Deleterious Associations of Sitting Time and Television Viewing Time With Cardiometabolic Risk Biomarkers

Australian Diabetes, Obesity and Lifestyle (AusDiab) study 2004–2005

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OBJECTIVE — We examined the associations of sitting time and television (TV) viewing time with continuously measured biomarkers of cardio-metabolic risk in Australian adults.

RESEARCH DESIGN AND METHODS — Waist circumference, BMI, resting blood pressure, triglycerides, HDL cholesterol, fasting and 2-h postload plasma glucose, and fasting insulin were measured in 2,761 women and 2,103 men aged ≥30 years (mean age 54 years) without clinically diagnosed diabetes from the 2004–2005 Australian Diabetes, Obesity and Lifestyle (AusDiab) study. Multivariate linear regression analyses examined associations of self-reported sitting time and TV viewing time (hours per day) with these biomarkers, adjusting for potential confounding variables.

RESULTS — For both women and men, sitting time was detrimentally associated with waist circumference, BMI, systolic blood pressure, fasting triglycerides, HDL cholesterol, 2-h postload plasma glucose, and fasting insulin (all $P < 0.05$), but not with fasting plasma glucose and diastolic blood pressure (men only). With the exception of HDL cholesterol and systolic blood pressure in women, the associations remained significant after further adjustment for waist circumference. TV viewing time was detrimentally associated with all metabolic measures in women and all except HDL cholesterol and blood pressure in men. Only fasting insulin and glucose (men only) remained deleteriously associated with TV viewing time after adjustment for waist circumference.

CONCLUSIONS — In women and men, sitting time and TV viewing time were deleteriously associated with cardio-metabolic risk biomarkers, with sitting time having more consistent associations in both sexes and being independent of central adiposity. Preventive initiatives aimed at reducing sitting time should focus on both nonleisure and leisure-time domains.

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S itting is ubiquitous in adults' daily routines: watching television (TV), using computers, performing desk-bound occupational tasks, and commuting by automobile (1). The majority of studies on the metabolic consequences of sitting time have focused on associations with leisure-time sitting, primarily TV viewing time. High levels of TV viewing are associated with elevated risk of obesity, type 2 diabetes, and abnormal glucose metabolism (2–4); additionally, detrimental associations have been observed with continuous measures of glucose and insulin in healthy adults (5) and with waist circumference and systolic blood pressure in physically active men and women (4). Associations have generally been stronger and more consistent in women than in men (2,3).

Prolonged sitting time is highly prevalent in contexts other than domestic TV viewing, including occupational sitting, which has been shown to be positively associated with a higher BMI, particularly in men (6). Studies examining sitting time across the whole day (including both leisure- and nonleisure contexts) have reported significant associations with overweight and obesity and with weight gain (7,8). However, the extent to which overall sitting time is associated with biomarkers of cardiovascular and diabetes risk has not been investigated. Furthermore, the extent to which both sitting and TV viewing time influence continuous measures of metabolic risk in the same population has not been explored.

We examined concurrently the associations of sitting time and TV viewing time with biomarkers of cardio-metabolic risk (waist circumference, BMI, systolic and diastolic blood pressure, fasting serum triglycerides, HDL cholesterol, fasting and 2-h postload plasma glucose, and fasting serum insulin) in a large population-based sample of Australian women and men without diagnosed diabetes.

RESEARCH DESIGN AND METHODS — The Australian Diabetes, Obesity and Lifestyle (AusDiab) study was a population-based survey of 11,247 Australians aged ≥25 years that was conducted to estimate the prevalence of diabetes and its associated health conditions. Baseline cardio-metabolic measurements were collected from participants in 1999/2000 with follow-up measurements undertaken in 2004/2005 (AusDiab 2). The study methods and sample representativeness for participants involved in the 1999/2000 baseline assessment have been previously reported (9). The present analyses use data collected from 6,400 participants (59.3% of baseline sample) who took part in AusDiab 2 and attended

Table 1—*Selected characteristics of the 2004–2005 AusDiab population according to sex*

	Women	Men	P
n	2,761	2,103	—
Age (years)	54.8 (54.3–55.2)	54.9 (54.4–55.5)	0.70
Completed university/further education (%)	64.5 (62.7–66.3)	69.4 (67.4–71.3)	<0.001
Current smoker (%)	7.2 (6.2–8.1)	10.5 (9.2–11.8)	<0.001
Employed (%)	59.5 (57.7–61.3)	71.8 (69.8–73.7)	<0.001
Parental history of diabetes (%)	20.4 (18.9–21.9)	17.6 (16.0–19.3)	0.02
Total energy intake (KJ/day)	6,925 (6,845–7,005)	9,216 (9,099–9,333)	<0.001
Antihypertensive medication (%)	19.8 (18.3–21.3)	17.8 (16.2–19.5)	0.09
Lipid-lowering medication (%)	11.0 (9.9–12.2)	13.3 (11.9–14.8)	0.02
Total alcohol (ml/day)	9.31 (8.83–9.78)	20.3 (19.4–21.2)	<0.001
Diet quality index (DQI-R, 1–100)*	66.5 (66.1–67.0)	61.5 (61.0–62.0)	<0.001
Leisure-time physical activity (h/day)	0.66 (0.63–0.69)	0.77 (0.73–0.80)	<0.001
Sitting time (h/day)	5.19 (5.09–5.29)	5.71 (5.60–5.82)	<0.001
TV viewing time (h/day)	1.73 (1.68–1.78)	1.89 (1.84–1.94)	<0.001
Waist circumference (cm)	86.5 (86.0–87.0)	98.1 (97.6–98.6)	<0.001
BMI (kg/m^2)	27.3 (27.0–27.5)	27.7 (27.5–27.8)	0.003
Systolic blood pressure (mmHg)	119.4 (118.6–120.1)	126.9 (126.2–127.7)	<0.001
Diastolic blood pressure (mmHg)	65.6 (65.2–65.9)	73.0 (72.6–73.4)	<0.001
2-h postload plasma glucose (mmol/l)	5.55 (5.50–5.61)	5.54 (5.47–5.62)	0.86
Fasting serum triglycerides (mmol/l)	1.14 (1.12–1.16)	1.39 (1.36–1.42)	<0.001
Fasting HDL cholesterol (mmol/l)	1.55 (1.53–1.56)	1.24 (1.22–1.25)	<0.001
Fasting plasma glucose (mmol/l)	5.19 (5.17–5.21)	5.44 (5.41–5.46)	<0.001
Fasting serum insulin (pmol/l)	46.9 (45.9–48.0)	52.0 (50.6–53.4)	<0.001

Data are means (95% CI) or %. Geometric means are reported for fasting triglycerides, fasting HDL cholesterol, plasma glucose, 2-h postload plasma glucose, and fasting insulin: natural log transformations of these variables were used to test for sex differences. *Based on a revised scale of 1–100, with 100 representing high diet quality.

the allocated testing site fasted. From the cohort of 6,400, we excluded those who were pregnant ($n = 18$), clinically diagnosed with diabetes ($n = 374$), had a history of cardiovascular disease ($n = 440$), reported an implausible sitting time (>18 h on a weekday or weekend day; $n = 61$), reported a mean TV viewing time (hours/day) greater than mean sitting time (hours/day; $n = 432$), reported an implausible dietary intake ($n = 257$) (10), or who had missing data for cardiometabolic measures ($n = 915$) or other variables of interest ($n = 1,440$). Exclusion criteria were not mutually exclusive, so participants could be excluded based on more than one criterion. The final sample consisted of 2,761 women and 2,103 men. The Ethics Committee of the Baker IDI Heart and Diabetes Institute approved the study, and written informed consent was obtained from all participants.

Measures and data management
Survey methods and data collection for AusDiab 2 closely replicated the baseline 1999–2000 AusDiab survey (11). Fasting (minimum of 9 h) and 2-h postload plasma glucose levels were determined by a spectrophotometric-hexokinase method; fasting serum triglycerides and HDL cholesterol were measured by enzymatic methods (Roche Modular, Roche Diagnostics, Indianapolis, IN) on an Olympus AU600 analyzer (Olympus Optical, Tokyo, Japan). Fasting serum insulin levels were determined using a human insulin-specific radioimmunoassay kit (Linco Research, St. Charles, MO). Duplicate waist circumference and triplicate resting blood pressure measurements were collected according to previously published protocols (9). Demographic (sex, age, parental history of diabetes, education, and employment status) and behavioral attributes (leisure-time physical activity, smoking status, alcohol intake, diet quality, and medications for hypertension or dyslipidemia at follow-up) of participants were assessed using interviewer-administered questionnaires. A self-administered, validated food frequency questionnaire was used to calculate habitual dietary intakes and to derive a diet quality score based on recommended daily macronutrient intakes (12).

Sitting time was determined by asking participants to report separately for a typical weekday and weekend day on the following question: "How many hours and/or minutes did you spend sitting down while doing things like visiting friends, driving, reading, watching TV, or working at a desk or a computer?" Sitting time (hours/day) was then calculated using the following formula [(weekday sitting × 5 + weekend sitting × 2)/7]. In a separate question, TV viewing time was assessed using a different recall period to that for sitting. Participants were asked to report separately across all workdays and non-workdays during the preceding 7 days via the following question: "Please estimate the total time during the last week that you spent sitting for watching TV or DVDs or playing games on the TV. This is when it was the main activity that you were doing." TV viewing time (hours/day) was then calculated using the following formula [(workdays TV viewing + non-workdays TV viewing/7].

Physical activity was assessed using the Active Australia Survey Questionnaire (13). Total leisure-time physical activity (hours/day) was calculated by methods previously described (4). Participants who reported ≥2.5 h of leisure-time physical activity per week were classified as meeting the public health guidelines for physical activity (14).

Table 2—Unstandardized regression coefficients of sitting time (h/day) and TV viewing time (h/day) with continuous metabolic risk variables for women and men

	Sitting time (h/day)		TV viewing time (h/day)	
	Women	Men	Women	Men
Waist circumference (cm)				
Model A	0.54 (0.36 to 0.73)‡	0.35 (0.17 to 0.53)‡	1.56 (1.17 to 1.95)‡	0.74 (0.35 to 1.13)‡
Model B	0.54 (0.36 to 0.73)‡	0.35 (0.17 to 0.53)‡	1.21 (0.81 to 1.61)‡	0.59 (0.20 to 0.99)†
Model D¶	0.39 (0.19 to 0.59)‡	0.30 (0.11 to 0.49)†	0.89 (0.45 to 1.32)‡	0.40 (−0.02 to 0.81)
BMI (kg/m^2)				
Model A	0.25 (0.16 to 0.33)‡	0.07 (0.01 to 0.14)*	0.65 (0.48 to 0.82)‡	0.18 (0.04 to 0.32)*
Model B	0.25 (0.17 to 0.33)‡	0.08 (0.01 to 0.14)*	0.50 (0.33 to 0.68)‡	0.15 (0.003 to 0.29)*
Model D¶	0.19 (0.11 to 0.28)‡	0.06 (−0.01 to 0.13)	0.35 (0.16 to 0.53)‡	0.11 (−0.04 to 0.26)
Systolic blood pressure (mmHg)‖				
Model A	0.38 (0.12 to 0.65)†	−0.31 (−0.57 to −0.04)*	1.40 (0.84 to 1.95)‡	0.51 (−0.07 to 1.08)
Model B	0.39 (0.13 to 0.64)†	−0.29 (−0.56 to −0.03)*	0.92 (0.36 to 1.448)‡	0.15 (−0.43 to 0.73)
Model C	0.21 (−0.04 to 0.46)	−0.40 (−0.66 to −0.14)†	0.54 (−0.004 to 1.09)	−0.02 (−0.59 to 0.55)
Model D	0.14 (−0.13 to 0.41)	−0.43 (−0.71 to −0.16)†	0.43 (−0.16 to 1.02)	0.27 (−0.33 to 0.86)
Diastolic blood pressure (mmHg)‖				
Model A	0.25 (0.11 to 0.40)‡	0.14 (−0.01 to 0.29)	0.69 (0.39 to 0.98)‡	0.27 (−0.06 to 0.60)
Model B	0.25 (0.11 to 0.39)‡	0.10 (−0.05 to 0.25)	0.59 (0.28 to 0.89)‡	0.31 (−0.02 to 0.64)
Model C	0.18 (0.04 to 0.32)*	0.04 (−0.10 to 0.19)	0.43 (0.13 to 0.73)†	0.22 (−0.11 to 0.54)
Model D	0.12 (−0.03 to 0.27)	0.02 (−0.14 to 0.17)	0.33 (0.01 to 0.65)*	0.21 (−0.13 to 0.55)
Triglycerides (mmol/l) (naturally log-transformed)§				
Model A	0.02 (0.01 to 0.02)‡	0.02 (0.01 to 0.03)‡	0.05 (0.03 to 0.06)‡	0.02 (0.01 to 0.04)†
Model B	0.02 (0.01 to 0.02)‡	0.02 (0.01 to 0.03)‡	0.04 (0.02 to 0.05)‡	0.02 (−0.001 to 0.04)
Model C	0.01 (0.005 to 0.02)‡	0.01 (0.01 to 0.02)‡	0.02 (0.01 to 0.03)†	0.01 (−0.01 to 0.03)
Model D	0.01 (0.002 to 0.01)*	0.01 (0.01 to 0.02)‡	0.01 (−0.0004 to 0.03)	0.001 (−0.02 to 0.02)
HDL cholesterol (mmol/l) (naturally log-transformed)§				
Model A	−0.005 (−0.01 to −0.001)†	−0.01 (−0.01 to −0.01)‡	−0.02 (−0.02 to −0.01)‡	−0.01 (−0.01 to 0.002)
Model B	−0.01 (−0.01 to −0.003)‡	−0.01 (−0.01 to −0.005)‡	−0.01 (−0.02 to −0.001)*	−0.005 (−0.01 to 0.004)
Model C	−0.002 (−0.01 to 0.001)	−0.01 (−0.01 to −0.003)‡	−0.001 (−0.01 to 0.01)	−0.001 (−0.01 to 0.01)
Model D	−0.003 (−0.01 to 0.001)	−0.01 (−0.01 to −0.003)‡	0.002 (−0.01 to 0.01)	0.003 (−0.005 to 0.01)
Fasting plasma glucose (mmol/l) (naturally log-transformed)				
Model A	0.001 (−0.001 to 0.002)	0.0002 (−0.002 to 0.002)	0.005 (0.002 to 0.01)†	0.01 (0.002 to 0.01)†
Model B	0.001 (−0.001 to 0.002)	0.0001 (−0.002 to 0.002)	0.004 (0.001 to 0.01)*	0.01 (0.001 to 0.01)†
Model C	−0.001 (−0.002 to 0.001)	−0.001 (−0.002 to 0.001)	0.0003 (−0.003 to 0.003)	0.004 (0.00 to 002 to 0.01)*
Model D	−0.001 (−0.002 to 0.001)	−0.001 (−0.003 to 0.0003)	0.001 (−0.002 to 0.004)	0.005 (0.001 to 0.01)*
2-h plasma glucose (mmol/l) (naturally log-transformed)				
Model A	0.01 (0.003 to 0.01)‡	0.01 (0.003 to 0.01)†	0.02 (0.01 to 0.03)‡	0.02 (0.01 to 0.03)‡
Model B	0.01 (0.004 to 0.01)‡	0.01 (0.003 to 0.01)†	0.01 (0.003 to 0.02)†	0.02 (0.01 to 0.03)‡
Model C	0.004 (0.0003 to 0.01)*	0.01 (0.001 to 0.01)*	0.004 (−0.005 to 0.01)	0.02 (0.01 to 0.03)†
Model D	0.004 (−0.0001 to 0.008)*	0.004 (−0.001 to 0.01)	0.0002 (−0.01 to 0.01)	0.01 (0.003 to 0.03)*
Fasting insulin (pmol/l) (naturally log-transformed)				
Model A	0.03 (0.02 to 0.04)‡	0.03 (0.02 to 0.04)‡	0.07 (0.05 to 0.08)‡	0.05 (0.03 to 0.07)‡
Model B	0.03 (0.02 to 0.04)‡	0.03 (0.02 to 0.04)‡	0.05 (0.03 to 0.07)‡	0.04 (0.02 to 0.06)‡
Model C	0.01 (0.01 to 0.02)‡	0.01 (0.01 to 0.02)‡	0.02 (0.001 to 0.03)*	0.02 (0.01 to 0.04)†
Model D	0.01 (0.01 to 0.02)‡	0.01 (0.004 to 0.02)†	0.01 (−0.01 to 0.02)	0.01 (−0.003 to 0.03)

Data are unstandardized β coefficients (95% CI) for forced entry linear regression. *$P \leq 0.05$; †$P \leq 0.01$; ‡$P \leq 0.001$. Mean and statistical significance for insulin, triglycerides, HDL cholesterol, and fasting and 2-h postload plasma glucose was derived from naturally log-transformed values. Sitting-time coefficients are based on self-report data using the timeframe of a "typical" weekday and weekend day, while TV viewing time is based on self-report data using the timeframe of the most recent 7 days. Model A: adjusted for age only. Model B: adjusted for age, education, parental history of diabetes, employment status, cigarette smoking, total energy intake, alcohol intake, diet quality, and total leisure-time physical activity time. Model C: adjusted for all covariates plus waist circumference. Model D: adjusted for all covariates, waist circumference, and sitting or TV viewing time. §Additional adjustment for lipid-lowering medication. ‖Additional adjustment for antihypertensive medication. ¶Model is not adjusted for waist circumference.

Statistical analysis

Statistical analyses were conducted using STATA Statistical Software Package, Release 10 (STATA, College Station, TX). Age-adjusted regression analyses were used to compare sex differences for sociodemographic, behavioral, and metabolic variables. Forced-entry linear regression models based on a priori hypotheses were used to examine the associations of sitting time and TV viewing time with individual cardio-metabolic risk variables, separately for women and for men. To account for skewness, the natural logarithm of triglycerides, HDL cholesterol, fasting

plasma glucose, 2-h postload plasma glucose, and insulin were used for regression analysis. Model A adjusted for age (years) only. Model B additionally adjusted for education (completed university or higher education), parental history of diabetes, employment status (employed part-time/full-time), current cigarette smoking, total energy (KJ/day), alcohol intake (ml/day), diet quality, and leisure-time physical activity (hours/day). Waist circumference was included in model B to examine the extent to which central adiposity may attenuate the associations of sitting time and TV viewing time with metabolic risk (model C). To examine the independent associations of sitting and TV viewing time with metabolic risk, model C was adjusted by each variable accordingly (model D). Caution is advised regarding the interpretation of model D, since sitting time and TV viewing time are two sedentary behavior markers that may act along the same causal pathway and thus cannot exhibit entirely independent associations with metabolic outcomes. Data are reported as unstandardized β regression coefficients to enable clinical interpretation of the effect of each 1 h/day increment in sitting time and TV viewing time on metabolic risk. (Data are also presented as standardized β regression coefficients in the online appendix, available at http://care. diabetesjournals.org/cgi/content/full/dc09-0493/DC1). To determine the dose-response association of sitting time and TV viewing time with cardio-metabolic risk, sex-specific quartiles of sitting and TV viewing time were derived (cut points for sitting time in women: 3.35, 4.85, and 6.78 h/day; and men: 3.78, 5.49, and 7.49 h/day; cut points for TV viewing time in women: 0.85, 1.63, and 2.49 h/day; and men: 1.06, 1.78, and 2.63 h/day). Sex differences in the associations of sitting time and TV viewing time with metabolic risk were assessed using interaction terms in linear regression models. Bivariate correlations (Spearman's *r*) assessed the relationship of daily sitting time with TV viewing time. Statistical significance was set at $P \leq 0.05$ for main effects and interactions. A global interaction P value was used to identify associations with metabolic markers that differed significantly in effect size between men and women. Sex-specific interaction P values were also used to identify significant dose-response associations across quartiles of sitting or TV viewing time.
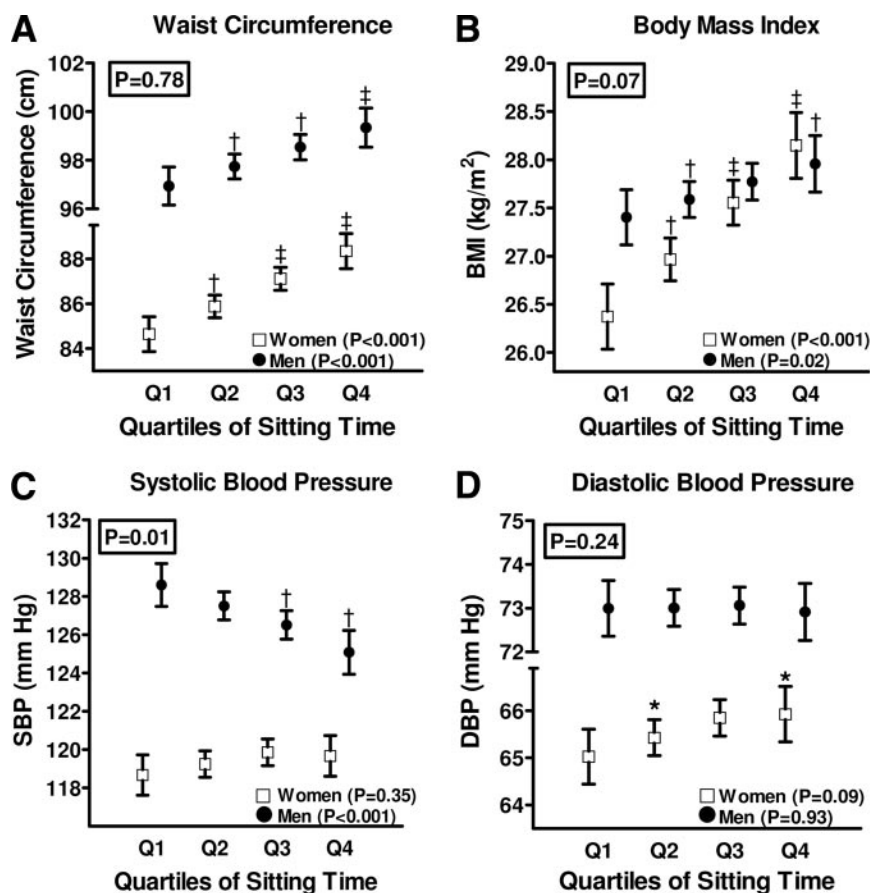
Figure 1—*Associations of individual metabolic risk variables with quartiles of sitting time for women (□) and men (●). Data are presented as marginal means (95% CI) adjusted for waist circumference (except for waist circumference and BMI outcomes), age, education, parental history of diabetes, employment status, cigarette smoking, total alcohol and total energy intake, diet quality, and leisure physical activity time. For insulin, triglycerides, HDL cholesterol, and fasting and 2-h postload plasma glucose, P values for trend and between individual quartiles of sitting time from reference category (Q1) are derived from the natural logarithm of these values. To allow for clinical interpretation, marginal means (95% CI) are presented as back-transformed log values. *P ≤ 0.05; †P ≤ 0.01; ‡P ≤ 0.001. Sex interaction P values are presented in the box. DBP, diastolic blood pressure; SBP, systolic blood pressure.*

RESULTS — Demographic, behavioral, and metabolic characteristics of participants are shown in Table 1. There was a significant positive correlation between sitting time and TV viewing time for women (Spearman's $r = 0.32$, $P < 0.001$) and men (Spearman's $r = 0.25$, $P < 0.001$).

Table 2 shows the associations of sitting time and TV viewing time with cardio-metabolic risk biomarkers.

Sitting time and metabolic risk
All metabolic biomarkers were detrimentally associated with sitting time (all $P < 0.05$), with the exception of diastolic blood pressure in men and fasting plasma glucose in men and women. Although additional adjustment for waist circumference (Table 2, model C) attenuated associations, they remained statistically

significant, except for systolic blood pressure and HDL cholesterol in women. Controlling for TV viewing time (Table 2, model D) maintained all associations, with the exception of BMI and 2-h plasma glucose in men and diastolic blood pressure in women. Significant sex interactions were observed for BMI and systolic blood pressure. Specifically, sitting time was associated with a significantly higher BMI and higher systolic blood pressure in women compared with men (Table 2).

The exclusion of participants on antihypertensive medication ($n = 921$) did not markedly attenuate the significance or effect size for associations of sitting time with blood pressure, after adjusting for leisure-time physical activity and waist circumference (model C).

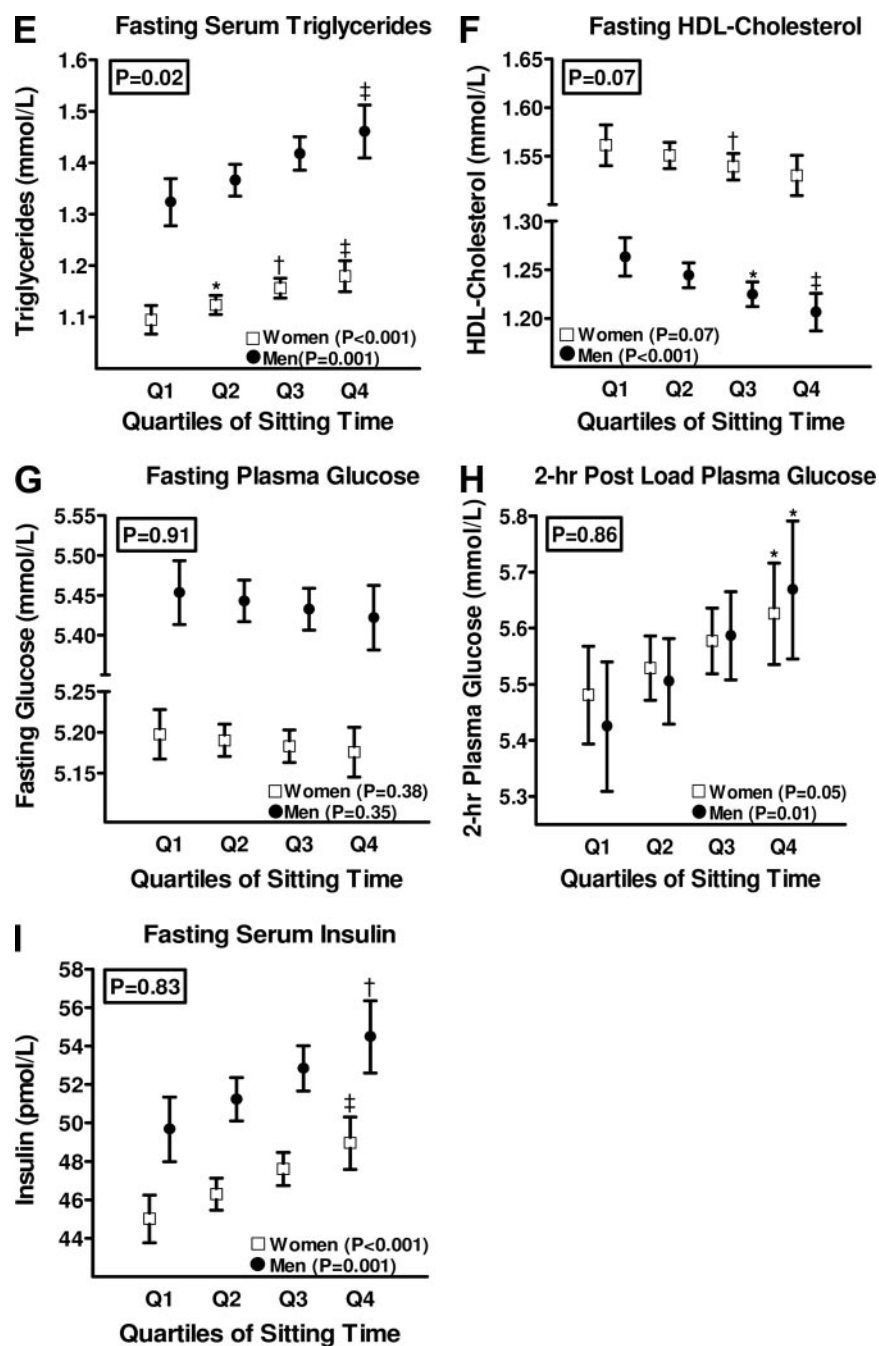Significant dose-response associations were observed between sex-specific

E Fasting Serum Triglycerides

F Fasting HDL-Cholesterol

G Fasting Plasma Glucose

H 2-hr Post Load Plasma Glucose

I Fasting Serum Insulin

Figure 1—*Continued.*

quartiles of sitting time and all cardio-metabolic risk outcomes, with the exception of diastolic blood pressure and fasting plasma glucose in men and women (Fig. 1*D* and *G*) and systolic blood pressure and HDL cholesterol in women (Fig. 1*C* and *F*). Significant sex interactions were observed for dose-response associations of sitting time with systolic blood pressure and triglycerides. As shown in Fig. 1, the dose-response association for sitting time was more pronounced in men than in women.

TV viewing time and metabolic risk
TV viewing time was detrimentally associated with waist circumference, BMI, glucose (fasting and 2-h postload), and fasting insulin in both men and women (Table 2, model B). Additionally, in women only, significant detrimental associations were also observed with blood pressure, triglycerides, and HDL cholesterol. Although attenuated, the associations remained significant for men after the inclusion of waist circumference into the model (Table 2, model *C*); for women,

only diastolic blood pressure, triglycerides, and fasting insulin remained statistically significant. Adjustment for total sitting time (Table 2, model D) attenuated all associations observed, except glucose (fasting and postload) in men and waist circumference, BMI, and diastolic blood pressure in women.

Sex interactions with TV viewing time were significant for waist circumference, BMI, systolic blood pressure, triglycerides, and 2-h postload glucose. Specifically, 1-h increments in TV viewing time were associated with a greater waist circumference, BMI, systolic blood pressure, and triglycerides in women and greater 2-h postload glucose in men.

Only BMI, diastolic blood pressure, and triglycerides in women (Fig. 2*B*, *D*, and *E*) and 2-h postload glucose and fasting insulin in men had significant dose-response associations with sex-specific quartiles of TV viewing time (Fig. 2*H* and *I*). Only waist circumference (Fig. 2*A*) exhibited a significant dose-response association with quartiles of TV viewing time in both men and women. Significant sex interactions were observed for waist circumference, BMI, triglycerides, and 2-h postload glucose. As shown in Fig. 2, the dose-response associations of TV time with waist circumference, BMI, and triglycerides were significantly greater in women; for 2-h postload glucose, the association was more pronounced in men.

As has been previously reported for TV viewing time (4), we examined associations of sitting time with cardio-metabolic variables in those who specifically met the minimum physical activity public health guideline of ≥2.5 h/week. For the 1,544 women and 1,278 men who met the guideline, all metabolic variables (except blood pressure and fasting plasma glucose) were detrimentally associated with sitting time, independent of leisure-time physical activity time (model B). With the exception of HDL cholesterol in women, adjustment for waist circumference maintained all deleterious associations (see online appendix).

CONCLUSIONS — In this population-based sample of Australian adults, sitting time and TV viewing time were deleteriously associated with several biomarkers of cardio-metabolic risk, independent of leisure-time physical activity (and also independent of waist circumference for sitting time). This is the first study to report the associations of sitting
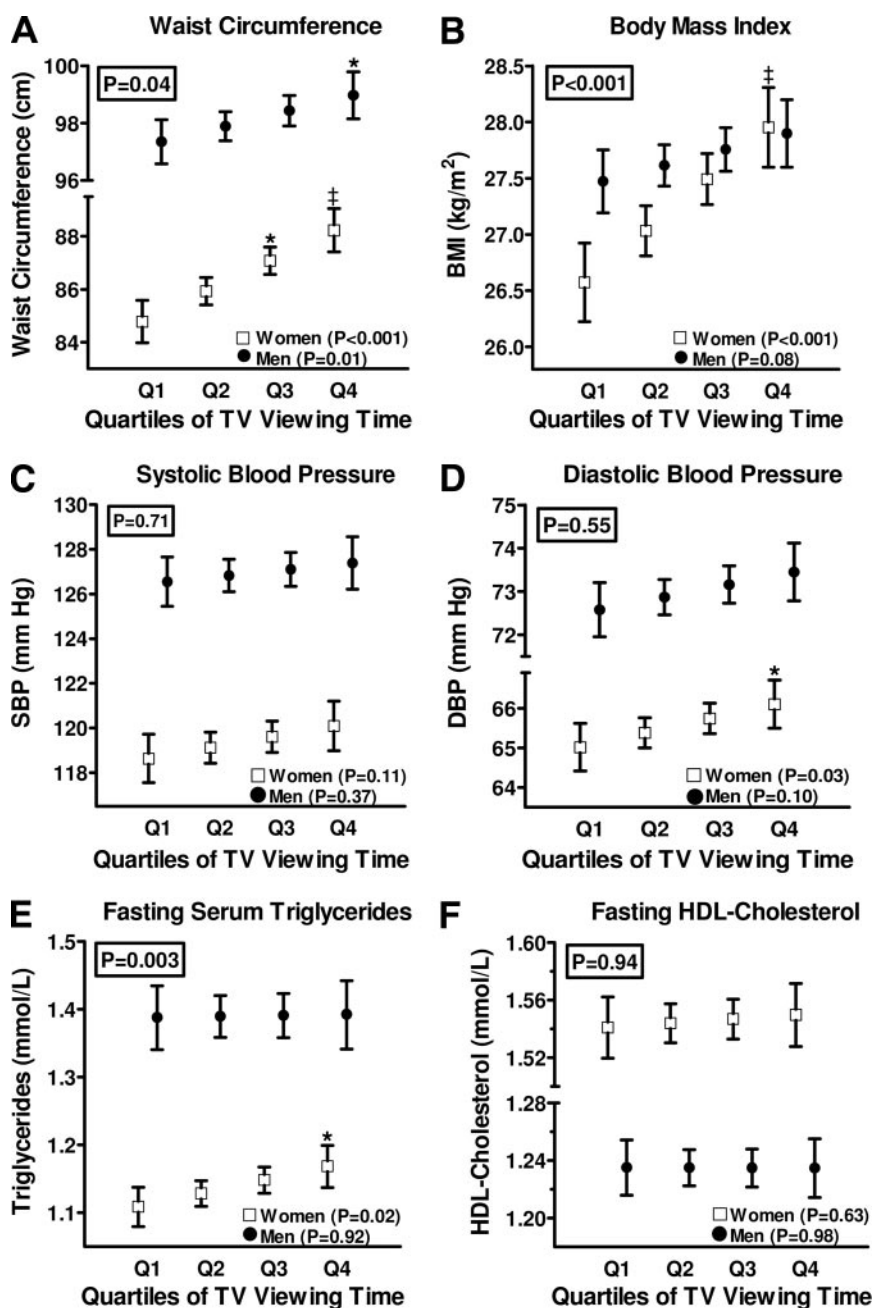
Figure 2—*Associations of individual metabolic risk variables with quartiles of TV viewing time for women (□) and men (●). Data are presented as marginal means (95% CI) adjusted for waist circumference (except for waist circumference and BMI outcomes), age, education, parental history of diabetes, employment status, cigarette smoking, total alcohol and total energy intake, diet quality, and leisure physical activity time. For insulin, triglycerides, HDL cholesterol, and fasting and 2-h postload plasma glucose, P values for trend and between individual quartiles of TV viewing time from reference category (Q1) are derived from the natural logarithm of these values. To allow for clinical interpretation, marginal means (95% CI) are presented as back-transformed log values. *P ≤ 0.05; †P ≤ 0.01; ‡P ≤ 0.001. Sex interaction P values are presented in the box.*

time (in both leisure and nonleisure contexts) with risk biomarkers. It is also the first study to concurrently report associations for sitting time and for TV viewing time with metabolic biomarkers in the same cohort of women and men.

The mechanisms through which prolonged sitting might contribute to an adverse cardio-metabolic profile are yet to be determined. Physiologically, it has been suggested that the loss of local contractile stimulation induced through sitting leads to both the suppression of skeletal muscle lipoprotein lipase (LPL) activity (which is necessary for triglyceride uptake and HDL cholesterol produc-

tion) and reduced glucose uptake through blunted translocation of GLUT4 glucose transporters to the skeletal muscle cell surface (15,16). Behaviorally, prolonged sitting displaces opportunities for engagement in light-intensity incidental activities that can lead to a reduction in whole-body energy expenditure (17). Over time, this is likely to contribute to a negative daily energy balance and poor metabolic outcomes (18).

Sitting time was shown to be more consistently associated with metabolic biomarkers than was TV viewing time in both men and women, after controlling for leisure-time physical activity and waist circumference. These observations further highlight the potential importance of reducing sitting time across the entire day and not just during selected leisure-time activities such as TV viewing.

It is plausible that higher average occupational sitting times may have at least partially accounted for the less favorable metabolic profile of men, since workplace sitting has previously been reported to be associated with greater adiposity, more so for men than for women (6). As we did not distinguish between occupational and leisure-time sitting, we are not able to argue that specific emphasis ought to be given to one context over the other with respect to targeted intervention strategies to improve health outcomes.

It is unclear whether prolonged sitting elevates the risk of hypertension (19,20). In our findings, prolonged sitting time in women was deleteriously associated with diastolic blood pressure and beneficially associated with systolic blood pressure in men. Whereas TV viewing time has been shown to be deleteriously associated with diastolic blood pressure (21), it is possible that factors not directly accounted for in our analysis could have contributed to the beneficial association with systolic blood pressure. It is plausible, for example, that the lowered systolic blood pressure observed in highly sedentary men in our study may reflect adaptations in hemodynamic responses to sitting (22), but confirmation in prospective cohort studies are needed.

A key strength of this study is the large sample size, which includes women and men across a wide age range and objective data on several continuous measures of cardio-metabolic risk. In contrast to previous studies that have typically focused on one leisure-time sedentary behavior (TV viewing), the sitting time measure we used incorporated time spent
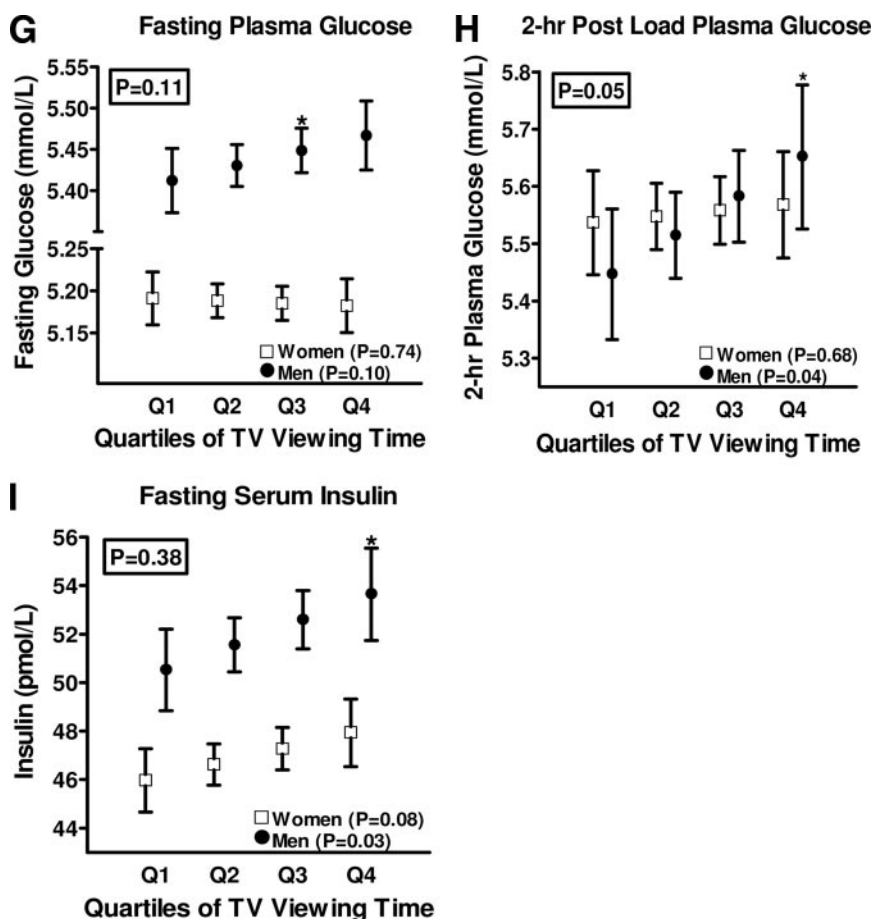
Figure 2—*Continued.*

sitting during travel, work, and leisure activities. However, separation of the relative effects of each domain of sitting is not possible with this measure. Other limitations include the cross-sectional design, which precludes inferences about causality, the reliance on self-reported measures, and the inability to make direct comparisons for clinical effects from 1 h of sitting time and TV viewing time on metabolic markers due to the timeframes used to capture this information differing for each question. Furthermore, despite adjusting for several potential confounding factors, including physical activity and diet quality, it is possible that other confounders may be relevant. For instance, the Food Frequency Questionnaire did not allow for specific examination of snacking behaviors.

We have reported new evidence that sitting time is deleteriously associated with biomarkers of cardio-metabolic risk in a large general population sample. We also report for the first time that sitting time has more consistent associations than does TV viewing time with continuous biomarkers of risk, in both women

and men. Importantly, the adverse associations observed for sitting time and TV viewing time in both men and women were independent of leisure-time physical activity and central adiposity (sitting time only). These findings indicate that the formulation of population strategies aimed at reducing type 2 diabetes and cardiovascular disease risk should focus not only on finding more effective ways to increase physical activity, but also identify the most appropriate targets for reducing overall levels of prolonged sitting time (which would include domestic, occupational, and transportation settings). Although it is not possible at this stage to have specific recommendations in adults regarding sitting time duration, a broad suggestion regarding reducing sitting time may provide a useful clinical and public health message.

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