34 to 1.71)	<0.001	1.74 (1.57 to 1.92)	<0.001	1.78 (1.61 to 1.96)	<0.001

*Mutually adjusted for other variables listed in the table and for education.
Notes: Physical impairment was measured using the Medical Outcomes Score-Physical Functioning (MOS-PF), which is equivalent to items from the physical functioning scale of the SF-36 health survey (none/minor=score of 75–100; moderate=score of 50–74; and severe=score of <50).

Table 7 Sensitivity analysis—adjusted* relative risk ratios (RRRs) 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 2 kg and 3 kg

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

*Adjusted for age group, sex, physical activity, physical impairment and smoking status.

Table 8 Sensitivity analysis—adjusted* relative risk ratios (RRRs) 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)*	p Value	RRR (95% CI)*	p Value	RRR (95% CI)*	p Value	RRR (95% CI)*	p Value
No school cert	1.00	–	1.00	–	1.00	–	1.00	–
School cert	0.83 (0.71 to 0.98)	0.032	0.84 (0.63 to 1.12)	0.235	0.79 (0.69 to 0.91)	0.001	0.74 (0.59 to 0.93)	0.010
Trade/cert/dip	0.71 (0.60 to 0.85)	<0.001	0.67 (0.50 to 0.89)	0.007	0.81 (0.71 to 0.94)	0.004	0.84 (0.67 to 1.04)	0.114
University degree	0.76 (0.63 to 0.90)	0.002	0.69 (0.50 to 0.94)	0.019	0.65 (0.56 to 0.75)	<0.001	0.65 (0.51 to 0.83)	0.001

*Adjusted for age group, sex, physical activity, physical impairment and smoking status.

Strengths and weaknesses 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 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 modelled 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 these studies were 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 the 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 inconsistencies in the literature.

We suggest from our results that, where sample sizes allow, weight change should be modelled as 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 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 both as a 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 is 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 the best of 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 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, that weight change should be modelled as a continuous and 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; also, when baseline weight substantially differs between exposure groups, consideration should 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 the practical application of research and comparability between studies.

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