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Predictors of increased body weight and waist circumference for middle-aged adults

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Abstract

Objective: To identify predictors of increased adiposity for different measures of adiposity.
Design: Prospective cohort study, the Melbourne Collaborative Cohort Study (MCCS), with data at baseline (1990–1994) and wave 2 (2003–2007).
Setting: Participants recruited from the community.
Subjects: Australian-born participants (*n* 5879) aged 40 to 69 years who were not current smokers and who were free from common chronic diseases at recruitment. At baseline and at wave 2, weight and waist circumference were measured; while demographic and lifestyle variables were obtained at baseline via structured interviews.
Results: Participants who reported any recreational physical activity at baseline had lower weight and smaller waist circumference at wave 2 than those who did not, particularly for younger participants and for vigorous physical activity. Walking for leisure was not associated, and greater physical activity at work was associated, with greater adiposity measures at wave 2. A diet low in carbohydrates and fibre, but high in fat and protein, predicted greater weight and waist circumference at wave 2. Participants were less likely to have elevated weight or waist circumference at wave 2 if they consumed low to moderate amounts of alcohol.
Conclusions: Our findings indicate that promoting vigorous physical activity, encouraging a diet high in carbohydrate and fibre but low in fat and protein, and limiting alcohol intake could be promising approaches for preventing obesity in middle-aged adults. Similar interventions should successfully address the management of both weight and waist circumference, as they were predicted by similar factors.

Keywords
Weight
Waist circumference
Obesity
Predictors
Physical activity

Understanding the individual-level predictors of weight and waist circumference gain is critical, both to identify individuals most at risk and to allow targeting of the behavioural risk factors likely to contribute the most to overweight and obesity. While consensus is forming around the role of specific dietary elements and markers of physical activity and inactivity associated with increased weight gain[1–3], few studies have analysed predictors of increasing waist circumference[4–7] and the majority of these have focused solely on dietary factors.

Waist circumference is a better indicator of excess visceral adiposity[8], which tends to be more closely associated with metabolic abnormalities and some cancers than overall adiposity as assessed by BMI[3]. Further, there is evidence that waist circumference is increasing at a faster rate than BMI[7,9], suggesting that there may be differential drivers of BMI and waist circumference. A recent analysis of cohorts in the European Prospective Investigation into Cancer and Nutrition suggested that specific dietary elements may predict changes in waist circumference independent of changes in BMI[5]. However, no studies have simultaneously analysed the association between a wide range of behavioural factors and changes in weight and waist circumference.

The predictors of weight gain may differ from the predictors of weight loss[10]. The health benefits for overweight individuals of losing weight compared with maintaining a stable weight are still unknown[11]. Exploring predictors

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of weight loss, in particular for elderly populations, is problematic as weight loss may be unintentional due to an undiagnosed disease[12].

We evaluated potential predictors of stable and increased weight and waist circumference using a prospective cohort study in which all participants were directly measured at baseline recruitment and at a later face-to face examination (mean 11·7 years after baseline), which we refer to as wave 2. We focused on potentially modifiable predictors such as physical activity (both leisure time and work related), alcohol consumption and nutrient intake for participants who were not current smokers and were free from common chronic diseases at baseline.

Participants and methods

Participants

The Melbourne Collaborative Cohort Study (MCCS) is a prospective cohort study comprising 17 045 men and 24 469 women, aged between 27 and 75 years at baseline (99·3 % aged 40 to 69 years). Participants were recruited from the Melbourne metropolitan area between 1990 and 1994 using the electoral rolls for direct invitations, advertisements and community announcements. Southern European migrants were oversampled at the time of recruitment to help increase the variability of dietary and non-dietary risk factors. Further details of the study have been published elsewhere[13]. The study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving participants were approved by the Cancer Council Victoria's Human Research Ethics Committee. Written informed consent was obtained from all participants.

A randomly selected total of 11 994 participants was targeted for attendance at wave 2 between 2003 and 2007. Participants were excluded if, at baseline, they were aged less than 40 years or over 69 years (*n* 7), had energy intakes in the extreme centiles of the sex-specific distributions (*n* 244), were missing values of weight or waist circumference (*n* 9), had a pre-existing disease (diabetes, cancer, angina, stroke or heart attack; *n* 1500) or were current smokers (to avoid possible weight changes due to quitting smoking; *n* 1168). After these exclusions, 9066 participants were eligible.

Ascertainment of cancer status and vital status

Cancer cases were identified from notifications to the Victorian Cancer Registry of diagnoses of invasive cancer (International Classification of Diseases 9th revision rubric 140–208 or 10th revision rubric C00–C99). Vital status and place of residence were obtained from electoral rolls, electronic phone books and death records until 2010.

Direct physical measurements

All participants attended a study centre at baseline, where physical measurements and blood sampling were performed. Height, weight and waist circumference were measured according to standard procedures[14]. Weight and waist circumference were measured similarly at wave 2. Heart rate was measured at baseline using Dinamap automatic monitors (see MacInnis *et al.*[15] for further details).

Questionnaire data and constructed variables

Participants' residential postcodes at baseline were used to assign them to a quintile of socio-economic status (SES) according to the Index of Relative Socio-economic Advantage and Disadvantage that was obtained from the Australian Bureau of Statistics census-based Socio-Economic Indexes for Areas[16].

A structured interview schedule was used to obtain information on country of birth, smoking ('Have you ever smoked at least seven cigarettes a week for at least a year?' and 'Do you now smoke at least seven cigarettes a week?'), highest level of education and self-reported history of diabetes, angina, stroke and heart attack.

Questions relating to frequency of walking (for recreation or exercise), vigorous exercise (exercise 'making you sweat or feel out of breath, and includes such activities as swimming, tennis, netball, athletics and running') and less-vigorous exercise (exercise 'which did not make you sweat or feel out of breath and includes such activities as bike riding, dancing, etc.') over the last 6 months were asked at baseline. These questions were obtained from the Risk Factor Prevalence Study conducted by the National Heart Foundation and Australian Institute of Health[17]. The reported frequency for each question was coded as follows: 0 (none), 1·5 (one or two times per week) or 4 (three or more times per week). Walking and less-vigorous exercise frequencies were added together along with two times the frequency of vigorous exercise to generate a physical activity score for each person. This score was then grouped based on approximate quartiles (0, >0–3, >3–4, >4). Two further questions were also asked about how much time participants spent in moderate to heavy physical exertion at work and at home.

Dietary data were collected at baseline using a self-administered 121-item FFQ specifically developed for the study[18]. Nutrient intakes were computed from the FFQ based on the NUTTAB95 nutrient composition data[19]. Intakes of protein, fat, total carbohydrates and fibre were analysed as their proportion of total energy intake, with each gram assumed to contain 17, 37, 16 and 1 kJ of total energy, respectively[20]. Alcohol intake data were collected at baseline using beverage-specific questions of frequency and quantity.

Statistical analysis

Multivariable linear regression was used for cross-sectional analyses and to predict weight and waist circumference at wave 2. Analyses for each predictor were adjusted for possible confounders at baseline identified *a priori*, including baseline measures of weight (or waist circumference), sex, age, physical activity (pseudo-continuous), alcohol intake (none, 0·1–19·9, 20·0–39·9, ≥40·0 g/d), educational attainment (primary school/some high or technical school, completed high or technical school, degree/diploma), smoking status (never, past), marital status (married/*de facto*, single/divorced/widowed/separated), SES (pseudo-continuous, based on approximate quintiles) and total dietary energy intake (kJ/d). Additional sub-analyses were also performed, including: tests for interactions between age, sex and predictor variables; further adjustment for duration since baseline; analyses restricted to participants without disease onset before wave 2 (cancer, heart attack, stroke, angina and diabetes); and analyses excluding those who reported having hypertension at baseline.

Statistical analyses were performed using the statistical software package Stata version 12·0.

Results

After baseline, 656 of the 9066 eligible people died before wave 2 was completed and a further 1894 declined to attend for physical examination at wave 2. Twenty-one of the people who attended wave 2 were excluded as they had no weight or waist circumference measurements collected at wave 2, leaving 6495 (72 %). A further 616 participants who lost 5 kg or more in weight between baseline and wave 2 were excluded because the predictors of loss may differ from those of maintenance or gain. This left 5879 participants in the final analysis.

On average, non-participants at wave 2 (which included current smokers at baseline) were more likely to be older (56 *v.* 54 years old), male (44 % *v.* 36 %), born in Southern Europe (31 % *v.* 18 %), less educated (36 % *v.* 51 % completed high school), not married (32 % *v.* 27 %), heavier (males 81 *v.* 80 kg, females 69 *v.* 67 kg) and to have larger waist circumference (males 94 *v.* 92 cm, females 81 *v.* 78 cm) than participants at baseline.

At wave 2, on average 11·7 years since baseline, participants were on average 3·3 kg heavier and had 8·0 cm larger waist circumferences. Additional descriptive characteristics of the participants are shown in Table 1.

Table 2 shows the cross-sectional associations between both weight and waist circumference at baseline and the various exposures. Measures of weight and waist circumference were greater for men and older participants at baseline, while many of the modifiable baseline exposures had positive (protein and fat intake) or negative (exercise, walking, low alcohol, carbohydrate and fibre intakes) associations with weight and waist circumference at baseline.

Table 3 shows the associations between both weight and waist circumference at wave 2 and the various baseline exposures. Measures of weight and waist circumference were higher for women and younger participants at wave 2. Also, the longer the duration since baseline, the greater the weight and waist circumference were at wave 2. Participants born in Southern Europe had a larger waist circumference at wave 2.

Participants who had completed high school or above had a lower waist circumference but not weight at wave 2 compared with those who had not. Weight and waist circumference at wave 2 were greater for people living in more disadvantaged areas. Married and *de facto* persons had on average lower weight at wave 2 than single, divorced or widowed people. Notably, greater waist circumferences at wave 2 were observed for divorced compared with married participants.

Positive associations were observed between waist circumference at wave 2 and baseline cardiovascular measures (systolic pressure, diastolic pressure, pulse rate) in contrast to the null associations with weight at wave 2.

Those who reported participating in recreational exercise at baseline had lower weight and smaller waist circumference at baseline and at wave 2 than those who did not. The associations strengthened with exercise intensity and frequency. The association with exercise was mainly restricted to younger participants (see Tables 4 and 5). On the other hand, moderate or heavy activity at work was positively associated with waist circumference at wave 2, even after adjustment for recreational exercise. Despite the fact that those participants who walked three times or more per week had lower baseline weight and smaller waist circumference, there was no discernible association between leisure-time walking and future weight or waist circumference.

There was no notable association observed with smoking status. Participants were less likely to have an elevated weight or waist circumference at wave 2 if they consumed low to moderate amounts of alcohol.

Baseline energy intake showed no association with future weight or waist circumference, but a higher proportional consumption of protein and fat at baseline was positively associated with both weight and waist circumference at wave 2, while carbohydrate and fibre consumption were negatively associated with waist circumference but not weight at wave 2. As with exercise, the associations with these nutrients were strongest for younger participants (see Tables 4 and 5).

Analyses restricted to participants without disease onset before wave 2 (cancer, heart attack, stroke, angina and diabetes) gave similar results to the main analyses (data not shown) and associations remained virtually unchanged after further adjustment for duration of follow-up time since baseline (data not shown). Analyses excluding those who reported having hypertension at baseline (1031 people) gave similar results to the main analyses (data not shown), except that systolic (β coefficient = $-0·11$, SE = 0·05, $P = 0·04$) and diastolic (β coefficient = $-0·16$, SE = 0·08, $P = 0·04$) blood pressure were inversely associated with weight at wave 2.

Table 1 Characteristics of participants stratified by sex: adults with data at baseline (1990–1994) and wave 2 (2003–2007), Melbourne Collaborative Cohort Study

	Male		Female	
	Mean or *n*	% or SD	Mean or *n*	% or SD
N	2128		3751	
Age at baseline (years)	53·5	8·4	53·6	8·2
Duration of follow-up (years)	11·7	1·5	11·7	1·5
Weight at baseline (kg)	80·2	11·1	67·2	11·3
Weight at wave 2 (kg)	82·9	12·7	70·7	13·4
Waist at baseline (cm)	91·7	9·4	78·0	10·9
Waist at wave 2 (cm)	98·1	10·6	87·0	12·6
Weight change at wave 2 (%)				
Within 5 kg of baseline weight	1554	73·0	2555	68·1
Gained 5–9·9 kg	413	19·4	747	19·9
Gained 10 kg or more	161	7·6	449	12·0
Country of birth (%)				
Australia/New Zealand/UK	1722	80·9	3097	82·6
Greece/Italy	406	19·1	654	17·4
Highest level of education (%)				
Primary/some high/technical school	828	38·9	2079	55·4
Completed high school	554	26·0	706	18·8
Completed tertiary degree/diploma	746	35·1	966	25·8
Smoking status (%)				
Never	1187	55·8	2801	74·7
Former	941	44·2	950	25·3
Marital status (%)				
Married	1644	80·0	2501	69·2
Single	184	9·0	322	8·9
Divorced	97	4·7	343	9·5
De facto	61	3·0	71	2·0
Widowed	38	1·9	290	8·0
Separated	32	1·6	85	2·4
Index of Relative Socio-economic Disadvantage (%)				
1st quintile (most disadvantaged)	222	10·5	450	12·0
2nd quintile	375	17·7	663	17·7
3rd quintile	389	18·4	673	18·0
4th quintile	466	22·0	822	22·0
5th quintile (least disadvantaged)	667	31·5	1132	30·3
Height (cm)	173·5	7·2	160·8	6·5
Energy intake (MJ/d)	10·5	3·2	8·6	2·8
Protein (% of energy)	18	3	19	3
Fat (% of energy)	33	5	33	6
Carbohydrates (% of energy)	42	7	44	7
Fibre (% of energy)	0·3	0·1	0·4	0·1
Diastolic blood pressure (mmHg)	80·1	10·5	71·9	10·6
Systolic blood pressure (mmHg)	136·3	16·5	132·0	17·9
Pulse (beats/min)	65·9	9·5	69·7	9·1
Total alcohol (%)				
Lifetime abstainers	345	16·2	1366	36·4
0·1–19·9 g/d	1025	48·2	1966	52·4
20·0–39·9 g/d	448	21·1	332	8·9
≥40·0 g/d	310	14·6	87	2·3
Walking (%)				
None	904	42·5	1391	37·1
1–2 times/week	425	20·0	846	22·6
≥3 times/week	799	37·6	1514	40·4
Exercise* (%)				
None	901	42·3	1758	46·9
Less vigorous only (≥once/week)	546	25·7	1061	28·3
Vigorous (≥once/week)	681	32·0	932	24·9
Physical activity score (%)				
0	392	18·4	717	19·1
1–3	420	19·7	787	21·0
4–5	644	30·3	1334	35·6
≥6	672	31·6	913	24·3
Moderate/heavy activity at work (%)				
None at all	1816	85·3	3450	92·0
≥1 h/week	312	14·7	301	8·0
Moderate/heavy activity at home (%)				
None at all	1388	65·2	2470	65·9
≥1 h/week	740	34·8	1281	34·2

*Participants in the vigorous group may have also reported doing less vigorous exercise.

Table 2 Associations of potential predictors of weight and waist circumference at baseline*: adults with data at baseline (1990–1994) and wave 2 (2003–2007), Melbourne Collaborative Cohort Study

	Weight at baseline (kg)			Waist circumference at baseline (cm)		
	β	SE	*P* value	β	SE	*P* value
Sex						
Male	0	Ref.		0	Ref.	
Female	−4·66	0·41	<0·001	−11·64	0·39	<0·001
Age at baseline attendance (per 10 years)	0·50	0·17	0·004	1·92	0·16	<0·001
Country of birth						
Australia/New Zealand/UK	0	Ref.		0	Ref.	
Greece/Italy	1·82	0·20	<0·001	2·15	0·19	<0·001
Follow-up time (per year)	0·26	0·11	0·02	0·30	0·10	0·004
Education level						
Primary, some high/technical school	0	Ref.		0	Ref.	
Completed high school	−1·13	0·37	0·002	−1·27	0·35	<0·001
Completed tertiary degree/diploma	−2·61	0·36	<0·001	−2·61	0·34	<0·001
Index of Relative Socio-economic Disadvantage						
1st quintile (most disadvantaged)	0	Ref.		0	Ref.	
2nd quintile	−1·26	0·51	0·01	−1·40	0·48	0·004
3rd quintile	−1·54	0·51	0·003	−1·95	0·48	<0·001
4th quintile	−2·02	0·50	<0·001	−2·29	0·47	<0·001
5th quintile (least disadvantaged)	−2·74	0·48	<0·001	−3·12	0·45	<0·001
Marital status						
Married	0	Ref.		0	Ref.	
Single	−0·76	0·50	0·13	−0·60	0·47	0·20
Divorced	−0·19	0·53	0·72	−0·66	0·50	0·19
De facto	0·20	0·93	0·83	−0·06	0·87	0·95
Widowed	−0·38	0·62	0·54	−0·06	0·58	0·92
Separated	−2·55	0·98	0·009	−1·98	0·92	0·03
Height (per 10 cm)	6·76	0·23	<0·001	1·78	0·21	<0·001
Diastolic blood pressure (per 10 mmHg)	1·76	0·13	<0·001	1·62	0·12	<0·001
Systolic blood pressure (per 10 mmHg)	1·24	0·09	<0·001	1·13	0·08	<0·001
Pulse (per 10 beats/min)	0·92	0·15	<0·001	1·03	0·14	<0·001
Walking						
None	0	Ref.		0	Ref.	
1–2 times/week	−0·33	0·37	0·37	−0·45	0·35	0·19
≥3 times/week	−1·19	0·31	<0·001	−1·16	0·29	<0·001
Physical activity score						
0	0	Ref.		0	Ref.	
1–3	−1·39	0·44	0·001	−1·19	0·41	0·004
4–5	−2·20	0·40	<0·001	−1·68	0·37	<0·001
≥6	−3·79	0·42	<0·001	−3·84	0·40	<0·001
Exercise†						
None	0	Ref.		0	Ref.	
Less vigorous only (≥once/week)	−1·34	0·33	<0·001	−1·35	0·31	<0·001
Vigorous (≥once/week)	−2·82	0·35	<0·001	−2·93	0·33	<0·001
Moderate/heavy activity at work						
No	0	Ref.		0	Ref.	
Yes	−0·55	0·45	0·23	−1·12	0·42	0·008
Moderate/heavy activity at home						
No	0	Ref.		0	Ref.	
Yes	−0·05	0·29	0·87	−0·05	0·27	0·84
Smoking						
Never	0	Ref.		0	Ref.	
Past	0·45	0·30	0·13	0·37	0·28	0·19
Total alcohol						
Lifetime abstainers	0	Ref.		0	Ref.	
0·1–19·9 g/d	−1·10	0·33	0·001	−0·74	0·31	0·02
20·0–39·9 g/d	−1·60	0·48	0·001	−0·68	0·45	0·13
≥40·0 g/d	0·06	0·62	0·93	0·77	0·58	0·19
Alcohol-specific‡						
Lifetime abstainers	0	Ref.		0	Ref.	
Beer	−0·38	0·38	0·31	0·44	0·35	0·21
Wine	−1·22	0·32	<0·001	−0·77	0·31	0·01
Spirits	−0·76	0·36	0·03	−0·50	0·34	0·14
Energy intake (MJ/d)	0·04	0·05	0·42	0·06	0·04	0·15
Protein (per 10 % of energy)	2·87	0·54	<0·001	2·45	0·48	<0·001
Fat (per 10 % of energy)	1·61	0·26	<0·001	1·59	0·23	<0·001
Carbohydrates (per 10 % of energy)	−1·51	0·22	<0·001	−1·58	0·19	<0·001
Fibre (per 1 MJ of energy)	−0·52	0·16	0·001	−0·81	0·14	<0·001

β, coefficient; Ref., referent category.
*Adjusted for sex, height, age, highest level of education (pseudo-continuous), physical activity score (pseudo-continuous), marital status (married/*de facto v.* single/divorced/widowed/separated), Index of Relative Socio-economic Disadvantage (pseudo-continuous), smoking status and dietary energy intake at baseline attendance.
†Participants in the vigorous exercise group may have also reported doing less vigorous exercise.
‡Participants in the alcohol-specific groups may have also reported drinking other types of alcoholic beverages.

Table 3 Associations of potential predictors of weight and waist circumference at wave 2: adults with data at baseline (1990–1994) and wave 2 (2003–2007), Melbourne Collaborative Cohort Study

	Weight (kg) at wave 2*			Waist circumference (cm) at wave 2†		
	β	SE	*P* value	β	SE	*P* value
Baseline weight (per 10 kg)	10·64	0·06	<0·001	N/A		
Baseline waist (per 10 cm)	N/A			8·90	0·10	<0·001
Sex						
Male	0	Ref.		0	Ref.	
Female	1·38	0·20	<0·001	1·25	0·31	<0·001
Age at baseline attendance (per 10 years)	−1·75	0·08	<0·001	−0·58	0·12	<0·001
Country of birth						
Australia/New Zealand/UK	0	Ref.		0	Ref.	
Greece/Italy	0·04	0·10	0·69	0·39	0·14	0·006
Follow-up time (per year)	0·46	0·05	<0·001	0·80	0·08	<0·001
Education level						
Primary, some high/technical school	0	Ref.		0	Ref.	
Completed high school	0·03	0·18	0·88	−0·42	0·26	0·10
Completed tertiary degree/diploma	−0·27	0·18	0·13	−1·07	0·25	<0·001
Index of Relative Socio-economic Disadvantage						
1st quintile (most disadvantaged)	0	Ref.		0	Ref.	
2nd quintile	0·18	0·25	0·48	0·32	0·36	0·38
3rd quintile	−0·35	0·25	0·16	−0·54	0·36	0·13
4th quintile	−0·47	0·24	0·05	−0·83	0·35	0·02
5th quintile (least disadvantaged)	−0·72	0·24	0·002	−1·16	0·34	0·001
Marital status						
Married	0	Ref.		0	Ref.	
Single	0·55	0·24	0·02	0·51	0·35	0·14
Divorced	1·04	0·26	<0·001	1·59	0·37	<0·001
De facto	−0·18	0·45	0·70	0·02	0·64	0·97
Widowed	1·01	0·30	0·001	0·20	0·43	0·64
Separated	0·61	0·48	0·20	0·17	0·68	0·80
Height (per 10 cm)	−0·08	0·12	0·49	0·39	0·16	0·01
Diastolic blood pressure (per 10 mmHg)	−0·03	0·07	0·68	0·39	0·09	<0·001
Systolic blood pressure (per 10 mmHg)	−0·03	0·04	0·55	0·24	0·06	<0·001
Pulse (per 10 beats/min)	−0·06	0·07	0·39	0·35	0·10	0·001
Walking						
None	0	Ref.		0	Ref.	
1–2 times/week	0·02	0·18	0·93	−0·07	0·25	0·77
≥3 times/week	−0·03	0·15	0·85	−0·23	0·22	0·28
Physical activity score						
0	0	Ref.		0	Ref.	
1–3	−0·24	0·21	0·26	−0·47	0·30	0·12
4–5	−0·25	0·19	0·20	−0·73	0·28	0·008
≥6	−0·43	0·21	0·04	−1·20	0·30	<0·001
Exercise‡						
None	0	Ref.		0	Ref.	
Less vigorous only (≥once/week)	−0·18	0·16	0·27	−0·53	0·23	0·02
Vigorous (≥once/week)	−0·46	0·17	0·006	−1·11	0·24	<0·001
Moderate/heavy activity at work						
No	0	Ref.		0	Ref.	
Yes	0·39	0·22	0·08	0·84	0·31	0·007
Moderate/heavy activity at home						
No	0	Ref.		0	Ref.	
Yes	0·03	0·14	0·83	−0·07	0·20	0·73
Smoking						
Never	0	Ref.		0	Ref.	
Past	−0·06	0·15	0·70	0·26	0·21	0·20
Total alcohol						
Lifetime abstainers	0	Ref.		0	Ref.	
0·1–19·9 g/d	−0·23	0·16	0·15	−0·58	0·23	0·01
20·0–39·9 g/d	−0·48	0·23	0·04	−1·07	0·33	0·001
≥40·0 g/d	−0·27	0·30	0·37	−0·13	0·43	0·76
Alcohol-specific§						
Lifetime abstainers	0	Ref.		0	Ref.	
Beer	−0·41	0·18	0·03	−0·82	0·26	0·002
Wine	−0·25	0·16	0·12	−0·67	0·23	0·003
Spirits	−0·37	0·17	0·03	−0·59	0·25	0·02
Energy intake (MJ/d)	0·00	0·02	0·85	−0·03	0·03	0·31
Protein (per 10 % of energy)	0·81	0·25	0·001	1·85	0·35	<0·001
Fat (per 10 % of energy)	0·26	0·12	0·03	0·85	0·17	<0·001
Carbohydrates (per 10 % of energy)	−0·19	0·10	0·06	−0·73	0·14	<0·001
Fibre (per 1 MJ of energy)	−0·07	0·07	0·36	−0·27	0·10	0·009

β, coefficient; N/A, not applicable; Ref., referent category.
*Adjusted for weight, sex, height, age, highest level of education (pseudo-continuous), physical activity score (pseudo-continuous), marital status (married/*de facto v.* single/divorced/widowed/separated), Index of Relative Socio-economic Disadvantage (pseudo-continuous), smoking status and dietary energy intake at baseline attendance.
†Adjusted for waist circumference, sex, height, age, highest level of education (pseudo-continuous), physical activity score (pseudo-continuous), marital status (married/*de facto v.* single/divorced/widowed/separated), Index of Relative Socio-economic Disadvantage (pseudo-continuous), smoking status and dietary energy intake at baseline attendance.
‡Participants in the vigorous exercise group may have also reported doing less vigorous exercise.
§Participants in the alcohol-specific groups may have also reported drinking other types of alcoholic beverages.

Table 4 Selected associations of potential predictors of weight at wave 2 by age at attendance*: adults with data at baseline (1990–1994) and wave 2 (2003–2007), Melbourne Collaborative Cohort Study

	40–49 years			50–59 years			60–69 years			
	β	SE	*P* value	β	SE	*P* value	β	SE	*P* value	*P* for interaction
Walking										0·38
None	0	Ref.		0	Ref.		0	Ref.		
1–2 times/week	0·07	0·31	0·83	0·18	0·31	0·56	−0·34	0·29	0·24	
≥3 times/week	0·00	0·27	1·00	0·14	0·26	0·59	−0·41	0·23	0·08	
Physical activity score										0·25
0	0	Ref.		0	Ref.		0	Ref.		
1–3	−0·51	0·38	0·19	0·16	0·35	0·66	−0·39	0·34	0·25	
4–5	−0·51	0·36	0·16	0·16	0·32	0·61	−0·44	0·30	0·15	
≥6	−0·77	0·36	0·03	−0·05	0·36	0·88	−0·32	0·35	0·35	
Exercise†										
None	0	Ref.		0	Ref.		0	Ref.		
Less vigorous only (≥once/week)	−0·83	0·32	0·01	0·02	0·27	0·95	0·24	0·23	0·31	0·009
Vigorous (≥once/week)	−0·89	0·28	0·001	−0·32	0·30	0·28	0·30	0·30	0·33	0·001
Moderate/heavy activity at work										
No	0	Ref.		0	Ref.		0	Ref.		
Yes	0·51	0·36	0·15	0·39	0·35	0·27	−0·10	0·51	0·85	0·23
Moderate/heavy activity at home										
No	0	Ref.		0	Ref.		0	Ref.		
Yes	−0·01	0·26	0·98	0·36	0·24	0·14	−0·31	0·21	0·14	0·46
Total alcohol										0·19
Lifetime abstainers	0	Ref.		0	Ref.		0	Ref.		
0·1–19·9 g/d	−0·31	0·31	0·31	−0·03	0·27	0·91	−0·35	0·24	0·14	
20·0–39·9 g/d	−0·74	0·43	0·08	−0·61	0·41	0·13	0·04	0·36	0·91	
≥40·0 g/d	−0·65	0·57	0·26	0·22	0·50	0·66	−0·35	0·46	0·45	
Energy intake (MJ/d)	0·02	0·04	0·67	0·00	0·04	0·92	−0·06	0·04	0·09	0·71
Protein (per 10 % of energy)	0·77	0·47	0·10	0·69	0·42	0·10	0·99	0·37	0·008	0·44
Fat (per 10 % of energy)	0·70	0·22	0·002	−0·01	0·20	0·94	0·05	0·18	0·79	0·001
Carbohydrates (per 10 % of energy)	−0·32	0·19	0·08	−0·09	0·17	0·60	−0·17	0·16	0·28	0·15
Fibre (per 1 MJ of energy)	−0·29	0·13	0·03	0·05	0·12	0·72	0·14	0·12	0·23	0·02

β, coefficient; Ref., referent category.
*Adjusted for weight, sex, height, age, highest level of education (pseudo-continuous), physical activity score (pseudo-continuous), marital status (married/*de facto v.* single/divorced/widowed/separated), Index of Relative Socio-economic Disadvantage (pseudo-continuous), smoking status and dietary energy intake at baseline attendance.
†Participants in the vigorous exercise group may have also reported doing less vigorous exercise.

Analyses stratified by sex indicated that male former smokers were more likely to have a greater waist circumference at wave 2 (males β coefficient = 0·87, SE = 0·28, *P* = 0·002; females β coefficient = 0·13, SE = 0·29, *P* = 0·67; *P* for interaction = 0·02). Compared with abstainers, female heavy drinkers of alcohol (≥40·0 g/d) were more likely to have a smaller waist circumference at wave 2 (males β coefficient = 0·62, SE = 0·51, *P* = 0·23; females β coefficient = −2·00, SE = 0·86, *P* = 0·02; *P* for interaction = 0·003). There were no other notable differences in results between males and females (data not shown).

Discussion

We have shown that some of the factors that predict greater weight and larger waist circumference in middle-aged and older adults over a 12-year follow-up period, such as physical activity and diet, are modifiable targets for individual behaviour change. Similar interventions could successfully address the management of weight and waist circumference, as both measures are predicted by similar factors.

One strength of our study is that weight and waist circumference were directly measured on both occasions, thus minimizing potential errors that can occur with self-reported measures. Restriction of the analyses to people who were not current smokers and did not report having been diagnosed with cancer, diabetes, angina, stroke or heart disease at baseline reduced the likelihood that the results are explained by confounding due to smoking or to reverse causation due to prevalent illness[12]. It is possible that some participants may not have known they had diabetes, but it is unlikely that they would have changed their reported lifestyle habits at baseline because of this. On the other hand, participants who were aware they had diabetes at baseline may have altered their lifestyle in response to the diagnosis. While some studies have analysed predictors of weight change, we analysed absolute weight at wave 2 conditional on weight at baseline, as there is considerable doubt that causal knowledge may be gained by substituting a derived variable (i.e. change in weight) for a measured variable[21]. In addition, our approach does not restrict the relationship between values at baseline and wave 2 in the way that analysing change does.

The major limitation is the loss to follow-up of 2571 eligible people, of whom 1894 declined to attend for physical examination at wave 2. Because they differed in

Table 5 Selected associations of potential predictors of waist circumference at wave 2 by age at attendance*: adults with data at baseline (1990–1994) and wave 2 (2003–2007), Melbourne Collaborative Cohort Study

	40–49 years			50–59 years			60–69 years			
	β	SE	*P* value	β	SE	*P* value	β	SE	*P* value	*P* for interaction
Walking										0·15
None	0	Ref.		0	Ref.		0	Ref.		
1–2 times per week	−0·10	0·43	0·82	0·01	0·42	0·98	−0·23	0·47	0·63	
≥3 times per week	−0·05	0·38	0·90	−0·01	0·35	0·97	−0·80	0·38	0·04	
Physical activity score										0·71
0	0	Ref.		0	Ref.		0	Ref.		
1–3	−1·04	0·53	0·05	0·17	0·48	0·72	−0·60	0·55	0·28	
4–5	−1·16	0·49	0·02	−0·02	0·43	0·96	−1·01	0·49	0·04	
≥6	−1·48	0·49	0·003	−0·58	0·49	0·24	−1·50	0·56	0·007	
Exercise†										
None	0	Ref.		0	Ref.		0	Ref.		
Less vigorous only (≥ once/week)	−1·42	0·45	0·002	0·05	0·37	0·90	−0·22	0·38	0·55	0·11
Vigorous (≥ once/week)	−1·67	0·39	<0·001	−0·79	0·41	0·05	−0·35	0·50	0·49	0·01
Moderate/heavy activity at work										
No	0	Ref.		0	Ref.		0	Ref.		
Yes	1·00	0·50	0·04	1·12	0·47	0·02	−0·87	0·82	0·29	0·10
Moderate/heavy activity at home										
No	0	Ref.		0	Ref.		0	Ref.		
Yes	−0·27	0·36	0·45	0·57	0·32	0·08	−0·63	0·34	0·07	0·69
Total alcohol										0·54
Lifetime abstainers	0	Ref.		0	Ref.		0	Ref.		
0·1–19·9 g/d	−0·78	0·42	0·07	−0·40	0·37	0·27	−0·46	0·39	0·24	
20·0–39·9 g/d	−0·96	0·59	0·11	−1·29	0·55	0·02	−0·99	0·58	0·09	
≥40·0 g/d	0·45	0·79	0·56	−0·20	0·69	0·78	−0·62	0·75	0·41	
Energy intake (MJ/d)	−0·02	0·06	0·79	−0·05	0·05	0·36	−0·04	0·06	0·48	0·46
Protein (per 10 % of energy)	2·38	0·65	<0·001	1·21	0·56	0·03	1·81	0·60	0·003	0·09
Fat (per 10 % of energy)	1·32	0·31	<0·001	0·68	0·28	0·01	0·43	0·29	0·14	0·02
Carbohydrates (per 10 % of energy)	−1·21	0·26	<0·001	−0·51	0·23	0·03	−0·36	0·25	0·16	0·02
Fibre (per 1 MJ of energy)	−0·58	0·18	0·001	−0·15	0·17	0·38	0·00	0·19	0·98	0·08

β, coefficient; Ref., referent category.
*Adjusted for waist circumference, sex, height, age, highest level of education (pseudo-continuous), physical activity score (pseudo-continuous), marital status (married/*de facto v.* single/divorced/widowed/separated), Index of Relative Socio-economic Disadvantage (pseudo-continuous), smoking status and dietary energy intake at baseline attendance.
†Participants in the vigorous exercise group may have also reported doing less vigorous exercise.

their baseline characteristics from those retained, selection bias is a possibility. We were unable to find any association with energy intake, which might be because FFQ are not good at measuring absolute energy. They are better at measuring composition and patterns of the diet (i.e. how much the diet is comprised of protein, fat, etc.)[22], which might explain our findings in this regard. It should also be noted that the questions asked on physical activity pertained to frequency, but not duration. We had no information on sedentary behaviour or sleep duration, which are also associated with weight gain[1,3]. We had measured behaviours at baseline, and if these changed markedly over the 12 years between waves, attenuation of associations is possible. Regression to the mean was unlikely to have had a major impact on results, since body weight and waist circumference are not highly prone to diurnal variability or reader or other measurement error[23].

Like us, Ellaway and colleagues found that neighbourhood of residence was associated with waist circumference after controlling for individual measures of affluence[24], and living in a socio-economically deprived area is consistently associated with higher weight[3,25]. These findings suggest that targeting individual behaviour alone is unlikely to reduce the proportion of overweight individuals in the population. Changing obesity-promoting environments to increase physical activity, reduce sedentary behaviour, increase the availability of healthier food products and decrease the availability of unhealthy food products should impact on a large proportion of the population and support individual behaviour change[26]. While difficult and expensive, such changes might be achieved through public policy, transport infrastructure, urban design and taxation. Any public education campaigns to improve eating habits and levels of physical activity should target disadvantaged population groups.

We found that people who were married or in *de facto* arrangements had lower weight and waist circumference at wave 2 than people who reported being single (widowed, divorced, separated or single), suggesting the importance of intimate social relationships to weight maintenance. On the other hand, a recent publication from the Whitehall II Study showed that adverse social relationships may contribute to weight and waist circumference increases over a 12-year period[27]. While we did not evaluate the quality of relationships, it may be that people living with partners had generally better social relationships than those on their own, or that being single was a marker of adverse social relationships. Future studies could explore how the number and quality of social relationships of various levels of intimacy relate to weight gain.

Waist circumference (but not weight) at wave 2 was positively associated with blood pressure at baseline. Elevated blood pressure is part of the constellation of abnormalities constituting the metabolic syndrome, along with abdominal obesity, dyslipidaemia, dysglycaemia and insulin resistance[28], and it may be that behavioural and genetic factors contributing to rising blood pressure also contribute to visceral fat accumulation. Adjusting for baseline waist circumference may not fully account for visceral adiposity as the external waist measurement also includes subcutaneous fat.

In 2007, the World Cancer Research Fund and American Institute for Cancer Research panel concluded there was convincing evidence that physical activity of all types protects against weight gain[3]. Conversely, a more recent systematic review by Summerbell and colleagues concluded that the evidence was weak and inconsistent[2]. As there is much heterogeneity between different study designs (including age, sex and baseline weight of participants, duration of follow-up, measurement of the exposure, inclusion and exclusion of participants who smoke or have a pre-existing chronic disease), it is difficult to draw meaningful conclusions. The evidence for an association with leisure-time physical activity, however, is more convincing. Two of three intervention trials in adults (see detailed review in reference 3) showed that weight decreased with exercise aimed at weight-loss maintenance. Several epidemiological studies have also shown some benefit of leisure-time physical activity on maintenance of weight and waist circumference[1,3,29]. Two[30,31] of the three cohort studies[30–32] that reported results for high-intensity physical activity showed inverse associations with future weight.

Previous studies have reported mixed associations between work-related physical activity and weight change (see detailed review in reference 3). These associations are likely to differ by SES. We found a positive association between moderate to heavy activity at work and future waist circumference, but not weight, even after adjusting for area-based SES, education level and leisure-time exercise. This finding, though, could be explained in part by participants no longer performing work-related activities by wave 2 due to retirement from work.

Limited information is available for the relationship between physical activity at home and weight or waist change. One study reported no association for women[6], but another showed a slightly reduced risk of becoming obese for women who spent 40 h or more per week standing or walking around at home compared with inactive women[33]. We did not observe any associations for this variable and it was likely that this would have been more difficult to recall accurately than leisure-time activity, especially vigorous activity.

Several cohort studies have reported inconsistent findings with regard to alcohol intake and weight gain (see detailed review in Summerbell *et al.*[2]). Similarly, the evidence for an association between alcohol intake and change in waist circumference is not convincing[7,34,35]. Our results showed that low to moderate alcohol consumption was inversely associated with future weight and waist circumference, even after adjustment for various potential confounders.

The lack of association between total energy intake and future weight or waist circumference for our population is consistent with results from most other epidemiological studies (reviewed in Summerbell *et al.*[2]). Obesity is determined by the imbalance of energy intake and energy expenditure[36], but it is difficult to differentiate small differences in energy intake (assuming energy expenditure is constant) using FFQ. Additionally, under-reporting food intake is more common in heavier people[37]. The ability to predict future weight and waist circumference based on total energy intake is also limited as people may change their dietary intakes over time.

In most published studies, carbohydrate as a percentage of energy intake at baseline was not associated with change in weight or waist circumference[2], although some studies (including ours) report negative associations with weight gain[38,39]. Results from a meta-regression showed that fat intake as a percentage of total energy intake was not associated with change in weight (effect size $= 0{\cdot}07$, 95 % CI $-0{\cdot}03$, $0{\cdot}16$)[2]. However, a couple of studies not included in the meta-analysis reported positive associations between fat intake and weight gain[32,40]. Protein intake (typically assessed from an FFQ) was not associated with weight gain in most previous studies[2], but results were inconsistent. There is also evidence that protein is associated with satiety and could help with weight loss[41]. In contrast, two studies showed that protein intake was inversely associated with changes in waist circumference[39,42]. Further research is needed to evaluate how subdivisions of energy, protein, fat and carbohydrate intakes are associated with weight gain.

Findings from the current prospective cohort study indicate that promoting vigorous exercise and encouraging a high-carbohydrate, low-fat and low-protein diet could be promising approaches for obesity prevention in middle age. These recommendations accord with current behavioural recommendations for chronic disease prevention (e.g. *Dietary Guidelines for Australian Adults*[43], *National Physical Activity Guidelines for Adults*[44]). In the present study, low to moderate alcohol consumption was linked to lower weight than was abstaining from drinking. Current Australian guidelines for alcohol use recommend people limit alcohol intake if they choose to drink (average of no more than two standard drinks per day)[45], because for some health outcomes, alcohol abstinence may be beneficial. Observed associations between residing in socially disadvantaged suburbs and increased weight and waist circumference highlight the importance of modifying settings to support healthy individual behaviour. Driving environmental change and supporting low-income communities to improve their levels of physical activity and healthy eating are appropriately listed as key action areas for obesity prevention in Australia[26].

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