Physical Activity, Television Viewing Time and 12-Year Changes in Waist Circumference

Ai Shibata[1,2], Koichiro Oka [1,3], Takemi Sugiyama[1,4,5], Jo Salmon[6], David W Dunstan[1,7-10], Neville Owen[1,8,11,12]

[1] Physical Activity and Behavioural Epidemiology Laboratories, Baker IDI Heart and Diabetes Institute, Melbourne, VIC, Australia

[2] Faculty of Health and Sport Sciences, University of Tsukuba, Ibaraki, Japan

[3] Faculty of Sport Sciences, Waseda University, Saitama, Japan

[4] School of Design, Swinburne University of Technology, Melbourne, VIC, Australia

[5] School of Population Health, University of South Australia, Adelaide, SA, Australia

[6] Centre for Physical Activity and Nutrition Research, Deakin University, Melbourne, VIC, Australia

[7] School of Sports Science, Exercise and Health, the University of Western Australia, Perth, WA, Australia

[8] School of Population Health, the University of Queensland, Brisbane, QLD, Australia

[9] School of Exercise and Nutrition Sciences, Deakin University, Melbourne, VIC, Australia

[10] School of Public Health and Preventive Medicine, Monash University, Melbourne, VIC, Australia

[11] School of Population and Global Health, Melbourne University, Melbourne, VIC, Australia

[12] Department of Medicine, Monash University, Melbourne, VIC, Australia

Corresponding author:
Neville Owen, PhD
Behavioural Epidemiology Laboratory, Baker IDI Heart and Diabetes Institute
99 Commercial Road, Melbourne, VIC 3004, Australia
Phone: +61 3 8532 1874, Fax +61 3 8532 1100, Email: neville.owen@bakeridi.edu.au

Running title: Waist Circumference Change

Conflict of interest: All authors declare no conflict of interest.

Funding sources: The study was supported by funding from the National Health and Medical Research Council of Australia. Please refer to the acknowledgments section for further information.

Abstract

Purpose: Both moderate-to-vigorous physical activity (MVPA) and sedentary behavior can be associated with adult adiposity. Much of the relevant evidence is from cross-sectional studies or from prospective studies with relevant exposure measures at a single time point prior to weight gain or incident obesity. This study examined whether changes in MVPA and television (TV) viewing time are associated with subsequent changes in waist circumference, using data from three separate observation points in a large population-based prospective study of Australian adults.

Methods: Data were obtained from the Australian Diabetes, Obesity and Lifestyle study collected in 1999-2000 (baseline), 2004–05 (Wave 2), and 2011–12 (Wave 3). The study sample consisted of adults aged 25 to 74 years at baseline who also attended site measurement at three time points (n=3261). Multilevel linear regression analysis examined associations of initial five-year changes in MVPA and TV viewing time (from baseline to Wave 2) with 12-year change in waist circumference (from baseline to Wave 3), adjusting for well-known confounders.

Results: As categorical predictors, increases in MVPA significantly attenuated increases in waist circumference (*p* for trend< 0.001). TV viewing time change was not significantly associated with changes in waist circumference (*p* for trend =0.06). Combined categories of MVPA and TV viewing time changes were predictive of waist circumference increases; compared to those who increased MVPA and reduced TV viewing time, those who reduced MVPA and increased TV viewing time had a 2cm greater increase in waist circumference (*p*=0.001).

Conclusion: Decreasing MVPA emerged as a significant predictor of increases in waist circumference. Increasing TV viewing time was also influential, but its impact was much weaker than MVPA.

Key words: exercise, sedentary lifestyle, obesity, central adiposity, prospective studies

Introduction

Increasing prevalences of overweight and obesity are a major global public health challenge (16). For example, in 2011-12, some 69% of Americans aged 20 years or older and 63% of Australians aged 18 years or older were overweight or obese (3, 27). With obesity related to increased risk of premature mortality and to a plethora of adverse health outcomes (9, 10, 41), there is an urgent need for effective public health interventions to prevent weight gain.

Population strategies for weight-gain prevention include increasing energy expenditure through physical activity. Moderate-to vigorous-intensity physical activity (MVPA) can attenuate increases in body weight, BMI, and waist circumference and reduce the risk of obesity (7, 14). More recently, sedentary behaviors – put simply, too much sitting as distinct from too little exercise – have been implicated in the weight gain equation. Television viewing (TV) time, a common sedentary behavior that occupies a large proportion of leisure-time, is now understood to be a health risk in its own right (28, 34). Evidence from prospective studies suggests that TV viewing time can be associated with the increase in adiposity after accounting for the role of leisure-time MVPA; although the relevant findings are mixed (37).

There is a body of evidence from cross-sectional studies showing independent and joint associations of MVPA and sedentary behavior with adiposity (11, 13, 23, 25, 30, 35). However, only a small number of prospective studies to date have assessed simultaneously the associations of MVPA and sedentary behavior with adiposity outcomes (5, 18, 29, 35). Findings from the Nurses' Health Study have shown both low volumes of brisk walking and high TV viewing time to be independently associated with increased incidence of obesity ($\geq$30kg/m^2) over 6 years (18). The Cancer Prevention Study II also found that both low levels of recreational leisure-time physical activity and higher non-occupational sedentary time to be associated with a higher odds of a 5- to 9-pound weight gain over 7 years among postmenopausal women, but only among those who initially were not overweight (5). A one-year prospective study examining the maintenance of weight loss among 1422 adults found that the combination of an increase in TV viewing time and a decrease in MVPA was a significant independent predictor of weight regain (29). Two prospective studies have reported that a combination of low or decreased MVPA and high or increased TV viewing time can increase the risk of obesity and weight gain (18, 29). Furthermore, engaging in high levels of physical activity or increasing physical activity level was found not to fully mitigate the adverse effects of TV viewing time on obesity risk (18, 29), which is consistent with evidence from cross-sectional studies (25).

Prospective studies have typically examined relationships of physical activity and/or sedentary behavior at baseline or a single point in time with subsequent weight change or incident obesity (5, 18). However, assessment of the relevant exposure variables at more than two time-points provides the advantage of examining the how preceding changes in behaviors might predict the subsequent changes in adiposity – providing more robust evidence on the potential causal roles of physical activity and sedentary behaviors in weight gain.

In understanding physical activity and sedentary behavior as determinants of adiposity, a limitation to the evidence is that a high proportion of the studies have employed BMI or body weight (5, 13,18, 23, 25, 29, 30, 35). Waist circumference is, however, a more-robust anthropometric marker of total body fat (6). Also anthropometric measures of abdominal obesity are more strongly associated with cardio-metabolic risk than is BMI (10), and are argued to be more reflective of the physiological effect of behaviors on body composition (11, 33). Adult weight gain tends to be reflected through increases in central adiposity, rather than overall body adiposity (15, 39).

We examined prospective changes in adults' waist circumference in relation to changes in MVPA and TV viewing time, using data from three observation points over 12 years (baseline; 5-year and 12-year follow-ups). Initial five-year changes in MVPA and TV viewing time (from baseline to 5 years) were examined as potential predictors of 12-year changes in waist circumference (from baseline to 12 years).

Methods and Procedures

Study sample

The Australian Diabetes, Obesity and Lifestyle Study (AusDiab) initially assessed 11,247 Australian adults aged 25 years or older to examine the national prevalence of diabetes and related risk factors. The baseline measurement was undertaken in 1999-2000 (Wave 1) with two follow-up measures in 2004-2005 (Wave 2) and 2011-2012 (Wave 3). The study methods and attributes of participants in the Wave 1 (12) and Wave 2 (24, 36) have been previously reported.

The study sample consisted of adults aged 25 to 74 years at baseline who also attended an on-site measurement in both Wave 2 and 3 (n=3918; 37.9% of baseline sample). Those who were clinically diagnosed with diabetes (n=203), reported history of cardiovascular diseases (angina: n=105; myocardial infarction: n=70; stroke: n=30), pregnant at any of 3 measurement periods (n=31), or had missing data for relevant variables (n=349) were excluded. Exclusion criteria were not mutually exclusive. The final study sample was 3261 (43.5% men).

A comparison of baseline values between the final study sample and those only attending the baseline 1999-2000 study (n=4960) showed that the final sample was comparable for distribution in gender and lipid-lowering medication use and for MVPA, total energy intake, and total alcohol intake. However, they were more likely to be highly educated ($p<0.001$), employed ($p<0.001$), and earning a higher income ($p<0.001$), and less likely to be taking antihypertensive medication ($p<0.001$) than those who took part only in the baseline study. Also, the final sample were younger ($p=0.004$), had lower waist circumference ($p<0.001$), watched less TV ($p<0.001$), and had higher physical functioning ($p<0.001$) compared with those who participated in the baseline study phase only. The study was approved by the Ethics Committee of International Diabetes Institute, and written informed consent was obtained from all participants.

Measures and instruments

Waist circumference change. Waist circumference (cm) measures at baseline and Wave 3 were used. On each occasion, trained field staff measured the participants' waist circumference halfway between the lower border of the ribs and the iliac crest on a horizontal plane. Two measurements to the nearest 0.5 cm were recorded and the mean was calculated; if the variation between the two measures was greater than 2cm, a third measure was taken and the mean of the two closest measures was calculated. Twelve-year changes in waist circumference were calculated as the measure at Wave 3 minus the measure at baseline.

Body mass index (BMI) change. The change in BMI ($kg \cdot m^{-2}$) from baseline to Wave 3 was also used as an outcome. Height and weight were measured with participants wearing light clothing and no shoes at each Wave. Twelve-year changes in BMI were calculated as the measure at Wave 3 minus the measure at baseline.

MVPA change. MVPA at both baseline and Wave 2 was assessed using the Active Australia Survey, a questionnaire that measures participation in predominantly leisure-time physical (but also includes walking for transport) during the previous week (4). The Active Australia instrument has been shown to have acceptable levels of reliability (intraclass correlation = 0.59; 95% CI = 0.52-0.65) and validity (criterion validity = 0.3) among adults (8, 38). Participants reported the amount of time (minutes/week) they spent in the past week in 1) walking for transport and recreation, 2) moderate-intensity physical activity, and 3) vigorous-intensity physical activity. Total MVPA ($h \cdot wk^{-1}$) was calculated as the sum of the time spent walking (if continuous and for 10 min or more), performing moderate-intensity physical activity, plus double the time spent in vigorous-intensity physical activity (1). Data for those who reported more than 28 hours per week (4 hours per day) of MVPA were truncated to 28 hours per week. Five-year changes in MVPA were calculated as the duration at Wave 2 minus the duration at baseline. Change in MVPA was examined both as a continuous and categorical predictor. Based on the distribution, three change categories were created: decreased ($>-1.0\ h \cdot wk^{-1}$); no change ($0\pm1.0\ h \cdot wk^{-1}$); and increase ($> 1.0\ h \cdot wk^{-1}$).

TV viewing time change. At both baseline and Wave 2, participants reported time spent watching TV or video/DVD on weekdays (that is, their total time over the five weekdays) and weekends (that is, their total time over the two weekend days), for the past week. This measure has been shown to have acceptable level of test-retest reliability (intraclass correlation = 0.82) and criterion validity (Spearman rank-order correlation with a 3-day log = 0.3) among adults (31). Average daily TV viewing time was calculated by summing the time for weekdays and for weekend days and dividing this by seven ($h \cdot wk^{-1}$). Data for those who reported more than 112 hours per week (16 hours per day) of television viewing time were truncated to 112 hours per week. Five-year changes in TV viewing time (h·wk^{-1}) were calculated as the duration at Wave 2 minus the duration at baseline. Change in TV viewing time was examined both as continuous and a categorical predictor. Based on the distribution, three change categories were created: decreased (>-3.5 h·wk^{-1}); no change (0±3.5 h·wk^{-1}); and increased (> 3.5 h·wk^{-1}).

Potential confounding variables. At baseline, the following socio-demographic, dietary and health-related measures were assessed with an interviewer-administered questionnaire (12): gender, age, marital status (currently married or de facto; yes/no), educational attainment (high school or further education; yes/no), household income (=> $32,200 per annum; yes/no), and working status (working full time or part time; yes/no), total energy intake (KJ/day [20]), alcohol intake (g/day [20]), and medications for hypertension and dyslipidemia. Self-rated physical function was assessed at baseline using the physical functioning domain from the version 1 of the SF-36 Health Survey (40).

<u>Statistical analyses</u>

Multilevel analysis was employed because the AusDiab study had a multi-stage cluster sampling design with 42 data collection areas (6 areas from each of seven Australian states and territory), as there was a small level of within-area clustering (Intraclass Correlation Coefficient=0.044). The structure of the analysis was that individuals (Level 1) were nested within collection districts (Level 2). A series of linear regression models were used to examine both independent and joint associations of initial five-year changes in MVPA and TV viewing time with 12-year changes in waist circumference. The same set of analyses were conducted for 12-year BMI changes as a sensitivity analysis. Results provided are unstandardized b coefficients for continuous exposure measures. For categorical exposures, adjusted mean changes in waist circumference were additionally calculated. Analyses were conducted using STATA 12.0. Statistical significance was set at $p<0.05$.

Independent associations MVPA and TV viewing time changes with waist-circumference change. Linear regression models were performed for the two behavioral exposure variables (changes in MVPA and TV viewing time). To test whether potential covariates influence the associations of initial 5-year changes in MVPA and TV viewing time with12-year changes in waist circumference, a four-step analysis was performed. Change in waist circumference over 12 years was regressed against: change and baseline behavior variable (MVPA or TV viewing time), baseline waist circumference, gender, age, education, employment status, income, antihypertensive medication and lipid-lowering medication (Model A). Model B additionally adjusted for baseline alcohol consumption and total energy intake. Model C further adjusted for baseline physical functioning. To examine the independent associations of either MVPA or TV viewing time, Model D further adjusted for one or the other behavior variable.

In separate linear regression models including changes in MVPA or TV viewing time as categorical variables (increased, no change, decreased), pair-wise comparisons were performed to examine the difference in adjusted mean waist circumference change across the three prospective categories for the behavior. In addition to pair-wise comparisons of the adjusted means, linear trends of changes in waist circumference across the three categories of the behaviors were also examined.

Joint associations of MVPA and TV viewing time changes with waist-circumference change
Each participant was allocated to one of the nine categories of MVPA change and TV viewing time change. Adjusted mean waist circumference changes were determined for each

category, adjusting for all potential confounding variables. Also, interactions between MVPA and TV viewing time in their association with waist circumference were examined. Analyses adjusted for baseline MVPA, TV viewing time, waist circumference, and also gender, age, education, employment status, income, antihypertensive medication and lipid-lowering medication, alcohol consumption, total energy intake, and physical functioning.

Results

Descriptive characteristics of the sample

Table 1 presents the study sample characteristics. Mean MVPA and TV viewing time increased from 4.75 to 5.10 $h \cdot wk^{-1}$ and from 11.47 to 12.58 $h \cdot wk^{-1}$ (from 1.64 to 1.80 $h \cdot day^{-1}$) respectively over the initial five years. Waist circumference increased from 88.5 to 94.0 cm over the 12-year study period (Table 2).

INSERT TABLES 1 AND 2 ABOUT HERE

Individual associations MVPA and TV viewing time changes (continuous) with waist circumference change

Results for the associations of continuous change in MVPA and TV viewing time over the initial five years with 12-year change in waist circumference are presented in Table 3. An increase in MVPA (1 $h \cdot wk^{-1}$) attenuated the increase in waist circumference observed over the 12-year period. This association was unchanged after additional adjustment for total energy intake, physical functioning, and TV viewing time (Table 3, Model B, C, D, $p<0.001$). Every 1-hour increase in MVPA per week for the initial 5 years was associated with an average 0.13 cm decrease in waist circumference over 12 years. An increase in TV viewing time (1 $h \cdot wk^{-1}$)

was significantly associated with an increase in waist circumference over the 12 year period. This association remained statistically significant after adjustment for dietary behavior, physical functioning, and MVPA although these variables slightly attenuated the effects of TV viewing time on waist circumference (Table 3, Model B, C, D, p=<0.05). Every 1-hour increase in TV viewing time per week for the initial 5 years was associated with a 0.035 cm increase in waist circumference over 12 years.

INSERT TABLE 3 ABOUT HERE

Associations of MVPA and TV viewing time changes (categorical) with waist circumference change

Figures 1 and 2 show 12-year changes in waist circumference in relation to categories of change in MVPA and TV viewing time in the initial 5 years. Results are shown after adjustment for potential confounders and for the counterpart behavior (MVPA in the case of TV viewing time; TV viewing time in the case of MVPA – Model D). Those who did not change MVPA and those who increased MVPA. increased their waist circumference significantly less than those whose MVPA decreased ($p<0.05$). Change in waist circumference among those who did not change MVPA was also significantly lower compared with those whose MVPA decreased ($p<0.05$). A dose-response relationship was observed across the three MVPA categories (p for trend< 0.001). Compared with those who decreased their TV viewing time, those who increased their TV viewing time did not have statistically-significant increases in waist circumference (p=0.054). The trend across the three TV viewing time categories was also non-significant (p for trend =0.06).

INSERT FIGURES 1 and 2 ABOUT HERE

Joint associations MVPA and TV viewing time changes with waist circumference change

Figure 3 shows adjusted mean changes in waist circumference for the joint categories of MVPA and TV viewing time changes. Although the influences of MVPA on waist circumference change were apparently stronger than those of TV viewing time, the combination of decreased MVPA and increased TV viewing time were strongest with respect to increases in waist circumference over the 12-years. For example, those who decreased MVPA and increased TV viewing time increased their waist circumference about 2.1 cm more than those who increased MVPA and decreased TV viewing time (the reference group; p=0.001). There was no statistically-significant interaction between change in MVPA and TV viewing time on 12-year changes with waist circumference.

INSERT FIGURE 3 ABOUT HERE

Findings on the independent and joint associations of continuous change in MVPA and TV viewing time over the initial five years with 12-year change in BMI. Similar to the findings for waist circumference change, significant associations of BMI changes with the exposure measures were observed. However, the associations were slightly weaker than were those found for waist circumference change.

Discussion

These findings help to confirm and extend previous prospective and cross-sectional studies examining the combined association of TV viewing time and MVPA with obesity outcomes, suggesting that there is evidence accumulative effects from declines in MVPA and increases in sedentary behavior on obesity markers (18, 25, 29) and also suggesting potentially limited mitigating capacity of MVPA on the adverse effects of TV viewing time (18, 25, 29). The relationships that we identified were largely independent of potential confounding factors, including medication use, diet, and physical functioning. MVPA emerged as an apparently more significant influence on waist circumference increase than did TV viewing time.

A small number of prospective studies have previously examined simultaneously the associations of MVPA and sedentary behaviors with adiposity outcomes (5, 18, 29, 33). However, these studies used a behavior measured at a single point in time or a concurrent measure of behavior, which is not able to directly assess the effect of continued exposure of behaviors or the potential direction of causality. The present study extended upon these findings by using multiple time-point measures of relevant behaviors, and found that preceding changes in MVPA and TV viewing time can impact on the subsequent changes in central adiposity.

It is important to note that previous prospective studies have shown that baseline adiposity status or adiposity increases can predict future sedentary behavior or physical activity levels (17, 21). It is plausible that physical activity, sedentary behavior, and adiposity could have bidirectional relationships. These relationships are complex, because pre-existing adiposity may also reflect the outcomes of previous long-term physical activity and sedentary behavior patterns. Further evidence from prospective studies with repeated measures of the exposure and outcome variables would help to more-definitively characterize the direction of such associations.

Distinct associations of MVPA and sedentary behavior with regional fat deposition may be one of possible reasons that might account for the stronger associations with MVPA than TV viewing time we have observed. Previous studies have shown MVPA or leisure-time physical activity to be negatively associated with visceral and subcutaneous fat, whereas total sedentary time was not associated with these types of fat regions but rather pericardial fat (22, 26). A Canadian prospective study found that increases in sedentary behavior from baseline to follow-up was associated with increases in waist circumference but not visceral adiposity (32), implying that other factors that can influence waist circumference, such as overall adiposity, may be more closely related to sedentary behavior. Thus, further research is needed to further explore these mechanisms.

Our findings may have some relevant implications from a public health perspective. Regardless of initial levels of MVPA and TV viewing time, the risk of long-term waist circumference increases could be partly controlled by relatively small, gradual changes in these two health behaviors (increasing about 10 or more minutes of MVPA or decreasing 60 minutes of TV viewing per day within a long time span of five years). Considering the consistent observations of progressive increases in average waist circumference in Australia (2), there is likely to be obesity prevention benefit from population-based strategies to increase MVPA and to reduce sedentary behaviors.

Strengths of our study included a large sample size, wide age range of the cohort, prospective design, multiple follow-ups, and the objective measurement of waist circumference. Taking account of a number of potential confounders, notably medication use, total energy intake, alcohol consumption, and physical functioning is a further strength. Limitations include TV viewing time and physical activity exposure measures being based on self-report, which could be subject to recall error and social desirability bias. This could potentially reduce the association between exposure and outcome variables due to regression dilution bias (19). In the assessment of physical activity level, domestic and occupational physical activities were not included. Furthermore, this study only measured TV viewing, not other types of sedentary behaviour, such as workplace sitting, car driving, and computer uses. Though TV viewing time may be reflective of a broader sedentary lifestyle, it is not a measure of total sedentary behavior. Thus, caution is needed in generalizing these findingsto what may be the case if all types of sedentary behavior were to be included (34). As we document, 61% of the baseline sample did not return for the wave 2 and wave 3 visits. This loss to follow-up was not completely at random, which may have biased aspects of the findings that we have reported. Compared to the original baseline sample, those followed up were more likely to be highly educated, employed and earning higher income, less likely to be taking antihypertensive medication, were younger, had a lower waist circumference, watched less TV, and had higher physical functioning

In conclusion, within the background of an average 5.5cm increase in waist circumference over 12 years in this sample of Australian adults, initial 5-year decreases in MVPA and increases in TV viewing time were associated with greater waist circumference increases at 12 years regardless of the initial levels of MVPA and TV viewing time. Specifically, a stronger association was observed for MVPA changes. The combination of reductions in MVPA and increases in TV viewing time during the initial 5 year observation period, was predictive of waist circumference increases; compared to those who increased MVPA and reduced TV viewing time, those who reduced MVPA by 1 hour/week or more and increased TV viewing time by 3.5 hour/week (0.5 hour/day) or more had a 2 cm greater increase in waist circumference. For understanding and influencing age-related increases in waist circumference – a marker of central adiposity and associated cardio-metabolic health risk – there is the need to consider both physical activity and sedentary behaviors such as TV viewing time.

Acknowledgements

The AusDiab study co-coordinated by the Baker IDI Heart and Diabetes Institute, gratefully acknowledges the support and assistance given by:

K Anstey, B Atkins, B Balkau, E Barr, A Cameron, S Chadban, M de Courten, D Dunstan, A Kavanagh, D Magliano, S Murray, N Owen, K Polkinghorne, J Shaw, T Welborn, P Zimmet and all the study participants.

Also, for funding or logistical support, we are grateful to: National Health and Medical Research Council (NHMRC grants 233200 and 1007544), Australian Government Department of Health and Ageing, Abbott Australasia Pty Ltd, Alphapharm Pty Ltd, Amgen Australia, AstraZeneca, Bristol-Myers Squibb, City Health Centre-Diabetes Service-Canberra, Department of Health and Community Services - Northern Territory, Department of Health and Human Services – Tasmania, Department of Health – New South Wales, Department of Health – Western Australia, Department of Health – South Australia, Department of Human Services – Victoria, Diabetes Australia, Diabetes Australia Northern Territory, Eli Lilly Australia, Estate of the Late Edward Wilson, GlaxoSmithKline, Jack Brockhoff Foundation, Janssen-Cilag, Kidney Health Australia, Marian & FH Flack Trust, Menzies Research Institute, Merck Sharp & Dohme, Novartis Pharmaceuticals, Novo Nordisk Pharmaceuticals, Pfizer Pty Ltd, Pratt Foundation, Queensland Health, Roche Diagnostics Australia, Royal Prince Alfred Hospital, Sydney, Sanofi Aventis, sanofi-synthelabo, the Victorian Government's OIS Program, and 2015-2019 MEXT-Supported Program for the Strategic Research Foundation at Private Universities (S1511017).

N Owen is supported by NHMRC Program Grant (NHMRC # 569940), a Senior Principal Research Fellowship (NHMRC #1003960) and by the Victorian Government's Operational Infrastructure Support Program. J Salmon is supported by a NHMRC Principal Research Fellowship (#APP1026216). D W Dunstan is supported by an Australian Research Council

Future Fellowship (FT100100918) and the Victorian Government's Operational Infrastructure Support Program. The results of the present study do not constitute endorsement by ACSM. The authors would like to acknowledge Parneet Sethi for useful discussions on this work.

Conflicts of Interest Statement

The authors have no conflicts of interest to disclose.

References

1. Armstrong T, Bauman A, Davies J. *Physical Activity Patterns of Australian adults. Results of the 1999 National Physical Activity Survey.*Canberra: Australian Institute of Health and Welfare; 2000; [cited 2015 March 31]. Available from: http://aihw.gov.au/WorkArea/DownloadAsset.aspx?id=6442454841.
2. Australian Bureau of Statistics. *Austrlaian Health Survey: First Results, 2011-12* [Internet]. Canberra: Australian Bureau of Statistics; [cited 2012 Oct 29]. Available from: http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/6A2304311987758FCA257AA30014C0C6?opendocument
3. Australian Bureau of Statistics. *Austrlaian Health Survey: Updated Results, 2011–12* [Internet]. Canberra: Australian Bureau of Statistics; [cited 2013 June 7]. Available from: http://www.abs.gov.au/ausstats/abs@.nsf/mf/4364.0.55.003
4. Australian Institute of Health and Welfare. *The Active Australia Survey. A Guide and Manual for Implementation, Analysis and Reporting,* Canberr: Australian Institute of Health and Welfare; 2003; [cited 2015 March 31]. Available from: http://www.aihw.gov.au/WorkArea/DownloadAsset.aspx?id=6442454895

5. Blanck HM, McCullough ML, Patel AV, et al. Sedentary behavior, recreational physical activity, and 7-year weight gain among postmenopausal U.S. women. *Obesity (Silver Spring)*. 2007;15(6):1578-1588.
6. Bouchard C. BMI, fat mass, abdominal adiposity and visceral fat: where is the 'beef'? *Int J Obes (Lond)*. 2007;31(10):1552-1553.
7. Britton KA, Lee IM, Wang L, et al. Physical activity and the risk of becoming overweight or obese in middle-aged and older women. *Obesity (Silver Spring)*. 2012;20(5):1096-1103.
8. Brown WJ, Trost SG, Bauman A, Mummery K, Owen N. Test-retest reliability of four physical activity measures used in population surveys. *J Sci Med Sport.* 2004;7(2):205-215.
9. Calle EE, Rodriguez C, Walker-Thurmond K, Thun MJ. Overweight, obesity, and mortality from cancer in a prospectively studied cohort of U.S. adults. *N Engl J Med.* 2003;348(17):1625-38.
10. Dalton M, Cameron AJ, Zimmet PZ, et al. Waist circumference, waist-hip ratio and body mass index and their correlation with cardiovascular disease risk factors in Australian adults. *J Intern Med.* 2003;254(6):555-563.
11. Dunstan DW, Salmon J, Owen N, et al. Associations of TV viewing and physical activity with the metabolic syndrome in Australian adults. *Diabetologia.* 2005;48(11):2254-2261.
12. Dunstan DW, Zimmet PZ, Welborn TA, et al. The Australian Diabetes, Obesity and Lifestyle Study (AusDiab)--methods and response rates. *Diabetes Res Clin Pract.* 2002;57(2):119-129.
13. Dunton GF, Berrigan D, Ballard-Barbash R, Graubard B, Atienza AA. Joint associations of physical activity and sedentary behaviors with body mass index: results from a time use survey of US adults.. *Int J Obes (Lond).* 2009;33(12):1427-1436.

14. Ekelund U, Besson H, Luan J, et al. Physical activity and gain in abdominal adiposity and body weight: prospective cohort study in 288,498 men and women. *Am J Clin Nutr.* 2011;93(4):826-835.
15. Elobeid MA, Desmond RA, Thomas O, Keith SW, Allison DB. Waist circumference values are increasing beyond those expected from BMI increases. *Obesity (Silver Spring).* 2007;15(10):2380-2383.
16. Finucane MM, Stevens GA, Cowan MJ, et al. National, regional, and global trends in body-mass index since 1980: systematic analysis of health examination surveys and epidemiological studies with 960 country-years and 9.1 million participants. *Lancet.* 2011;377(9765):557-567.
17. Golubic R, Ekelund U, Wijndaele K, et al. Rate of weight gain predicts change in physical activity levels: a longitudinal analysis of the EPIC-Norfolk cohort. *Int J Obes (Lond).* 2013;37(3):404-409.
18. Hu FB, Li TY, Colditz GA, Willett WC, Manson JE. Television watching and other sedentary behaviors in relation to risk of obesity and type 2 diabetes mellitus in women. *JAMA.* 2003;289(14):1785-1791.
19. Hutcheon JA, Chiolero A, Hanley JA. Random measurement error and regression dilution bias. *BMJ.* 2010;340:c2289.
20. Ireland P, Jolley D, Giles G, et al. Development of the Melbourne FFQ: a food frequency questionnaire for use in an Australian prospective study involving an ethnically diverse cohort. *Asia Pac J Clin Nutr.* 1994;3:19–31.
21. Lakerveld J, Dunstan D, Bot S, et al. Abdominal obesity, TV-viewing time and prospective declines in physical activity. *Prev Med.* 2011;53(4-5):299-302.
22. Larsen BA, Allison MA, Kang E, et al. Associations of physical activity and sedentary behavior with regional fat deposition. *Med Sci Sports Exerc.* 2013;46(3):520-528.

23. Liao Y, Harada K, Shibata A, et al. Joint associations of physical activity and screen time with overweight among japanese adults. *Int J Behav Nutr Phys Act.* 2011;8:131.
24. Magliano DJ, Barr EL, Zimmet PZ, et al. Glucose indices, health behaviors, and incidence of diabetes in Australia: the Australian Diabetes, Obesity and Lifestyle Study. *Diabetes Care.* 2008;31(2):267-272.
25. Maher CA, Mire E, Harrington DM, Staiano AE, Katzmarzyk PT. The independent and combined associations of physical activity and sedentary behavior with obesity in adults: NHANES 2003-06. *Obesity (Silver Spring).* 2013; 21(12):730-737.
26. McGuire KA, Ross R. Incidental physical activity and sedentary behavior are not associated with abdominal adipose tissue in inactive adults. *Obesity (Silver Spring).* 2012;20(3):576-82.
27. Ogden CL, Carroll MD, Kit BK, Flegal KM. Prevalence of childhood and adult obesity in the United States, 2011-2012. *JAMA.* 2014;311(8):806-14.
28. Owen N. Sedentary behavior: understanding and influencing adults' prolonged sitting time. *Prev Med.* 2012;55(6):535-539.
29. Raynor DA, Phelan S, Hill JO, Wing RR. Television viewing and long-term weight maintenance: results from the National Weight Control Registry. *Obesity (Silver Spring).* 2006;14(10):1816-1824.
30. Salmon J, Bauman A, Crawford D, Timperio A, Owen N. The association between television viewing and overweight among Australian adults participating in varying levels of leisure-time physical activity. *Int J Obes Relat Metab Disord.* 2000;24(5):600-606.
31. Salmon J, Owen N, Crawford D, Bauman A, Sallis JF. Physical activity and sedentary behavior: a population-based study of barriers, enjoyment, and preference. *Health Psychol.* 2003;22(2):178-188.

32. Saunders TJ, Tremblay MS, Despres JP, Bouchard C, Tremblay A, Chaput JP. Sedentary behaviour, visceral fat accumulation and cardiometabolic risk in adults: a 6-year longitudinal study from the Quebec Family Study. *PLoS One.* 2013;8(1):e54225.
33. Sternfeld B, Wang H, Quesenberry CP, Jr., et al. Physical activity and changes in weight and waist circumference in midlife women: findings from the Study of Women's Health Across the Nation. *Am J Epidemiol.* 2004;160(9):912-922.
34. Sugiyama T, Healy GN, Dunstan DW, Salmon J, Owen N. Is television viewing time a marker of a broader pattern of sedentary behavior? *Ann Behav Med.* 2008;35(2):245-250.
35. Sugiyama T, Healy GN, Dunstan DW, Salmon J, Owen N. Joint associations of multiple leisure-time sedentary behaviours and physical activity with obesity in Australian adults. *Int J Behav Nutr Phys Act.* 2008;5:35.
36. Thorp AA, Healy GN, Owen N, et al. Deleterious associations of sitting time and television viewing time with cardiometabolic risk biomarkers: Australian Diabetes, Obesity and Lifestyle (AusDiab) study 2004-2005. *Diabetes Care.* 2010;33(2):327-334.
37. Thorp AA, Owen N, Neuhaus M, Dunstan DW. Sedentary behaviors and subsequent health outcomes in adults a systematic review of longitudinal studies, 1996-2011. *Am J Prev Med.* 2011;41(2):207-215.
38. Timperio A, Salmon J, Bull F, Rosenberg M. *Validation of Physical Activity Questions for Use in Australian Population Surverys.* Canberra: Commonwealth Department of Aging; 2002. p.25-27.
39. Walls HL, Stevenson CE, Mannan HR, et al. Comparing trends in BMI and waist circumference. *Obesity (Silver Spring).* 2011;19(1):216-219.
40. Ware JE, Jr., Sherbourne CD. The MOS 36-item short-form health survey (SF-36). I. Conceptual framework and item selection. *Med Care.* 1992;30(6):473-83.

41. Whitlock G, Lewington S, Sherliker P, et al. Body-mass index and cause-specific mortality in 900 000 adults: collaborative analyses of 57 prospective studies. *Lancet.* 2009;373(9669):1083-96.

Figure captions

Figure 1: Associations of categories of 5-year MVPA change with waist circumference change

Analysis adjusted for baseline waist circumference; baseline MVPA; gender, age, education, employment status, income, antihypertensive medication, lipid-lowering medication, alcohol consumption, total energy intake, physical functioning at baseline; and for baseline and 5-year change in TV viewing time (Model D). Data are adjusted means. *p<0.05, ***p<0.001

Figure 2: Associations of categories of 5-year TV viewing time change with waist circumference change

Analysis adjusted for baseline waist circumference; baseline TV viewing time; gender, age, education, employment status, income, antihypertensive medication, lipid-lowering medication, alcohol consumption, total energy intake, physical functioning at baseline; and for baseline and 5-year change in MVPA (Model D). Data are adjusted means. †p<0.1.

Figure 3: Associations of joint categories of MVPA and TV viewing time changes with waist circumference change

Analysis adjusted for baseline waist circumference; baseline MVPA and TV viewing time; gender, age, education, employment status, income, antihypertensive medication, lipid-lowering medication, alcohol consumption, total energy intake and physical functioning at baseline. Data are adjusted means. Significant differences from the reference category (increased MVPA and decreased TV viewing time) are shown. †p<0.1, *p<0.05, **p<0.01

Tables

Table 1 Sample characteristics at baseline (n=3261)

	% or mean (SD)
Gender (% men)	43.5
Age	48.3 (10.5)
Educational attainment (% with high school completion)	53.3
Household Income	
% < $32,200 p.a.	27.3
% => $32,200 p.a.	71.8
% Refused answer or missing	0.9
Work status (%working)	74.3
Antihypertensive medication (% yes)	7.8
Lipid-lowering medication (%yes)	4.6
Total energy intake (KJ·d^{-1})	8229.4 (3137.8)
Total alcohol consumption (g·d^{-1})	14.0 (17.4)
SF-36 physical functioning score	52.1 (6.3)

Table 2 Descriptive information on MVPA, TV viewing time and waist circumference

	n (%) or means (SD)
MVPA at baseline ($h \cdot wk^{-1}$)	4.75 (5.50)
MVPA at Wave 2 ($h \cdot wk^{-1}$)	5.10 (5.59)
5-year MVPA change ($h \cdot wk^{-1}$)	0.36 (6.01)
5-year MVPA change category[a]	
Decreased	1009 (30.9)
No change	1018 (31.2)
Increased	1234 (37.8)
TV time at baseline ($h \cdot wk^{-1}$)	11.47 (8.45)
TV time at Wave 2 ($h \cdot wk^{-1}$)	12.58 (8.92)
5-year TV time change ($h \cdot wk^{-1}$)	1.10 (8.28)
5-year TV time change category[b]	
Decreased	734 (22.5)
No change	1428 (43.8)
Increased	1099 (33.7)
Waist circumference at baseline (cm)	88.5 (13.1)
Waist circumference at Wave 3 (cm)	94.0 (14.0)
12-year waist circumference change (cm)	5.5 (7.7)

[a] decreased (> -1.0 $h \cdot wk^{-1}$); no change (0±1.0 $h \cdot wk^{-1}$); increased (> +1.0 $h \cdot wk^{-1}$)

[b] decreased (> -3.5 $h \cdot wk^{-1}$); no change (0±3.5 $h \cdot wk^{-1}$); increased (> +3.5 $h \cdot wk^{-1}$)

Table 3 Associations of 5-year change in MVPA (1 h·wk^{-1}) and TV viewing time (1 h·wk^{-1}; continuous) with 12-year change in waist circumference (n=3261)

		Unstandardised *b* Coefficients (cm)	95% CI	p
5 year-change in MVPA	Model A	-0.127	-0.177, -0.077	<0.001
	Model B	-0.129	-0.178, -0.079	<0.001
	Model C	-0.127	-0.177, -0.077	<0.001
	Model D	-0.126	0.176, -0.076	<0.001
5 year-change in TV viewing	Model A	0.038	0.004, 0.072	0.029
	Model B	0.038	0.004, 0.072	0.031
	Model C	0.037	0.003, 0.071	0.034
	Model D	0.035	0.001, 0.069	0.042

(Coefficients correspond to 1 h·wk^{-1} of MVPA change and 1 h·wk^{-1} of TV viewing time change)

Model A: 5-year change in MVPA and in TV viewing time, adjusted for baseline behaviour (MVPA or TV viewing time), gender, age, education, employment status, income, antihypertensive medication, and lipid-lowering medication

Model B: Adding baseline alcohol consumption and total energy intake into Model A

Model C: Adding baseline Physical Functioning (SF-36) into Model B

Model D: Adding baseline and 5-year change in TV viewing time into Model C for MVPA change; adding baseline and 5-year change in MVPA into Model C for TV viewing time change

Figures

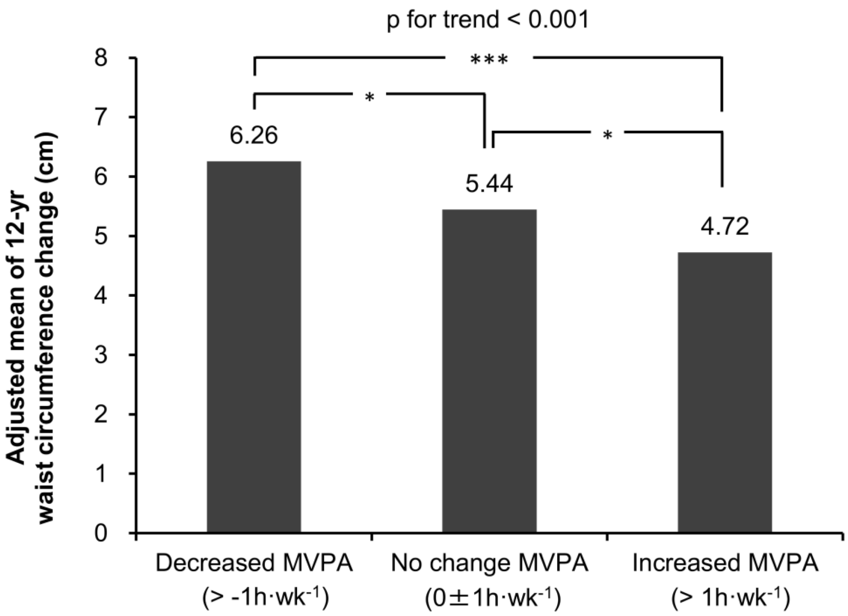

Figure 1: Associations of categories of 5-year MVPA change with waist circumference change

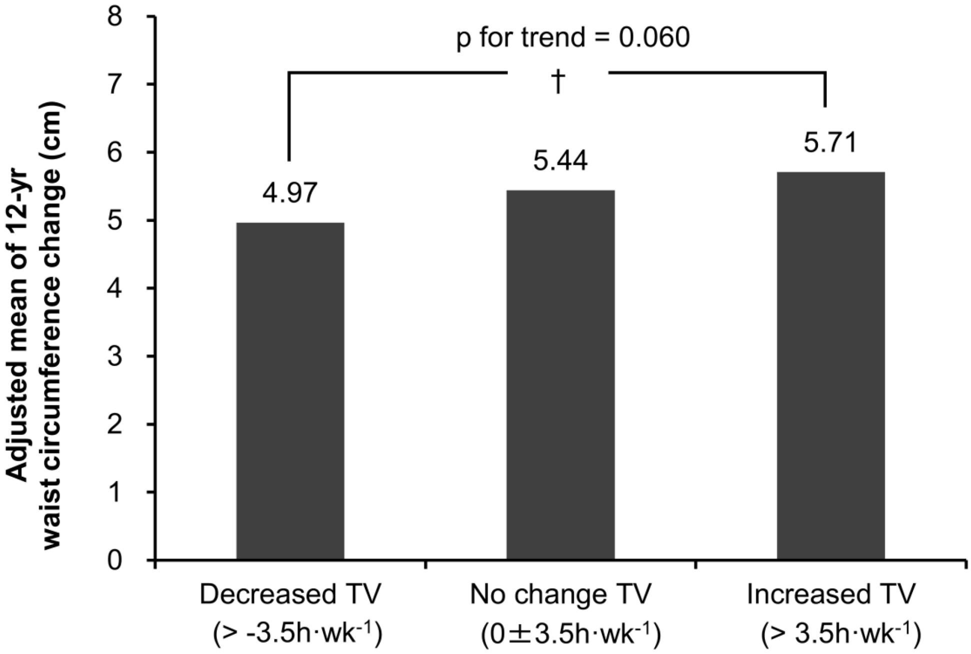

Figure 2: Associations of categories of 5-year TV viewing time change with waist circumference change

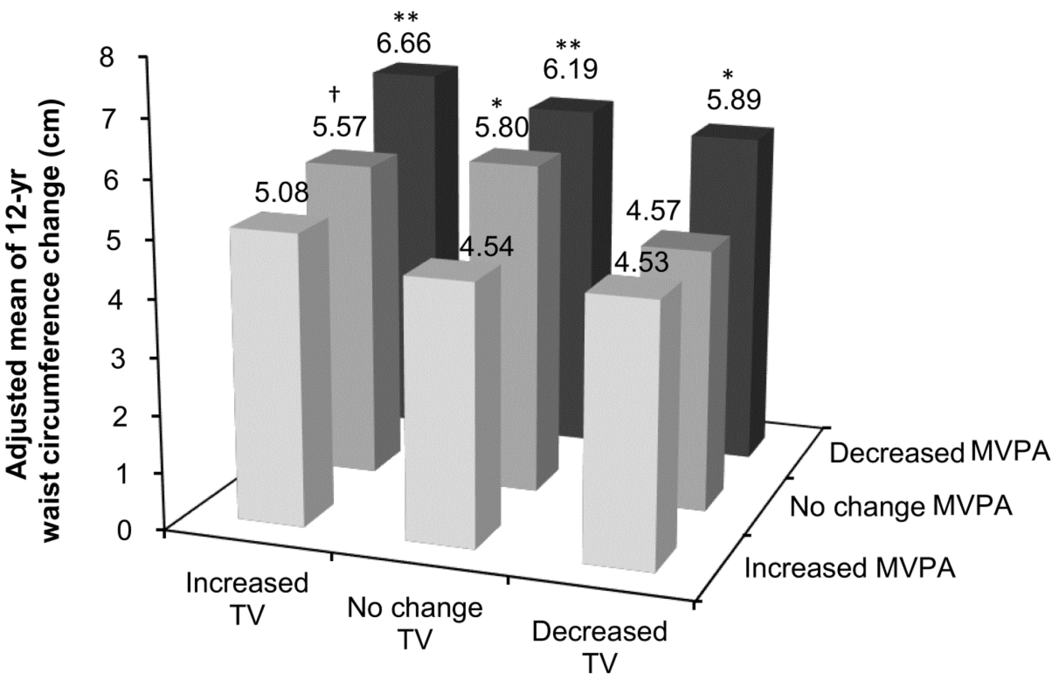

Figure 3: Associations of joint categories of MVPA and TV viewing time changes with waist circumference change