

ORIGINAL ARTICLE

The inverse relationship between number of steps per day and obesity in a population-based sample – the AusDiab study

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Background: Physical activity (PA) is inversely associated with obesity but the effect has been difficult to quantify using questionnaires. In particular, the shape of the association has not yet been well described. Pedometers provide an opportunity to better characterize the association.

Methods: Residents of households over the age of 25 years in randomly selected census districts in Tasmania were eligible to participate in the AusDiab cross-sectional survey conducted in 1999–2000. 1848 completed the AusDiab survey and 1126 of these (609 women and 517 men) wore a pedometer for 2-weekdays. Questionnaire data on recent PA, TV time and other factors were obtained. The outcomes were waist circumference (in cm) and body mass index (BMI) (kg/m²).

Results: Increasing daily steps were associated with a decline in the obesity measures. The logarithmic nature of the associations was indicated by a sharper decline for those with lower daily steps. For example, an additional 2000 steps for those taking only 2000 steps per day was associated with a reduction of 2.8 (95% confidence interval (CI): 2.1, 4.4) cm in waist circumference among men (for women; 2.2 (95% CI: 0.6, 3.9 cm)) with a baseline of only 2000, steps compared to a 0.7 (95% CI 0.3, 1.1) cm reduction (for women; 0.6 (95% CI: 0.2, 1.0)) for those already walking 10 000 steps daily. In the multivariable analysis, clearer associations were detected for PA and these obesity measures using daily step number rather than PA time by questionnaire.

Interpretation: Pedometer measures of activity indicate that the inverse association between recent PA and obesity is logarithmic in form with the greatest impact for a given arithmetic step number increase seen at lower levels of baseline activity. The findings from this study need to be examined in prospective settings.

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Introduction

Recent increases in obesity and type 2 diabetes in many countries, including the US and Australia, have been attributed to declining physical activity (PA).^{1–4} Evidence for this comes from comparisons of time trends in PA and in obesity and diabetes, and also from both cross-sectional and prospective cohort data on the associations in individuals.^{2,5,6} The extent of the contribution of PA to obesity,

however, has been difficult to quantify because questionnaire measures of PA, which have been the means of measuring PA,⁷ are not able to adequately capture the more dispersed incidental activity, such as short periods of walking around the home or workplace.⁸ That there might be an important contribution from this source is indicated by the finding in a number of studies that television watching predicts obesity or diabetes independently of PA estimated from questionnaires.^{9–11} This possibly reflects the fact that time spent TV watching is a proxy for inactivity during periods when, otherwise, incidental PA may have been performed.

The development of relatively inexpensive movement monitors – pedometers – which objectively measure the number of steps taken per day by an individual – has made it

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possible to objectively estimate total daily PA from subjects in epidemiological studies.^{12,13} To this point, pedometers have only been used in relatively small or non-representative samples or in intervention settings, limiting inference about the quantitative relationship between steps taken per day and health outcomes in a free-living population.^{2,14–16} Data providing information on the shape of the relationship and whether a threshold might exist, for example, is likely to be important in the development of public health messages.

In this report, we aim to (i) describe the association between recent PA (measured by both pedometer and questionnaire) and waist circumference and body mass index (BMI) and (ii) to compare the association of number of steps per day measured by pedometer with waist circumference and body mass index (BMI) to that of PA time over the past week by questionnaire and these measures of obesity. We do this by using data available on these measures and related factors, such as television watching time and alcohol intake, from the Tasmania sample of those who were enrolled in the AusDiab study.⁴

Methods

Study sample

The AusDiab Study estimated the national prevalence of diabetes and its risk factors in a representative sample of adults aged 25 years and older from the six States and the Northern Territory of Australia during 2000. Methods and central findings for the study have been reported in detail previously.^{2,14,17} The study had ethics committee approval. Essential details of the study design in Tasmania were as follows: six census collection districts (CDs) were sampled at random from the Tasmanian list, based on the 1996 Australian Census. Within those CDs all houses were approached and all adults 25 years and over were asked to participate. Approximately, 40% of contacted eligible subjects took part. The sample included 1848 Tasmanian adults who were invited to also wear pedometers. In all, 1126 provided additional pedometer data for 2 week days. Twenty-nine other subjects who wore a pedometer on at least one weekend day were excluded from analyses. Among the 1126 subjects, 59% were from families with a single study subject and 41% came from families with two or more subjects participating in the study. Among families with more than one participant 93% had one male and one female subject. The study was approved by the International Diabetes Institute ethics committee.¹⁷

Pedometers

The pedometer protocol for this study was developed at the Menzies Research Institute based on the literature¹⁸ and on experience with administration of the pedometers over time. The pedometers used were the Omron HJ-003 and Omron HJ-102. These were regularly checked for accuracy of count.

Research staff demonstrated to each participant the correct placement and operation of the pedometer, as well as providing them with printed instructions. A diary was supplied for recording of daily steps. We collected 2 days of pedometer readings for each subject. A previous study found an intraclass correlation of 0.71–0.84 for any 2 days of recording, and two consecutive days captured 89% of the variance of a 7-day recording period.¹⁹

Assessment of recent PA time, TV time, diet and demographic attributes

Self-reported PA, TV time, diet, alcohol, cigarette consumption and demographic attributes, were assessed using an interviewer-administered questionnaire. Participants reported the frequency and duration of their PA for the previous week using the Active Australia Survey questionnaire.²¹ For this study, PA was estimated by the time spent walking for recreation or transport, undertaking moderate intensity non-work, non-domestic activity and vigorous activity, usually of a sporting nature, during the last week. These questions have been found to provide reliable and valid estimates of adult PA.^{21–23} Vigorous activity was given double the weighting of moderate activity when calculating the total hours of PA time.²¹ In addition, participants also self-reported the total time they spent watching TV over the past week. This measure provides a reliable and valid estimate of TV time among adults.²⁴ Participants completed a dietary questionnaire with a semiquantitative food frequency section as well as questions relating to alcohol intake for the calculation of total daily energy intake (kJ/day).²⁵ Further questions relating to alcohol consumption and tobacco use and number of children for female subjects were asked in a structured interview.

Assessment of anthropometric measures of obesity

Waist circumference was measured halfway between the lower border of the ribs and the iliac crest on a horizontal plane. Two measurements using a steel measuring tape to the nearest 0.5 cm were recorded. If the measurements varied by more than 2 cm, a third measurement was taken. The mean of the two closest measurements was calculated. Height without shoes was measured to the nearest 0.005 m (0.5 cm) using a stadiometer. Weight was measured in light clothes on a mechanical beam balance, and was recorded to the nearest 0.1 kg. BMI was calculated as weight (kg)/height² (m²).

Statistical analysis

Statistical analyses were performed for the two obesity-related outcomes, waist circumference and BMI. Analyses were performed using either SPSS Version 11.0²⁶ or Stata Version 8.0.²⁷ SPSS was used to compute descriptive statistics (means and standard errors), tests and significance levels comparing gender differences shown in Table 1 and BMI

Table 1 Estimated means and s.e. or percents for study variables for men and women

	Men		Women		Gender difference P-values
	n	Mean (s.e.)	n	Mean (s.e.)	
Age	517	52.1 (0.61)	609	49.7 (0.55)	<0.01
Waist circumference	513	96.2 (0.51)	607	84.5 (0.50)	<0.01
BMI (kg/m ²)	515	27.2 (0.18)	604	26.6 (0.21)	0.06
Weight (kg)	515	83.9 (0.62)	604	70.2 (0.60)	<0.01
Height (cm)	517	175.7 (0.32)	607	162.3 (0.25)	<0.01
Avg. steps (000's)/day	503	10.9 (0.23)	599	11.2 (0.21)	0.34
Hours of PA ^a /past week	516	6.4 (0.33)	607	4.5 (0.23)	<0.01
Hours of TV watching/past week	515	14.0 (0.44)	607	13.1 (0.41)	0.14
Alcohol consumed (drinks/day)	516	3.8 (0.17)	608	2.2 (0.11)	<0.01
Energy from all sources (kJ/day)	489	9615.5 (161.67)	572	6973.1 (100.41)	<0.01
Dietary fat (gm/day)	489	95.6 (1.89)	572	65.9 (1.13)	<0.01
Number of children	+	+	567	2.7 (0.06)	
Current smoking status	509	16.7%	600	17.7%	0.61

Abbreviations: BMI, body mass index; PA, physical activity. + Data not collected for male subjects. ^aNote loading for vigorous activity – see Methods.

Table 2 Distribution of average number of steps per day

Average number of steps	Males (%)	Females (%)	Total (%)
<2000	1 (0.2)	4 (0.7)	5 (0.5)
2001–4000	25 (5.0)	22 (3.7)	47 (4.3)
4001–6000	53 (10.5)	54 (9.0)	107 (9.7)
6001–8000	80 (15.9)	93 (15.5)	173 (15.7)
8001–10 000	94 (18.7)	96 (16.0)	190 (17.2)
10 001–12 000	76 (15.1)	97 (16.2)	173 (15.7)
12 001–14 000	59 (11.7)	81 (13.5)	140 (12.7)
> 14 000	115 (22.9)	152 (25.4)	267 (24.2)
Total	503 (100.0)	599 (100.0)	1102 (100.0)

groups within gender in Table 2. Stata was used to perform all linear regression modeling. The linear regression modeling took account of correlation of observations of subjects within families by using a robust estimator of standard errors obtained by defining families as clusters. The regression analyses were weighted to account for the AusDiab sampling. Rather than use a complicated single model containing multiple gender by covariate interactions we chose to use gender-specific models developed using the following five step procedure for each outcome variable: (1) parallel but separate gender-specific multivariable models containing all the covariates in Table 1 were fitted, with the exception that number of children was considered for women but not men as the number of children was not collected for men. Robust estimates of the standard errors of the estimated coefficients were used in the computation of significance levels for the estimated regression coefficients; (2) the models were simplified by successively deleting the covariate with the least significant estimated coefficient until all the estimated coefficients were significant in one or both gender-specific models. No variable not included in the model changed the estimate of the coefficient of any variable in the model by more than 15 percent; (3) the assumption of linearity in the model of continuous covariates was checked using the method of fractional polynomials.²⁸ These analyses were

performed without weighting or clustering observations as Stata's implementation of fractional polynomials does not support these options; (4) interactions were created between main effects in the model. These were added one at a time to the main effects model resulting at step 3 and tested for significance. There were no significant interactions; (5) sensitivity to individual observations was checked using measures of leverage, residual and influence. Model assumptions were evaluated using a test for normality of the residuals and a test for homogeneity of error variance.²⁹ Suspected influential or outlying observations were identified from box plots of the diagnostic statistics. If the data values were judged to be implausible or highly unusual using standard criteria²⁹ then the subject was excluded from the fit of the final model. We note that two men and six women were identified as being outliers for waist circumference and four men and five women for BMI. In all cases the reason for exclusion was an unrealistic number of hours of TV, average number of steps or alcohol per day relative to the rest of the subjects in their gender group.

Results

Gender-specific means and standard errors for the obesity measures, pedometer data and demographic and lifestyle variables are shown in Table 1 along with the *P*-value from the two sample *t*-test for continuous variables or χ^2 -test for current smoking status. Significant gender differences were observed for all variables except average daily steps, current smoking status and weekly hours of TV. For all variables where there was a significant gender difference, men had higher values than women. While men reported more time in PA than women (men: 6.4 (0.33), women: 4.5 (0.23), *P*<0.01); the average number of steps (in 000's) taken per day was not significantly different (men: 10.9 (0.23), women: 11.2 (0.21), *P*=0.34). The relatively greater time in PA

reported by men was not explained by their participation in vigorous activity.

The overall distribution of the average number of steps per day among male and female subjects is shown in Table 2. The distributions are not significantly different ($P=0.56$).

Men who did not wear a pedometer ($n=306$) were not significantly different to those who did with respect to age, waist circumference, weekly hours of exercise and of TV watching. Women who did not wear a pedometer ($n=387$) were significantly older than those who did (mean 53.0 years, $P<0.001$) and had a larger mean waist circumference (87.3 cm, $P<0.01$), but were not significantly different in their weekly hours of exercise and TV watching.

Gender-specific means and standard errors or percentages according to BMI groups for the anthropometric measures, pedometer data, demographic and lifestyle variables are shown in Table 3a and b. For men, significant differences were observed for average daily steps and weekly hours of TV. Difference in average daily steps from the lowest to the highest category was observed for women, it was not significant.

As many of the associations in Table 3a and b were different for men and women, a single regression model

would require multiple gender by covariate interactions. Hence, we decided to build gender-specific but parallel regression models for each outcome (waist circumference and BMI) – that is, separately fit models but ones that contained the same covariates. The models were obtained by applying the five steps described in statistical methods and are shown in Table 4 for waist circumference and in Table 5 for BMI. The common set of variables included average number of steps, hours of TV time, alcohol consumption per day, hours of PA, age and height (for waist circumference). The number of children was significant in the univariable models for waist circumference and BMI but not in the multivariable models for women. Application of the method of fractional polynomials showed that the models for both outcomes were linear in the log transformation of average steps and hours of PA. This is reflected in the fact that these variables are denoted by Ln (*) in Tables 4 and 5.

The results for waist circumference in Table 4 show that the association of daily steps was the most highly significant of the PA measures in the models for both men and women: the estimated coefficient (effect) for men being about 28% larger than that for women (men: -4.1 , women -3.2). The estimated coefficients for Ln (PA Time), TV time and alcohol consumption per day were significant for men but not for

Table 3 (a) Estimated means and s.e. or percents for study variables for three BMI groups for men and (b) estimated means and s.e. or percents for study variables for three BMI groups for women

	BMI group						Group difference P-value
	<25		25–29		≥30		
	n	Mean (s.e.)	n	Mean (s.e.)	n	Mean (s.e.)	
(a)							
Age	149	51.6 (1.21)	265	52.7 (0.86)	101	51.2 (1.15)	0.57
Waist circumference	148	85.3 (0.51)	263	96.5 (0.39)	100	111.8 (1.03)	<0.01
Weight (kg)	149	71.5 (0.68)	265	83.8 (0.46)	101	102.7 (1.28)	<0.01
Height (cm)	149	176.6 (0.66)	265	175.2 (0.42)	101	175.7 (0.71)	0.19
Average steps (000's)/day	144	12.4 (0.46)	259	10.6 (0.30)	98	9.4 (0.53)	<0.01
Hours of PA/past week	148	7.0 (0.58)	265	6.5 (0.49)	101	5.3 (0.70)	0.21
Hours of TV watching/past week	149	13.5 (0.82)	263	13.1 (0.57)	101	17.2 (1.17)	<0.01
Alcohol consumed (drinks/day)	148	3.4 (0.31)	265	3.7 (0.22)	101	4.4 (0.43)	0.18
Energy from all sources (kJ/day)	138	9776.3 (288.56)	252	9469.5 (211.50)	97	9789.18 (441.98)	0.63
Dietary fat (gm/day)	138	95.7 (3.20)	252	94.6 (2.50)	97	98.4 (5.30)	0.75
Current smoking status	147	17.7%	260	16.2%	100	17%	0.92
(b)							
Age	261	48.6 (0.85)	218	51.3 (0.92)	125	48.9 (1.14)	0.07
Waist circumference	261	75.2 (0.39)	218	85.8 (0.40)	125	101.5 (1.01)	<0.01
Weight (kg)	261	59.6 (0.41)	218	71.3 (0.44)	125	90.3 (1.36)	<0.01
Height (cm)	261	163.0 (0.40)	218	161.6 (0.41)	125	161.9 (0.53)	0.05
Average steps (000's)/day	256	11.7 (0.32)	216	11.0 (0.33)	122	10.6 (0.51)	0.11
Hours of PA/past week	260	4.9 (0.35)	218	4.3 (0.39)	125	4.1 (0.46)	0.27
Hours of TV watching/past week	260	12.8 (0.66)	218	13.1 (0.60)	125	13.9 (1.02)	0.60
Alcohol consumed (drinks/day)	261	2.2 (0.16)	218	2.2 (0.16)	125	2.3 (0.35)	0.93
Energy from all sources (kJ/day)	246	7194.9 (167.32)	208	6804.2 (151.14)	115	6786.7 (211.45)	0.15
Dietary fat (gm/day)	246	68.0 (1.89)	208	64.5 (1.76)	115	63.7 (22.57)	0.25
Number of children	231	2.5 (0.09)	200	2.9 (0.09)	121	2.7 (0.13)	0.05
Current smoking status	258	19.8%	214	15.4%	124	17.7%	0.47

Abbreviations: BMI, body mass index; PA, physical activity.

women. The effects of age and height were significant in each model.

Table 5 shows that the association between daily step number and BMI was significant for men and marginally significant for women ($P=0.062$). In contrast, recent PA time measured by questionnaire was not significantly associated with BMI. Note that in Table 5 an additional term for Age² was also included, because age has a significant quadratic effect for both men and women (with those of middle age having higher BMI than younger and older study subjects). Food frequency questionnaire measurement of daily energy intake from all sources was not associated with either waist circumference or BMI after the variables shown in Tables 3 and 4 were taken into account.

Table 4 Multivariable regression models showing associations with waist circumference

Variable	Est.	Robust (s.e.)	P-value	95% CI
Men*				
Ln (Avg. steps/day)	-4.09	1.124	<0.001	-6.30, -1.88
Ln (PA time (h/week))	-1.58	0.588	0.008	-2.73, -0.42
TV time (h/week)	0.14	0.058	0.014	0.03, 0.26
Alcohol (drinks/day)	0.39	0.140	0.005	0.12, 0.67
Age (years)	0.17	0.039	<0.001	0.09, 0.25
Height (cm)	0.23	0.082	0.005	0.07, 0.39
Constant	55.04	15.79	0.001	24.02, 86.07
Women**				
Ln (Avg. steps/day)	-3.22	1.197	0.007	-5.57, -0.87
Ln (PA time (h/week))	-0.91	0.594	0.127	-2.07, 0.26
TV time (h/week)	0.05	0.055	0.333	-0.05, 0.16
Alcohol (drinks/day)	0.02	0.232	0.917	-0.43, 0.48
Age (years)	0.14	0.039	<0.001	0.07, 0.22
Height (cm)	0.24	0.082	0.003	0.08, 0.40
Constant	45.94	13.95	0.001	18.53, 73.34

Abbreviations: BMI, body mass index; CI, confidence interval; PA, physical activity. *N=493, number of families=485, F(6, 484)=11.66, P<0.001, R²=0.15. Note the standardized normal deviate for Ln (Avg. steps/day) is greater than for Ln (PA time (h/week)): z=-3.64 vs z=-2.69. **N=589, number of families=575, F(6, 574)=5.70, P<0.001, R²=0.08. Note the standardized normal deviate for Ln (Avg. steps/day) is greater than for Ln (PA time (h/week)): z=-2.69 vs z=-1.53.

Another way to present the effect of number of steps is the estimate for, say, a 50% increase in the number of steps. As the model for waist circumference and BMI are linear in log steps this estimate does not depend on the number of steps. For waist circumference the estimate is a decrease of 1.7 cm (95% confidence interval (CI) 0.77, 2.56) (men) and 1.3 cm (95% CI 0.82, 1.79) (women). The estimate for BMI is a decrease of 0.66 (95%CI. 32, 1.0) (men) and 0.42 (95% CI 0.02 increase to 0.87 decrease) (women). Specific examples of the estimated difference in means for an increase of 2000 steps per day are shown in Table 6. These results demonstrate that most of the differences in mean waist circumference and BMI associated with a difference of 2000 daily steps occurs in subjects walking less than 10000 steps per day.

Table 5 Multivariable regression models showing associations with BMI

Variable	Est.	Robust (s.e.)	P-value	95% CI
Men*				
Ln (Avg. steps/day)	-1.64	0.422	<0.001	-2.47, -0.81
Ln (PA time (h/week))	-0.20	0.207	0.328	-0.61, 0.20
TV time (h/week)	0.04	0.020	0.035	0.003, 0.08
Alcohol (drinks/day)	0.11	0.053	0.049	0.001, 0.21
Age (years)	0.33	0.101	0.001	0.13, 0.53
Age (years) ²	-0.003	0.001	0.001	-0.005, -0.001
Constant	22.42	2.698	<0.001	17.12, 27.72
Women**				
Ln (Avg. steps/day)	-1.06	0.566	0.062	-2.17, 0.05
Ln (PA time (h/week))	-0.14	0.252	0.568	-0.64, 0.35
TV time (h/week)	0.02	0.025	0.376	-0.03, 0.07
Alcohol (drinks/day)	-0.10	0.091	0.256	-0.28, 0.08
Age (years)	0.21	0.115	0.069	-0.02, 0.43
Age (years) ²	-0.002	0.001	0.044	-0.004, 0.000
Constant	24.64	3.042	<0.001	18.66, 30.61

Abbreviations: BMI, body mass index; CI, confidence interval; PA, physical activity. *N=493, number of families=485, F(6, 484)=6.69, P<0.001, R²=0.09. Note the standardized normal deviate for Ln (Avg. steps/day) is greater than for Ln (PA time (h/week)): z=-12.7 vs z=-0.97. **N=587, number of families=573, F(6, 574)=1.41, P=0.207, R²=0.02. Note the standardized normal deviate for Ln (Avg. steps/day) is greater than for Ln (PA time (h/week)): z=-1.87- vs z=-0.56.

Table 6 Estimated decrease in mean waist circumference and mean BMI associated with an additional 2000 steps per day varies by the baseline of number of steps per day

Baseline	Males		Females	
	Waist circumference (cm)(95% CI)	BMI (kg/m ²) (95% CI)	Waist circumference (cm) (95% CI)	BMI (kg/m ²) (95% CI)
2000	2.8 (1.3, 4.4)	1.1 (0.6, 1.7)	2.2 (0.6, 3.9)	0.7 (-0.04, 1.5)
4000	1.7 (0.8, 2.6)	0.7 (0.3, 1.0)	1.3 (0.4, 2.3)	0.4 (-0.02, 0.9)
6000	1.2 (0.5, 1.8)	0.5 (0.2, 0.7)	0.9 (0.2, 1.6)	0.3 (-0.02, 0.6)
8000	0.9 (0.4, 1.4)	0.4 (0.2, 0.6)	0.7 (0.2, 1.2)	0.2 (-0.01, 0.5)
10000	0.7 (0.3, 1.1)	0.3 (0.1, 0.5)	0.6 (0.2, 1.0)	0.2 (-0.01, 0.4)
15000	0.5 (0.2, 0.8)	0.2 (0.1, 0.3)	0.4 (0.1, 0.7)	0.1 (-0.01, 0.3)
20000	0.4 (0.2, 0.6)	0.2 (0.1, 0.2)	0.3 (0.1, 0.5)	0.1 (-0.01, 0.2)

Abbreviations: BMI, body mass index; CI, confidence interval.

Discussion

The inverse association between PA and obesity has been difficult to characterize using self-report activity data. Here, using pedometer measures of recent PA in a large population-based sample, an increasing number of average daily steps was inversely associated with waist circumference and BMI. The inverse association was logarithmic in form. The estimated coefficient for the effect of average number of steps in logarithmic form for men was 22% larger than that for female subjects for waist circumference and was 35% larger for BMI. After taking into account other factors associated with obesity, such as the time spent watching TV, independent associations for daily steps remained but PA was significant only for waist circumference in men. Although the average daily step number was similar for female and male subjects, males reported significantly more PA time.

In the 1995 recommendation on PA and public health by the Centres for Disease Control and Prevention and the American College of Sports Medicine,³⁰ it was stated that the lower the baseline PA status, the greater will be the health benefit associated with a given increase in PA.³⁰ Here, this concept has now been demonstrated quantitatively for average daily steps and waist circumference as well as BMI. The decline in these obesity measures associated with an additional 2000 daily steps varied according to baseline activity with a larger decline for those who were sedentary or with a low daily step count. These results suggest baseline activity should be taken into account when studying the health effect of an arithmetic exercise 'dose' – defined by time, intensity and/or daily steps or when providing an exercise prescription.

The associations between PA and obesity here are cross-sectional and thus the underlying connection cannot be assumed to be causal. For example, high BMI has been associated with subsequent physical inactivity.³¹ However, although people who are obese are usually inactive,³² body composition, in terms of percentage body fat, is not a powerful predictor of PA habits.³⁰ In an intervention, baseline BMI was not significantly related to changes in step number.¹⁶ That is, BMI did not appear to influence the intervention-associated increase in step number. Previously cross-sectional associations between self-reported PA and BMI^{2,33} have also been found in prospective studies.^{6,10,34,35} It seems reasonable to infer that the cross-sectional associations observed for PA measured by pedometer rather than questionnaire report are likely to similarly reflect cause. Nonetheless, prospective data on large samples with concurrent measurement of other determinants of anthropometry, such as diet, are required. Such studies are currently underway.

Strength of these data is that they were from a large representative sample of a defined population within Australia – a country that has a standard of living comparable to North America and Western Europe, ready access to

modern manufactured goods, and shares a growing problem of obesity. The size of the data set make it possible to estimate with reasonable validity the shape of the line or curve of best fit, which has not been performed previously. While it has been suggested that pedometer readings be captured for more than 2 days to validly estimate habitual activity,²⁰ a 2-day capture was not only more feasible in a large free-living sample such as this, it also accounts for 89% of the variance of 7 days of recording (compared with 94% for 3 days of readings).²⁰ The association was nonlinear and best fitted by a log function. The estimates from this model indicate that one would be likely to see prospectively a greater reduction in obesity by increasing number of steps for those who are at the lower end of daily energy expenditure, particularly among those taking fewer than 10 000 steps per day.

The stronger independent associations observed for PA and obesity when assessing activity by pedometer rather than questionnaire may have reflected an improvement in measurement validity due to increased precision and/or to the inclusion of incidental activity in the daily step tally. The gender difference in PA found in questionnaire data, but not in pedometer data, may reflect a higher level of incidental activity in women picked up by the pedometer. Past work showing weak or absent prospective associations detected between questionnaire measures of PA and waist circumference³⁶ or walking less than 4 h/week and BMI³⁷ may partly reflect these measurement issues. Here, possible inaccuracies in measuring energy intake by questionnaire and the fact that energy intake is positively correlated with PA might have obscured the association between daily energy intake and obesity in this study.

Recommendations on exercise are a major public health priority but definitive data are lacking. In 2002, a consensus meeting concluded that 45–60 min a day of moderate PA per day was required to prevent the transition to overweight or obesity,³⁸ substantially more than the 1995 recommendation that every adult should accumulate 30 min or more of moderate-intensity PA on most, preferably all, days of the week.³⁰ Future prospective studies incorporating pedometer or accelerometer measures of activity should assist the evidence base for future recommendations.

In the USA in 1999–2000, more than 60% of adults aged 20–74 years were classified as overweight or obese.³⁹ As of 2001, more than 25% were not active at all in their leisure time.³⁹ The findings here suggest that clinicians working with overweight patients would be justified in recommending even modest increases in daily activities, such as walking, among inactive patients, to achieve benefits. Pedometers have been shown in other studies to effectively motivate individuals to increase and maintain additional levels of PA.⁴⁰ They also assist the individual and the physician to monitor their efforts to increase PA. The increasing availability of information to assist the clinician to use pedometer devices in structured programs⁴¹ is making their introduction to clinical practice more feasible.

In conclusion, this study has characterized the inverse association between PA and obesity using a pedometer measure of average daily steps. It provides quantitative evidence to support the proposal that the health effect of a given increase in activity will vary depending on baseline activity level. A greater reduction in obesity by increasing daily step number is likely for those who are at the lower end of daily energy expenditure, particularly in the range under 10 000 steps per day.

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