Sedentary Behavior and Cardiovascular Morbidity and Mortality

A Science Advisory From the American Heart Association

Endorsed by The Obesity Society

ABSTRACT: Epidemiological evidence is accumulating that indicates greater time spent in sedentary behavior is associated with all-cause and cardiovascular morbidity and mortality in adults such that some countries have disseminated broad guidelines that recommend minimizing sedentary behaviors. Research examining the possible deleterious consequences of excess sedentary behavior is rapidly evolving, with the epidemiology-based literature ahead of potential biological mechanisms that might explain the observed associations. This American Heart Association science advisory reviews the current evidence on sedentary behavior in terms of assessment methods, population prevalence, determinants, associations with cardiovascular disease incidence and mortality, potential underlying mechanisms, and interventions. Recommendations for future research on this emerging cardiovascular health topic are included. Further evidence is required to better inform public health interventions and future quantitative guidelines on sedentary behavior and cardiovascular health outcomes.

Deborah Rohm Young, PhD, FAHA, Chair
Marie-France Hivert, MD, MMSc, FAHA, Co-Chair
Sofiya Alhassan, PhD
Sarah M. Camhi, PhD, FAHA
Jane F. Ferguson, PhD, FAHA
Peter T. Katzmarzyk, PhD, FAHA
Cora E. Lewis, MD, MSPH, FAHA
Neville Owen, PhD
Cynthia K. Perry, PhD, FNP, FAHA
Juned Siddique, DrPH
Celina M. Yong, MD, MBA, MSc
On behalf of the Physical Activity Committee of the Council on Lifestyle and Cardiometabolic Health; Council on Clinical Cardiology; Council on Epidemiology and Prevention; Council on Functional Genomics and Translational Biology; and Stroke Council

Evidence is accumulating that sedentary behavior might be associated with increased cardiovascular-specific and overall mortality. Insufficient physical activity predicts premature cardiovascular disease (CVD) mortality and disease burden, such that the United States and other developed countries have issued physical activity guidelines, but these guidelines are specific to physical activity and do not include sedentary behavior.[1] Sedentary behavior guidelines to reduce the risk of chronic diseases for adults have been developed in some countries, but they are broadly stated and nonquantitative. For example, Australia and the United Kingdom have public health guidelines stating that adults should minimize the amount of time spent being sedentary (sitting) for extended periods.[2,3] Such broad public health guidelines for adults are likely appropriate, because evidence is still accumulating regarding the strength of the association, the evidence for causation (including understanding mechanisms), and the support for dose-response relationships that demonstrate sedentary behavior to be an independent risk factor for adverse health outcomes. Although at one time, excess sedentary behavior was considered to be at one end of the continuum of physical activity such that a person with no moderate-to-vigorous physical activity (MVPA) was considered “sedentary,” consensus is building that sedentary behavior is distinct from lack of MVPA. Even the word “sedentary,” derived from the Latin “sedentarius” and defined as “sitting, remaining in one place,” connotes a different set of behaviors than non-MVPA.[4] Thus, researchers studying MVPA, physical inactivity, and sedentary behavior are now viewing these behaviors as separate entities with their own unique determinants and health consequences.

Key Words: AHA Scientific Statements ■ adults ■ cardiovascular disease ■ diabetes mellitus ■ metabolic syndrome ■ mortality ■ prevalence ■ sedentary lifestyle

This American Heart Association science advisory summarizes the existing evidence about sedentary behavior as a potential risk factor for CVD and diabetes mellitus, including how the behavior is assessed, its prevalence and potential determinants, its association with CVD outcomes, initial potential mechanisms that might explain observed associations, and interventions designed to reduce it. We limit this advisory to the available evidence of sedentary behavior and disease outcomes rather than examining relationships with CVD risk factor precursors, such as hypertension or obesity. Finally, recommendations are provided for future research needed before the development of quantitative national guidelines.

To date, most of the scientific evidence on sedentary behavior and CVD morbidity and mortality has been with adult populations. The effects of sedentary behavior on CVD and metabolic disease risk in children and adolescents have been reviewed elsewhere.[5] Furthermore, correlates of sedentary behavior are different for children than adults, as are potential intervention strategies. Therefore, we restrict this advisory to adults without ambulatory limitations. On the basis of objective measurements, US adults spend an average of 6 to 8 hours per day sitting,[6] thus, sedentary behavior is highly prevalent. The Figure illustrates the average 24-hour day for US adults based on NHANES (National Health and Nutrition Examination Survey) data, highlighting the significant portion of time spent in sedentary and light activities and the little time spent, on average, in MVPA.[6,8]

The Sedentary Behaviour Research Network, an organization of researchers and health professionals, suggests the following definition for sedentary behavior: "Sedentary behavior refers to any waking behavior characterized by an energy expenditure ≤1.5 metabolic equivalents while in a sitting or reclining posture."[9] One metabolic equivalent is defined as the energy expended while sitting at rest, or the standard of 3.5 mL of oxygen per kilogram of body weight per minute.[10] (MVPA is defined as activities that expend at least 3.0 metabolic equivalents.) We adopt this definition for this advisory. This is similar to the 2013 American Heart Association scientific statement "Guide to the Assessment of Physical Activity: Clinical and Research Applications," in which sedentary behavior intensity was defined as 1 to 1.5 metabolic equivalents.[11] Common sedentary behaviors, displayed in the Table, include television (TV) viewing, computer use (ie, screen time), driving, and reading.

SEDENTARY BEHAVIOR MEASUREMENT

Sedentary behavior is typically assessed from self-report instruments or through the use of objective measurement devices. Direct observation is another assessment that can be performed in discrete locations, but it is not discussed in this advisory. For the purpose of this advisory, we refer to "sedentary time" when estimates or measures of time per day or week are assessed; in other instances, we refer to "sedentary behavior." Device-derived measures of sedentary time can provide improved measurement precision over self-report assessments, as well as unique insights into different patterns of behavior. However, to develop relevant guidelines, inform intervention design, and assist in the development of broad-reaching environmental and policy initiatives, there is a need to understand sedentary behavior in the contexts (behavior settings) within which it takes place.[12] This requires the use of self-report assessment tools.[13] For example, sedentary behavior commonly occurs in the settings of home, work or school, and transport, as well as during leisure time. For example, going to the theater usually involves sitting through the performance. Although objective measures can provide the precise time a person was sitting, self-report instruments are necessary to understand "why, where, and what" (ie, context) the individual was doing. Thus, device-based and self-report measurements are complementary.

Two recent publications provide perspectives on why both device-based and self-report measurements of sedentary behavior are necessary.[14,15] Compared with device-derived measures, self-report indices can deliver underestimates of actual time spent sitting in some domains. Objective devices for assessment of sedentary time are in a rapid state of technical evolution and cannot be regarded as a "gold standard." Many still need their measurement properties assessed through validation and calibration studies and their real-world feasibility tested in population-based studies and intervention trials.[16]

Self-Report Assessments

The virtue of self-report measures is that they can be context specific; however, accuracy across contexts varies. TV viewing time at home typically is reported with considerable accuracy.[17,18] On the other hand, self-report measures of workplace sedentary behavior appear to be less accurate, with sitting time underestimated compared with device-derived measures.[19] In the context of transport, little is known about the measurement properties for time spent sitting in motor vehicles.[20]

Self-report instruments range from a single item to detailed questionnaires to complex behavior diaries; which instrument to use depends on the information's purpose. Although not an exhaustive list, the Sedentary Behaviour Research Network identifies 13 questionnaires on its website.[21] In 2011, Healy et al[14] reviewed the reliability and validity of self-report sedentary behavior instruments. Test-retest reliability has been assessed from 3 days to 2 months, with correlation coefficients ranging from 0.30 to 0.97. Validity against accelerometers as

CLINICAL STATEMENTS AND GUIDELINES

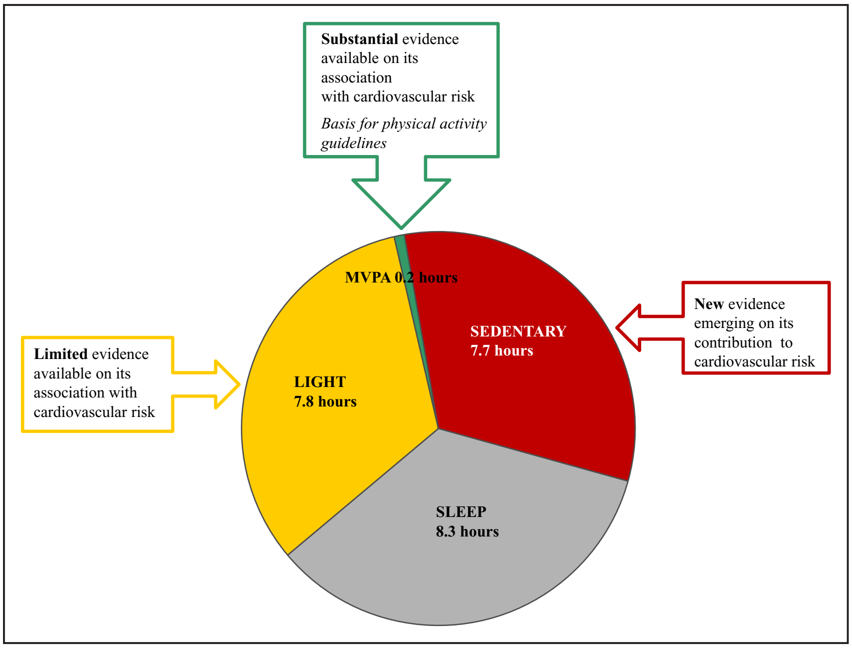

Figure. Estimated daily time spent in different contexts of energy expenditure among adults, based on the National Health and Nutrition Examination Survey.[6,7]
Light time=24–MVPA–Sleep–Sedentary time. MVPA indicates moderate to vigorous physical activity.

the criterion resulted in correlation coefficients of 0.07 to 0.49. Criterion correlations tended to be higher when an activity log was used as the criterion, although a large range was still reported (r=0.13 to 0.75). When selecting an appropriate self-report instrument, investigators should consider the primary aim of the study or project, the target population, the importance of the context of the behavior, and logistical constraints.[22] Also, a combination of simple forms of self-report (eg, work start time, lunch break time, and finishing time) or the use of travel diaries to identify time spent sitting in vehicles can be combined with device-based measurement to provide accurate context-anchored assessments.[13,15]

Device-Based Assessments

Accelerometers have been the most commonly used devices to objectively monitor sedentary time. Accelerometers measure acceleration, defined as change in velocity. Participants have traditionally worn accelerometers on a belt around their waist during waking hours and remove them for water-based activities, a methodology and protocol that has been shown to be both valid and reliable.[23,24] Wearing a device on a wrist or ankle can be helpful in quantifying behaviors that have different positions[25,26] and can be less burdensome than using a waist-worn device. The movement detected by accelerometers is converted to electrical signals or “counts” that can be summed over a period of time to quantify total sedentary time (minutes) or patterns of sedentary time (eg, duration of bouts or episodes, breaks in sedentary time).[14] Data from accelerometers are typically reported as a percentage of total wear time or absolute hours per day.

Although objective devices reduce measurement error associated with self-report, they do have limitations. As mentioned previously, they are not able to provide context or domain for the behavior. However,

Table. Common Sedentary Behavior Activities Performed While Sitting or Reclining That Require Energy Expenditure <1.5 METs

Home	Work/School	Transportation	Leisure
TV viewing: sitting, reclining	Computer work	Driving or riding in a vehicle	Playing an instrument
Talking on the phone	Sitting		Arts and crafts
Listening to music	Writing		Knitting/sewing
Eating	Talking on the phone		Meditating
Bathing	Sitting in class		Playing cards or board games
Reading	Typing		Viewing a sports event
	Reading		Attending a religious service

METS indicates metabolic equivalents; and TV, television.

Circulation. 2016;134:e262–e279. DOI: 10.1161/CIR.0000000000000440

new emerging analytic methods, such as neural network techniques, could help to identify specific activities through pattern recognition.[27] Furthermore, accelerometers worn around the waist are not able to accurately detect lower-body movements in activities such as cycling, water-based activities, or upper-body movements associated with activities like resistance training. Thus, these activities might be misclassified as sedentary. Although wearing a device on a wrist or ankle can minimize these limitations, the validity of the data when used in this position is still being established.[25,26] Furthermore, accelerometers can be inaccurate in distinguishing sitting from standing,[14] although those that include inclinometers could mitigate this concern. New analytic techniques are being developed that identify, analyze, and visually present sedentary behaviors from wrist-worn triaxial accelerometers[28] and that are capable of assessing posture by including inclinometers.[29–33] Other methods in development include inclinometers that are combined with cameras to assess body position and estimate sedentary behavior.[34]

Accelerometer data reduction involves several steps. A count-per-minute cut point can be chosen to quantify time in sedentary behavior. Less than 100 counts per minute is most commonly used to identify sedentary time from waist-worn accelerometers.[35] Devices worn at the wrist or ankle might require different thresholds, which are not known at this time because these techniques are still being evaluated.[36] For data analysis, wear-time algorithms take into account how many hours within a day, how many days, and which days (weekday and/or weekend) the device is worn to determine whether there has been adequate wear time to characterize sedentary time, and many variations of data processing exist within the sedentary behavior research literature.[14,35] Choosing different algorithms for wear time can result in significantly different estimates for sedentary time.[37] Thus, accelerometer data reduction can be quite complex; it is a sedentary behavior research priority to standardize data reduction techniques.[29]

Sedentary Behavior Measurement: Summary of Key Findings

- There is no “gold standard” for sedentary behavior assessment; self-report measures provide information on the behavioral context that is not available from objective measures.
- New objective measures are under development to assess body position. Reliability and validity properties will need to be established.
- Approaching accelerometry data processing with standardized procedures can help to better synthesize the sedentary behavior scientific literature. Existing datasets can be reanalyzed after standardized methods are in place.

SEDENTARY BEHAVIOR PREVALENCE

Data from economic, occupational, and time use surveys suggest that sedentary behavior has increased at the population level from the 1960s. Sedentary occupations constituted ≈15% of the total US jobs in 1960, increasing to >20% by 2008.[38] Ng and Popkin, using time use data, reported that average sedentary time increased from 26 hours per week in 1965 to 38 hours in 2009 in the United States and from 30 hours per week in 1960 to 42 hours per week in 2005 in the United Kingdom.[39] Because of insufficient measurement tools, more specific data are not available to be able to more definitively ascertain trends. In the 2000s, sedentary behavior began to be reported from large population-based surveys using a variety of assessment methods and resulting in differing estimates of its prevalence.

On the basis of objective measurement from accelerometers, adults spend an average of 6 to 8 hours per day in sedentary time,[6,7,18,40–42] and adults >60 years of age average 8.5 to 9.6 hours per day in sedentary time.[43–48] Data from NHANES suggest these findings on sedentary time remained stable from 2003–2004 to 2005–2006.[6,7] Those who spent more time in MVPA had similar sedentary time to those who were less physically active (mean sedentary time 472 minutes per day vs 489 minutes per day [7.9 hours per day versus 8.2 hours per day]),[7] which suggests that MVPA might not displace sedentary time.

Evidence conflicts as to whether there are sex differences: the 2003 to 2004 NHANES accelerometer data indicate that women <60 years of age were more sedentary than men, although after age 60, men were more sedentary.[6] Other studies also concluded that older women were less sedentary than older men.[40,43,46] A recent review concluded that there was no difference in sedentary time by sex, although studies of adults and older adults were combined.[49] Occupational status and type, as well other factors (eg, child-caring responsibilities, chores, volunteer activities), might vary by sex and age and could confound results, which makes demographic comparisons difficult to interpret.

Self-report data on sedentary behavior (queried by time spent sitting, TV viewing, computer use, screen time) are less consistent, with the amount of time in sedentary behaviors ranging from 2 to 8 hours per day.[50–55] Differences might result from the self-report assessment, domain, context, and country examined. For example, civil service employees in Northern Ireland reported sitting an average of 7.8 hours per day.[55] In contrast, a large review examining sitting time, as measured by the International Physical Activity Questionnaire, with 49 493 adults residing in 20 countries reported an average sitting time of ≈5 hours per day,[52] which is similar to the results reported in the 2010 US National Health Interview Survey.[51] A recent review of research conducted with older adults found 59% reported sitting for >4 hours and 27% reported sitting for >6 hours per day.[47]

TV viewing, a common leisure-time sedentary behavior, is a subset of sitting time, and thus, time spent watching TV is lower than overall sedentary time. For example, accelerometry data from the 2008 Health Survey for England found that on average, adults spent 8.5 hours per day in sedentary time, of which ≈4 hours per day was reported to be TV viewing.[41] In an Australian sample of ≈10000 adults, the mean daily time self-reported watching TV was 2 hours for men and 1.8 hours for women.[54] A large US study, based on self-report, found more than half of all adults viewed >2 hours of TV per day.[56] TV viewing time might be greater for older adults: A review found that 54% and 53% reported TV watching time and screen time, respectively, for >3 hours per day.[47]

Sedentary Behavior Prevalence by Race/Ethnicity

The association between race/ethnicity and sedentary behavior has been examined in a number of large adult samples.[57–69] Most have focused on TV viewing time; it has been commonly found that blacks watch more TV than adults of other races/ethnicities.[60,62,63,65,66,69–71] For example, Bowman[56] analyzed data from 9157 adults and found that blacks were more likely to watch >2 hours per day of TV than other racial/ethnic groups. However, these findings must be considered in the context of the inherent limitations of survey-based studies; large reliability differences between race/ethnic groups have been found, with TV viewing time questions more reliable for white than black populations.[72]

An NHANES analysis found a positive association between TV viewing time and total sedentary time across all racial/ethnic groups[18] ; however, for blacks and Mexican Americans, the association between TV viewing time categories and average sedentary time was only significant for those reporting ≥5 hours of TV viewing per day compared with the <1 hour category. In contrast, the association between the 2 variables was more linear for non-Hispanic whites. Three studies showed no association between screen time or general sitting time and race/ethnicity.[57,59,73]

Another NHANES analysis using data collected from accelerometers in 2003 to 2004 found that Mexican American adults spent significantly less time being sedentary than other US adults. There was no difference in sedentary time between white and black adults, with one exception: White men aged 40 to 59 years were more sedentary than same-aged black men.[6] One major review of sedentary behavior prevalence in adults was not able to find consistent associations between race/ethnicity and sedentary time.[49]

Sedentary Behavior Prevalence: Summary of Key Findings

- Prevalence of sedentary behavior differs depending on the assessment tool; however, it is estimated that adults spend 6 to 8 hours per day in sedentary behavior, including sitting, TV viewing, screen time, and computer use. The prevalence is greater for older adults.
- Data conflict as to whether there are differences in sedentary behavior by sex or race/ethnicity. Different instruments and types of sedentary behavior assessed contribute to the differences.

POTENTIAL PSYCHOSOCIAL AND ENVIRONMENTAL INFLUENCES ON SEDENTARY BEHAVIOR

The documentation of prevalence in sedentary behavior overall and across demographic groups helps to identify those at potentially higher risk; however, such evidence does not identify mutable factors for interventions to reduce sedentary behavior. An ecological model across the 4 domains of sedentary behavior proposes that multiple levels of determining factors will influence sedentary behaviors differently in these domains.[74] Although the relevant evidence is still rudimentary, studies have begun to identify some of the correlates of sedentary behaviors. Most studies have used cross-sectional designs, which can identify significant associations but cannot infer causality. Nevertheless, evidence on the correlates of sedentary behaviors, particularly on cognitive, social, and environmental attributes, can generate plausible hypotheses to be tested and can provide initial insights relevant to the development of interventions.

Psychosocial Influences

A number of cross-sectional studies have shown higher sedentary time to be inversely associated with psychological well-being[49,75] and health-related quality of life[49,76,77] and positively associated with depressive symptoms.[49,78] The psychosocial constructs of attitudes toward sedentary behavior, social norms, social support, and self-efficacy for sitting less have varying cross-sectional associations.[79–82] Prospective associations or results from intervention studies examining psychosocial variables as outcomes or mediators of effects are not currently available in the literature.

Built Environment Influences

The built environment could play a role in promoting some sedentary behaviors or discouraging other health-enhancing behaviors such as physical activity, although the existing evidence for associations is modest.[83] A pre-

 Circulation. 2016;134:e262–e279. DOI: 10.1161/CIR.0000000000000440

intervention/postintervention study that manipulated the microenvironment of sedentary behavior (by removing seating from a playground) found significantly less sitting among adults visiting the park with children.[84] Also, the adults were more likely to engage in MVPA (odds ratio, 4.50; 95% confidence interval [CI], 2.1–9.8) relative to sitting, although no difference was found between sitting and standing. Cross-sectional associations for macroenvironmental factors (eg, land use mix, walkability) and sedentary behavior have been mixed, with some studies finding no associations[85] and others reporting positive associations.[74,86] One study in Australia indicated that living in low-walkable neighborhoods was associated with a greater increase in TV time over 4 years for those residents who were unemployed.[87]

Summary of Key Findings: Potential Influences

- There is cross-sectional evidence that psychological well-being could be inversely associated with sedentary behavior, but prospective studies are needed to understand the directionality of potential associations.
- Little evidence exists on how built environment attributes might contribute to the amount of time spent in sedentary behavior.

POTENTIAL GENETIC INFLUENCES ON SEDENTARY BEHAVIOR

There is some evidence to suggest that a predisposition toward sedentary behavior is in part genetically determined. In an objective measurement of behavior, which used heart rate and movement sensors in monozygotic and dizygotic twins, the heritability of sedentary behavior was estimated at 31% (95% CI, 9%–51%), with heritability of physical activity energy expenditure estimated at 47% (95% CI, 23%–53%).[88]

Several investigator groups have used candidate gene approaches to assess the effects of genetic variation on sedentary behavior phenotypes.[89] Genes that have been investigated and might be involved in physical activity or inactivity include *ACE*, *CASR*, *DRD2*, *EDNRB*, *FABP2*, *FTO*, *LEPR*, *MC4R*, *NHLH2*, *SLC9A9*, and *UCP1*[89,90]; however, results are conflicting, and many findings have not been replicated. Although agnostic analytic approaches through genome-wide association studies have not yet yielded convincing loci, larger sample sizes combined with objective measurements of sedentary behavior might be required to detect significant effects. It is likely that multiple genetic variants with small effect sizes are present in the population and could interact with environmental factors to contribute to the overall degree of sedentary behavior in an individual.

Summary of Key Findings: Potential Influences

- There might be a significant genetic component contributing to sedentary behavior in individuals; however, no specific loci have been convincingly identified and replicated.

SEDENTARY BEHAVIOR AND CVD AND DIABETES MELLITUS RISK, MORBIDITY, AND MORTALITY

There is now a substantial body of prospective data on associations of sedentary behavior with risk of developing diabetes mellitus and CVD, as well as with overall mortality. Several (mainly cross-sectional) studies have also found significant associations of sedentary time (deleterious) and breaks from sedentary time (protective) with risk biomarkers.[91] However, this body of evidence is modest compared with what is known about how higher physical activity is associated with lower CVD and diabetes mellitus risk. For the most part, the sedentary behavior studies have arisen from existing cross-sectional and cohort studies that have baseline self-report assessments of ≥1 sedentary behavior domains (most commonly self-reported), with the outcomes of interest obtained over follow-up. More recent studies have been able to statistically control for the effects of either leisure-time MVPA or total physical activity, thus leading to analyses to assess the independent effects of sedentary behavior on the outcomes. Other work has investigated the potential health benefits of reallocating sedentary time to alternative activities (ie, sleep, light-intensity activity, MVPA) via isotemporal substitution modeling.[92,93] In studies in which the sample sizes were sufficient, effects by major population subgroups, such as sex and race/ethnicity, have also been reported.

Metabolic Syndrome

Metabolic syndrome is a cluster of risk factors that increase risk for CVD and diabetes mellitus. In the United States, ≈34% of US adults have metabolic syndrome.[94] Few studies have reported on prospective associations of sedentary behavior as a possible risk factor for developing metabolic syndrome. A meta-analysis of 10 cross-sectional studies found that greater time spent in sedentary behavior resulted in higher odds of metabolic syndrome (odds ratio, 1.73; 95% CI, 1.55–1.94)[95]; however, 9 of the 10 studies defined sedentary behavior from self-reported screen time.[95] More recent research has defined sedentary behavior using either reports of total sitting time or low activity counts from accelerometer data. Results have shown a robust positive association of self-reported sitting time with odds of metabolic syndrome,[96–100] even with adjustment for MVPA. Only 2 studies have examined prospective associations of sedentary behavior and metabolic syndrome. Wijndaele et al[101] found

CLINICAL STATEMENTS AND GUIDELINES

that baseline TV time was not significantly associated with 5-year change in a clustered metabolic risk score, a measure analogous to metabolic syndrome; however, an increase in TV time over this period was associated with an increase in the score in women but not men.[101] Shuval et al[102] found that prolonged baseline sedentary behavior (TV viewing or sitting in a car) was not associated with metabolic syndrome incidence in men. Sedentary time assessed from objective measures examining development of metabolic syndrome has not been reported.

Diabetes Mellitus

A small number of prospective studies have investigated the association of sedentary behavior as a risk factor for developing type 2 diabetes mellitus, with most showing a consistent positive association.[58,103–105] Meta-analyses and systematic reviews have confirmed this association, reporting a fairly consistent effect size with little evidence of publication bias.[106–108] In the meta-analysis by Grøntved et al,[107] each additional 2 hours per day in TV viewing was associated with a relative risk of 1.20 (95% CI, 1.14–1.27) of developing type 2 diabetes mellitus. High sedentary behavior has been associated with increased risk of type 2 diabetes mellitus in both men[104] and women[58] of diverse ethnic backgrounds.[105] Most studies have investigated sedentary behavior in the context of physical activity and found that both high sedentary behavior and low MVPA independently predicted higher risk of developing type 2 diabetes mellitus.[58,103–105] The association between high sedentary behavior and higher risk of type 2 diabetes mellitus was also found to be independent of the demographic characteristics of age, sex, race/ethnicity, and socioeconomic status. Adjustment for indices of adiposity (typically body mass index [BMI] or waist circumference) in the models usually reduced the effect size,[58,103–105] which supports the notion that the association could be mediated in part through excess weight. For example, in the previously mentioned meta-analysis, controlling for BMI reduced the relative risk to 1.13 (95% CI, 1.08–1.18) for each additional 2 hours of daily TV viewing time.[107]

Most studies have used self-reported TV viewing time to assess sedentary behavior; however, in the Nurses' Health Study,[58] increased risk of developing type 2 diabetes mellitus was associated with other sedentary behaviors (such as sitting at work, away from home, or while driving) and with sitting at home, whereas low-intensity activity behaviors such as standing or walking around home were associated with reduced risk of type 2 diabetes mellitus. Specifically, they found that each additional 2 hours per day of TV viewing was associated with a 14% (95% CI, 5%–23%) increase in the risk of type 2 diabetes mellitus, whereas each additional 2 hours per day in standing or walking around the home was associated with a 12% (95% CI, 7%–16%) reduction in risk of type 2 diabetes mellitus.

Cardiovascular Disease

A number of meta-analyses and reviews have been published in the past several years evaluating the prospective evidence on the associations of sedentary behavior with CVD outcomes.[106,107,109,110] Although sedentary behavior was assessed using different methods from studies evaluated by several meta-analyses and systematic reviews, increased risk was found to be consistent for TV time and CVD events (hazard ratio [HR], 1.17 [95% CI, 1.13–1.20][109]; relative risk, 1.15 [95% CI, 1.06–1.23][107]), with a greater risk when defined as overall sedentary behavior for CVD incidence (pooled relative risk, 2.47; 95% CI, 1.44–4.24[110]) and for CVD mortality (pooled HR, 1.90; 95% CI, 1.36–2.66[110]). In an analysis of data from the EPIC (European Prospective Investigation Into Cancer and Nutrition) Norfolk study, Wijndaele et al[111] demonstrated that each additional hour per day of TV viewing was associated with an increased risk for incident total (fatal and nonfatal) CVD (HR, 1.06; 95% CI, 1.03–1.08), nonfatal CVD (HR, 1.06; 95% CI, 1.03–1.09), and coronary heart disease (HR 1.08, 95% CI, 1.03–1.13) after adjustment for a number of covariates, including demographics, estimated total daily physical activity, CVD, and diabetes mellitus history. BMI only partially mediated the effects. Stamatakis et al[112] also reported a significant association (HR, 2.10; 95% CI, 1.14–3.88) between screen time (≥4 hours per day versus <2 hours per day) and incident CVD events (fatal and nonfatal) among Scottish adults after adjustment for sociodemographics, health status, obesity status, and MVPA. Chomistek et al[113] reported that sitting at least 10 hours per day versus ≤5 hours per day was associated with an increased risk of incident fatal and nonfatal CVD (HR, 1.18; 95% CI, 1.05–1.32) among middle-aged American women participating in the Women's Health Initiative, after adjustment for leisure-time physical activity, sociodemographics, dietary patterns, CVD risk factor status, and BMI. The risk of incident stroke (HR, 1.21; 95% CI, 1.07–1.37) was of a similar magnitude.[113] The association between sedentary behavior and CVD incidence does not appear to be appreciably altered by the inclusion of BMI as a covariate.[107]

All-Cause and Cause-Specific Mortality

Several large prospective cohort studies have shown significant associations between sedentary behavior and mortality risk.[114–121] Most have used self-report measures, including time spent watching TV, sitting, lying down, or riding in a car. For example, the US National Institutes of Health–AARP Diet and Health Study[119] followed up 240 819 middle-aged adults for a mean of 8.5 years, classifying them according to time spent in TV viewing, sitting, and MVPA. All-cause, CVD, and cancer deaths and other causes of mortality were each significantly related to greater time spent TV viewing, even after adjustment for demographics and MVPA. Time spent sitting was re-

Circulation. 2016;134:e262–e279. DOI: 10.1161/CIR.0000000000000440

lated to all-cause death and other causes of mortality (but not CVD or cancer). The SUN (Seguimiento Universidad de Navarra) cohort, a follow-up of graduates of the University of Navarre in Spain, examined self-reported TV viewing, computer use, and driving at baseline over a median follow-up of 8.2 years.[114] Participants reporting ≥3 hours per day of TV viewing had twice the risk of mortality of those reporting <1 hour per day after adjustment for multiple covariates, including leisure-time physical activity (incidence rate ratio, 2.04; 95% CI, 1.16–3.57). There were no subgroup differences by sex, BMI, or leisure-time physical activity. There were no significant associations with computer use or time spent driving, although small to moderate relationships cannot be ruled out given the relatively small number of deaths (n=128) and wide CIs.

Two recent prospective studies have examined this issue with objective measures of sedentary time. In the Mr OS study (Osteoporotic Fractures in Men), men ≥71 years old wore an armband activity monitor and were followed up for an average of 4.5 years.[122] Comparisons of quartiles of time spent in sedentary behavior, light activity, and MVPA were made with respect to all-cause mortality: (1) More time spent in sedentary behavior (at least 915 minutes per day) compared with the least (<77 minutes per day) had an HR of 1.79 (95% CI, 1.19–2.70); (2) less time spent in light activity (<42 minutes per day) compared with the most (≥88 minutes per day) had an HR of 1.57 (95% CI, 1.08–2.29); and (3) less time spent in MVPA (<38 minutes) compared with the most (≥114 minutes per day) had an HR of 1.58 (95% CI, 1.10–2.27). The association between sedentary time and mortality was most pronounced in men who were exceeding current recommendations for MVPA, which suggests that MVPA does not counter the risks of also being highly sedentary. In the second study, Koster et al[123] studied NHANES participants ≥50 years of age who had at least 1 valid day of accelerometer data. After an average follow-up of 2.8 years, all-cause mortality risk increased significantly with greater sedentary time in both the third and fourth quartiles, whether hours per day or percent time spent being sedentary was assessed. People in the highest quartile of the proportion of time spent being sedentary (>73.5% of time in men and >70.5% of time in women) had a nearly 6 times greater risk of death (HR, 5.94; 95% CI, 2.49–14.15) compared with those in the lowest quartile of sedentary time (55.4% in men and 53.9% in women); these associations were independent of time spent in MVPA, mobility limitation, demographics, and multiple morbidities.

Several reviews, systematic reviews, and meta-analyses have also examined sedentary behavior and mortality.[106–110,124–126] These have shown fairly consistent relationships between various sedentary behavior measures and all-cause and CVD mortality, whereas findings for cancer mortality were not consistent. One meta-analysis evaluated the effects of sedentary behavior in adults who were classified as physically active and physically inactive. The results showed that the effects of sedentary time on all-cause mortality were greater among those with low levels of physical activity (HR, 1.46; 95% CI, 1.22–1.75) than among those with high levels of physical activity (HR, 1.16; 95% CI, 0.84–1.59).[106]

Isotemporal substitution modeling analyses are starting to appear in the literature to attempt to discern the morbidity and mortality benefits that could be achieved when sedentary time is replaced with other movement behaviors. In an analysis of older adults participating in the National Institutes of Health–AARP Diet and Health Study, the effects on all-cause mortality of replacing 1 hour of sedentary time with MVPA, or exercise, and nonexercise behaviors was much greater among those who were physically inactive than among those who were physically active.[93] In contrast, a cross-sectional study using similar modeling procedures with NHANES 2005 to 2006 accelerometry data indicated that replacing sedentary time with MVPA yielded the greatest benefits in CVD risk factors.[92] Future work emerging from these modeling approaches will inform eventual public health messages regarding the intensity of activity needed to replace sedentary time to confer CVD-reducing benefits.

Summary of Key Findings: Sedentary Behavior and CVD and Diabetes Mellitus Risk

- Prospective evidence is accumulating that sedentary behavior could be a risk factor for CVD and diabetes mellitus morbidity and mortality and for all-cause mortality. The degree to which this is independent of the effects of MVPA needs further study.

POTENTIAL MECHANISMS TO EXPLAIN THE ASSOCIATIONS OF SEDENTARY BEHAVIOR WITH CVD AND DIABETES MELLITUS RISK AND MORTALITY

For MVPA, there is a large body of experimental evidence identifying how different durations, intensities, and types of physical activity can influence CVD risk biomarkers.[127] Although this work provides insights of potential relevance to understanding the mechanistic basis for the association of sedentary behavior with CVD and diabetes mellitus risk, it is likely that sedentary behavior influences risk in part through some distinct mechanisms that act independent of MVPA.[128] Physical inactivity, whether genetically determined (eg, in animal models of reduced physical activity) or forced (eg, animal models using running wheel lock or hindlimb unloading), can influence precursors of CVD and diabetes mellitus. There is evidence that important effects of increasing physical activity can be mediated centrally through the brain[129–131] and that the metabolic and vascular consequences of inadequate physical activity appear to be mediated primarily through peripheral tissues and cells, including muscle, adipose tissue, and endothelial and inflammatory cells.[132] There is considerable cross talk between skeletal muscle, adipose tissue, and other organs and tissues,[133] and it is likely that physical inactivity (and potentially sedentary behavior) could lead to CVD or diabetes mellitus through a complex systemic network of responses.

An immediate result of a change from a high physical activity state to a highly sedentary state is a reduction in muscle and systemic insulin sensitivity, and if the resulting energy imbalance is sustained, adipose tissue will expand.[134] The consequences of energy surplus, adiposity, and insulin resistance on inflammation and CVD risk have been well described.[135–137] Additionally, postprandial glucose spikes are regular daily exposures that can promote oxidative stress, triggering a biochemical inflammatory cascade, endothelial dysfunction, and sympathetic hyperactivity. This creates a chronic biological state of exaggerated postprandial dysmetabolism, a milieu conducive for the development of atherosclerosis and CVD.[138,139] A decrease in insulin sensitivity that results from becoming sedentary can occur independent of increased adiposity or energy surplus. Relative to the physically active condition, 3 days of inactivity (reduction in daily steps from ≈12 000 to 5000) resulted in significantly higher postprandial glucose concentrations obtained from a free-living diet, with no change in weight.[140] Stephens et al[141] found that compared with a low physical activity but minimal sitting condition (<6 hours per day), 41% greater insulin was required after a standard glucose infusion after 1 day in the high sitting condition (>16 hours per day) when in positive energy balance, and 20% greater insulin was required in the high sitting/energy balance condition. When 7 hours of sitting time was broken up by 2-minute bouts of either light or moderate activity every 20 minutes, insulin sensitivity in response to a standard glucose load was increased compared with uninterrupted sitting.[142] These studies exemplify the short-term peripheral effects of becoming sedentary and how they can be mitigated with even light physical activity. How these physiological changes might progress to pathophysiological changes has not yet been demonstrated in animal or human studies.

Blood flow increases from a seated to a standing position and is further increased during physical activity in response to increased oxygen requirements in muscle. The increase in blood flow affects the vasculature through both mechanical and molecular signaling, with increased shear stress, as well as increases in signaling molecules and vasodilators.[143] The absence of exercise-induced hemodynamic vascular signaling brought on by sedentary behavior is thought to lead to dysregulation and development of inflammatory-mediated atherogenesis,[132] as well as altered muscle gene expression.[144] Acute laboratory-based studies provide some initial evidence to support this hypothesis: 5 days of inactivity (<5000 steps per day) among regularly physically active young men reduced vascular dilation function compared with the physically active state.[145] Furthermore, 3 hours of uninterrupted sitting also reduced vascular function; however, 5-minute bouts of light walking at regular intervals prevented this decline.[146]

There are clearly physiological changes that occur when physically active individuals become inactive. Changes can also be detected in experiments testing prolonged sitting conditions. Despite these potentially relevant findings on how physical inactivity can be associated with biological dysregulation, we do not have direct evidence that this leads to CVD. Additionally, the distinction between the positive benefits of MVPA and the deleterious consequences of physical inactivity versus the newly identified negative effects of sedentary behavior remains unresolved.[128] For example, is CVD risk in sedentary behavior mediated primarily through the absence of exercise-derived signaling molecules or through adverse signaling that occurs specifically through sedentary behavior? Further studies in animals and humans and increased use of unbiased profiling techniques could shed light on additional molecular mediators of sedentary behavior-associated CVD risk and pave the way for novel therapeutic options.

Summary of Key Findings: Potential Mechanisms

- Sedentary behavior might increase CVD and diabetes mellitus risk through distinct mechanisms that are independent of MVPA; however, further study is needed.
- Reduced insulin sensitivity is found during prolonged sedentary behavior that can be mitigated with short bouts of physical activity.
- Substantially more research using animal and human models is needed to understand pathophysiological changes that support the epidemiological research findings.

INTERVENTIONS TO REDUCE SEDENTARY BEHAVIOR

There is a modest body of evidence on interventions with adults to reduce sedentary behavior. These have focused primarily on those settings most associated with sedentary behavior: TV viewing and the workplace. More recent interventions have used technology to encourage participants to take breaks from prolonged sitting. Few interventions have included participants from a range of sociodemographic and cultural backgrounds.[147]

In a systematic review of interventions for reducing sedentary time in adults, Prince et al[148] performed a meta-analysis of 7 interventions, the primary focus of which

Circulation. 2016;134:e262–e279. DOI: 10.1161/CIR.0000000000000440

was the reduction of sedentary behavior. The interventions focused on reducing overall sitting time or sitting in the workplace. They found that these interventions resulted in a significant and clinically meaningful reduction in self-reported and objectively measured sedentary time, with a mean difference of 91 minutes per day between the intervention and control groups. The quality of the studies was classified as very low and moderate, however, which implies that further research is needed to provide confidence in the estimate. In the same review, they also performed meta-analyses on interventions that measured sedentary behavior but were primarily focused on physical activity (n=22) or both physical activity and sedentary behavior (n=6). In these studies, the effect sizes were modest, with a mean difference of 19 minutes per day between the intervention and control groups in the physical activity–focused interventions and 35 minutes per day in the 6 interventions that focused on both behaviors. These results suggest that to reduce sedentary time, an intervention must focus specifically on the behavior rather than intend for a reduction of sedentary behavior to be a carryover effect of increasing physical activity.

Many workplace-based interventions have used activity-permissive workstations to reduce sedentary behavior by enabling office workers to stand, walk, or pedal while working at their usual computer and other desk-based job tasks. In a meta-analysis of 8 interventions using activity-permissive workstations, Neuhaus et al[149] reported a mean difference in intervention and control groups of 77 minutes per 8-hour workday, which suggests that installation of such workstations can lead to substantial reductions in sedentary time.

There is increasing interest in using technology to reduce sedentary behavior, for example, using smartphone applications (apps) to interrupt sedentary time. These technologies offer the potential to deliver time- and context-sensitive health information across a broad segment of the population.[150] Smartphone apps can be designed that incorporate behavior change theory strategies (self-monitoring, goal setting, positive reinforcement)[151] and social networking[152] and provide just-in-time interventions in which prolonged sedentary behavior is detected in real time and participants are then encouraged to engage in brief physical activity breaks of at least light intensity.[153,154] Recently, Bond et al[153] used a smartphone app to monitor and interrupt sedentary behavior in real time in 30 overweight or obese adults. Participants were presented with 3 smartphone-based physical activity break conditions in counterbalanced order: (1) 3-minute break after 30 minutes of sitting time; (2) 6-minute break after 60 minutes; or (3) 12-minute break after 60 minutes. Participants followed each condition for 7 days. All 3 of the break conditions yielded significant decreases in sedentary time, with the 3-minute break condition being superior to the 12-minute break condition. As rates of smartphone ownership continue to increase, it is likely that future interventions for reducing sedentary behavior will rely on mobile apps because of their adaptability and scalability, so that interventions can be conducted on larger samples across multiple populations in a variety of different settings.

Key Findings: Interventions

- Interventions focusing solely on reducing sedentary behavior appear to be more effective at reducing sedentary behavior than those that include strategies for both increasing physical activity and reducing sedentary behaviors.
- The use of technology to reduce sedentary behaviors requires further study but appears promising.

RECOMMENDATIONS FOR FUTURE RESEARCH ON SEDENTARY BEHAVIOR

As indicated by the reference list that accompanies this science advisory, the scientific evidence for the deleterious CVD effects of sedentary behavior is quite recent. Thus, the future research needs are vast.

Reliable, valid, precise, and standard measures of sedentary behavior are needed for both self-report and objective assessments. Researchers working in this field have a unique opportunity to come to a consensus on a set of self-report instruments that assess sedentary behavior across the various behavior domains and protocols, data processing methods, and summaries of sedentary time using devices. Common sets of measurements will allow for meaningful systematic reviews and meta-analysis results. With common measurement instruments, researchers can more accurately ascertain which population subgroups are at increased risk for being sedentary and in which contexts. We will also learn more about where sedentary behaviors are most likely to occur and what domains are associated with the greatest CVD risk.

The risk of adverse CVD and diabetes mellitus outcomes associated with sedentary behavior must be quantified. This is necessary to produce specific guidelines for limits of sedentary time and in which contexts sedentary behavior might be particularly deleterious. Evidence is insufficient to determine a threshold for how much sedentary behavior is too much; a linear, dose-response pattern with no identifiable threshold is a possibility. Valid and reliable instruments are key to accurately assess the patterns of association between sedentary behavior and adverse CVD outcomes. Advanced analytic techniques may be needed to understand the cardiovascular health risks across the continuum of movement behaviors. Identification of the amounts or patterns of sedentary behavior at which cardiovascular risk becomes elevated is a key research issue.

Surveillance on the prevalence of sedentary behavior among the population must continue. National surveillance should be made with valid and reliable sedentary behavior assessment methods. Surveillance should include not only overall sedentary behavior but also the contexts in which the behaviors occur and the time spent in different sedentary behaviors.

More data are needed to determine sociodemographic characteristics for those who are at greatest risk for sedentary behavior. Current data are inconsistent regarding what demographic characteristics are associated with higher sedentary behavior participation. High-quality research is needed to identify groups at higher risk according to age, sex, race/ethnicity, occupation, and socioeconomic status. It is also important to understand how specific sedentary behaviors might vary by sociodemographic characteristics.

Covariates associated with sedentary behavior need to be identified. Spurious associations could result if the incorrect covariates are included in analytical models that assess associations between sedentary behavior and health outcomes. To date, researchers have been including covariates that are known to be associated with physical activity or those that might be associated with the outcome of interest. The scientific base is currently too sparse to recommend the appropriate covariates that should be included in data analyses.

Potential mechanisms for the observed associations between sedentary behavior and outcomes must be investigated. Evidence remains scarce, relying essentially on a few animal models. Future studies should carefully parse out differences of effects of being sedentary per se from reduction in physical activity. Randomized trials could contribute to understanding this distinction. The few short-term physiological studies conducted to date are informative, but more human studies are needed; recent advances in human genetics and other "omics" technology could help to reveal biological mechanisms. It is hoped that a better understanding of mechanisms will inform interventions and support clinical and public health recommendations. To accomplish this work, considerably more researchers are required, with expertise ranging from genomics to population science.

Risk factors for sedentary behaviors need to be identified. There is a paucity of prospective data on modifiable risk factors for sedentary behaviors, from personal psychological characteristics to microenvironmental and macroenvironmental factors. Both observational prospective cohort and intervention studies, including randomized trials, are necessary to address these gaps. A cadre of researchers studying sedentary behavior through the social ecological lens will allow for scientific discovery at the genetic through the policy level. This broad spectrum of inquiry should be encouraged and, if possible, systematized. Interventions are needed to understand whether changes in sedentary behavior can change outcomes, then to understand the underlying mechanisms and whether policy- or environment-level changes can reduce time spent in sedentary behaviors.

Interventions are critical to determine whether reductions in sedentary time can reduce the risk of CVD and diabetes mellitus. Current findings suggest that it is possible to create interventions to reduce sedentary time; future studies should also assess whether sedentary-reduction interventions lead to improvements in CVD health and reduction of adverse outcomes. Randomized controlled trials are needed to produce the strongest evidence. Trials that compare different doses of reduced sedentary time on outcomes are needed. This is especially critical for development of an evidence base for quantitative sedentary behavior guidelines. Both individual and community-based interventions, as well as a combination of the two, should be proposed and evaluated.

As displayed in the Figure, adults spend about as much daily time in light activities as they do in sedentary behaviors. This could represent a huge potential to decrease sedentary time and increase time spent in light activities. However, we know virtually nothing about the cardiovascular health benefits of doing "something," or engaging in light activities. A comparison of the health benefits of promoting MVPA to those of reducing sitting time by 3 to 6 hours per day could eventually result in different public health recommendations.[155]

CONCLUSIONS

The evidence to date is suggestive, but not conclusive, that sedentary behavior contributes to CVD and diabetes mellitus risk. Nonetheless, there is evidence to suggest that sedentary behavior could contribute to excess morbidity and mortality. However, there currently is insufficient evidence on which to base specific public health recommendations regarding the appropriate limit to the amount of sedentary behavior required to maximize CVD health benefits. Given the current state of the science on sedentary behavior and in the absence of sufficient data to recommend quantitative guidelines, it is appropriate to promote the advisory, "Sit less, move more."

FOOTNOTES

The American Heart Association makes every effort to avoid any actual or potential conflicts of interest that may arise as a result of an outside relationship or a personal, professional, or business interest of a member of the writing panel. Specifically, all members of the writing group are required to complete and submit a Disclosure Questionnaire showing all such relationships that might be perceived as real or potential conflicts of interest.

This advisory was approved by the American Heart Association Science Advisory and Coordinating Committee on February 15, 2016, and the American Heart Association Executive Committee on March 28, 2016. A copy of the document is available at http://professional.heart.org/statements by using either "Search for Guidelines & Statements" or the "Browse by Topic" area. To purchase additional reprints, call 843-216-2533 or e-mail kelle.ramsay@wolterskluwer.com.

The American Heart Association requests that this document be cited as follows: Young DR, Hivert M-F, Alhassan S, Camhi SM, Ferguson JF, Katzmarzyk PT, Lewis CE, Owen N, Perry CK, Siddique J, Yong CM; on behalf of the Physical Activity Committee of the Council on Lifestyle and Cardiometabolic Health; Council on Clinical Cardiology; Council on Epidemiology and Prevention; Council on Functional Genomics and Translational Biology; and Stroke Council. Sedentary behavior and cardiovascular morbidity and mortality: a science advisory from the American Heart Association. *Circulation*. 2016;134:e262–e279. doi: 10.1161/CIR.0000000000000440.

Expert peer review of AHA Scientific Statements is conducted by the AHA Office of Science Operations. For more on AHA statements and guidelines development, visit http://professional.heart.org/statements. Select the "Guidelines & Statements" drop-down menu, then click "Publication Development."

Circulation is available at http://circ.ahajournals.org.

DISCLOSURES

Writing Group Disclosures

Writing Group Member	Employment	Research Grant	Other Research Support	Speakers' Bureau/ Honoraria	Expert Witness	Ownership Interest	Consultant/ Advisory Board	Other
Deborah Rohm Young	Kaiser Permanente Southern California	None	None	None	None	None	None	None
Marie-France Hivert	Harvard Pilgrim Health Care Institute	None	None	None	None	None	None	None
Sofiya Alhassan	University of Massachusetts	None	None	None	None	None	None	None
Sarah M. Camhi	University of Massachusetts	None	None	None	None	None	None	None
Jane F. Ferguson	Vanderbilt University Medical Center	None	None	None	None	None	None	None
Peter T. Katzmarzyk	Pennington Biomedical Research Center	None	None	None	None	None	None	None
Cora E. Lewis	University of Alabama at Birmingham	NIH*	None	None	None	None	None	None
Neville Owen	Baker IDI Heart and Diabetes Institute, Melbourne	National Health and Medical Research Council of Australia*	None	None	None	None	None	National Health and Medical Research Council of Australia*
Cynthia K. Perry	Oregon Health & Science University	None	None	None	None	None	None	None
Juned Siddique	Northwestern University	None	None	None	None	None	None	None
Celina M. Yong	Stanford University	None	None	None	None	None	None	None

This table represents the relationships of writing group members that may be perceived as actual or reasonably perceived conflicts of interest as reported on the Disclosure Questionnaire, which all members of the writing group are required to complete and submit. A relationship is considered to be "significant" if (a) the person receives $10 000 or more during any 12-month period, or 5% or more of the person's gross income; or (b) the person owns 5% or more of the voting stock or share of the entity, or owns $10 000 or more of the fair market value of the entity. A relationship is considered to be "modest" if it is less than "significant" under the preceding definition.

*Significant.

CLINICAL STATEMENTS AND GUIDELINES

Reviewer Disclosures

Reviewer	Employment	Research Grant	Other Research Support	Speakers' Bureau/ Honoraria	Expert Witness	Ownership Interest	Consultant/ Advisory Board	Other
David Buchner	University of Illinois	NIH* (Co-PI on a grant from NIH that uses accelerometers to assess physical activity and sedentary behavior)	None	None	None	None	None	None
I-Min Lee	Harvard Medical School	NIH† (PI of grant on objectively assessed physical activity, sedentary behavior, and health outcomes)	None	None	None	None	Virgin Pulse*	None
Mark Tremblay	CHEO Research Institute (CANADA)	None	None	None	None	None	None	None

This table represents the relationships of reviewers that may be perceived as actual or reasonably perceived conflicts of interest as reported on the Disclosure Questionnaire, which all reviewers are required to complete and submit. A relationship is considered to be "significant" if (a) the person receives $10 000 or more during any 12-month period, or 5% or more of the person's gross income; or (b) the person owns 5% or more of the voting stock or share of the entity, or owns $10 000 or more of the fair market value of the entity. A relationship is considered to be "modest" if it is less than "significant" under the preceding definition.

*Modest.

†Significant.

REFERENCES

1. US Department of Health and Human Services. *2008 Physical Activity Guidelines for Americans*. Washington, DC: US Department of Health and Human Services; 2008.
2. *Australia's Physical Activity and Sedentary Behaviour Guidelines for Adults (18–64 years)*. Canberra, Australia: Australian Government Department of Health; 2014.
3. UK Department of Health. *Start Active, Stay Active: A Report on Physical Activity for Health from the Four Home Countries' Chief Medical Officers*. London, England: Crown Copyright; 2011.
4. Dictionary.com LLC. Sedentary [definition]. http://dictionary.Reference.Com/browse/sedentary. Accessed June 19, 2015.
5. Saunders TJ, Chaput JP, Tremblay MS. Sedentary behaviour as an emerging risk factor for cardiometabolic diseases in children and youth. *Can J Diabetes*. 2014;38:53–61. doi: 10.1016/j.jcjd.2013.08.266.
6. Matthews CE, Chen KY, Freedson PS, Buchowski MS, Beech BM, Pate RR, Troiano RP. Amount of time spent in sedentary behaviors in the United States, 2003-2004. *Am J Epidemiol*. 2008;167:875–881. doi: 10.1093/aje/kwm390.
7. Schuna JM Jr, Johnson WD, Tudor-Locke C. Adult self-reported and objectively monitored physical activity and sedentary behavior: NHANES 2005-2006. *Int J Behav Nutr Phys Act*. 2013;10:126. doi: 10.1186/1479-5868-10-126.
8. Troiano RP, Berrigan D, Dodd KW, Mâsse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. *Med Sci Sports Exerc*. 2008;40:181–188. doi: 10.1249/mss.0b013e31815a51b3.
9. Sedentary Behaviour Research Network. Standardized use of the terms "sedentary" and "sedentary behaviours." *Appl Physiol Nutr Metab*. 2012;37:540–542. doi: 10.1139/h2012-024.
10. Ainsworth BE, Haskell WL, Whitt MC, Irwin ML, Swartz AM, Strath SJ, O'Brien WL, Bassett DR Jr, Schmitz KH, Emplaincourt PO, Jacobs DR Jr, Leon AS. Compendium of physical activities: an update of activity codes and MET intensities. *Med Sci Sports Exerc*. 2000;32(suppl):S498–S504.
11. Strath SJ, Kaminsky LA, Ainsworth BE, Ekelund U, Freedson PS, Gary RA, Richardson CR, Smith DT, Swartz AM; on behalf of the American Heart Association Physical Activity Committee of the Council on Lifestyle and Cardiometabolic Health and Cardiovascular, Exercise, Cardiac Rehabilitation and Prevention Committee of the Council on Clinical Cardiology, and Council on Cardiovascular and Stroke Nursing. Guide to the assessment of physical activity: clinical and research applications: a scientific statement from the American Heart Association. *Circulation*. 2013;128:2259–2279. doi: 10.1161/01.cir.0000435708.67487.da.
12. Sallis JF, Owen N. Ecological models of health behavior. In: Glanz K, Rimer BK, Viswanath K, eds. *Health Behavior: Theory, Research, and Practice*. San Francisco, CA: Jossey-Bass; 2015:23–42.
13. Owen N. Ambulatory monitoring and sedentary behaviour: a population-health perspective. *Physiol Meas*. 2012;33:1801–1810. doi: 10.1088/0967-3334/33/11/1801.
14. Healy GN, Clark BK, Winkler EA, Gardiner PA, Brown WJ, Matthews CE. Measurement of adults' sedentary time in population-based studies. *Am J Prev Med*. 2011;41:216–227. doi: 10.1016/j.amepre.2011.05.005.
15. Troiano RP, Pettee Gabriel KK, Welk GJ, Owen N, Sternfeld B. Reported physical activity and sedentary behavior: why do you ask? *J Phys Act Health*. 2012;(suppl 1):S68–S75.
16. Owen N, Salmon J, Koohsari MJ, Turrell G, Giles-Corti B. Sedentary behaviour and health: mapping environmental and social contexts to underpin chronic disease prevention. *Br J Sports Med*. 2014;48:174–177. doi: 10.1136/bjsports-2013-093107.
17. Clark BK, Sugiyama T, Healy GN, Salmon J, Dunstan DW, Owen N. Validity and reliability of measures of television viewing time and other non-occupational sedentary behaviour of adults: a review. *Obes Rev*. 2009;10:7–16. doi: 10.1111/j.1467-789X.2008.00508.x.
18. Clark BK, Healy GN, Winkler EA, Gardiner PA, Sugiyama T, Dunstan DW, Matthews CE, Owen N. Relationship of television time with accelerometer-derived sedentary time: NHANES. *Med Sci Sports Exerc*. 2011;43:822–828. doi: 10.1249/MSS.0b013e3182019510.
19. Thorp AA, Healy GN, Winkler E, Clark BK, Gardiner PA, Owen N, Dunstan DW. Prolonged sedentary time and physical activity in workplace and non-work contexts: a cross-sectional study of office, customer service and call centre employees. *Int J Behav Nutr Phys Act*. 2012;9:128. doi: 10.1186/1479-5868-9-128.

20. Sugiyama T, Ding D, Owen N. Commuting by car: weight gain among physically active adults. *Am J Prev Med*. 2013;44:169–173. doi: 10.1016/j.amepre.2012.09.063.
21. Sedentary behavior questionnaires. Sedentary Behaviour Research Network Web site. http://www.sedentarybehaviour.org/sedentary-behaviour-questionnaires/. Accessed April 28, 2015.
22. Sternfeld B, Goldman-Rosas L. A systematic approach to selecting an appropriate measure of self-reported physical activity or sedentary behavior. *J Phys Act Health*. 2012;9(suppl 1):S19–S28.
23. Plasqui G, Bonomi AG, Westerterp KR. Daily physical activity assessment with accelerometers: new insights and validation studies. *Obes Rev*. 2013;14:451–462. doi: 10.1111/obr.12021.
24. Esliger DW, Tremblay MS. Technical reliability assessment of three accelerometer models in a mechanical setup. *Med Sci Sports Exerc*. 2006;38:2173–2181. doi: 10.1249/01.mss.0000239394.55461.08.
25. Mannini A, Intille SS, Rosenberger M, Sabatini AM, Haskell W. Activity recognition using a single accelerometer placed at the wrist or ankle [published correction appears in *Med Sci Sports Exerc*. 2015;47:448–449]. *Med Sci Sports Exerc*. 2013;45:2193–2203. doi: 10.1249/MSS.0b013e31829736d6.
26. Rosenberger ME, Haskell WL, Albinali F, Mota S, Nawyn J, Intille S. Estimating activity and sedentary behavior from an accelerometer on the hip or wrist. *Med Sci Sports Exerc*. 2013;45:964–975. doi: 10.1249/MSS.0b013e31827f0d9c.
27. Staudenmayer J, Pober D, Crouter S, Bassett D, Freedson P. An artificial neural network to estimate physical activity energy expenditure and identify physical activity type from an accelerometer. *J Appl Physiol (1985)*. 2009;107:1300–1307. doi: 10.1152/japplphysiol.00465.2009.
28. Rowlands AV, Olds TS, Hillsdon M, Pulsford R, Hurst TL, Eston RG, Gomersall SR, Johnston K, Langford J. Assessing sedentary behavior with the GENEActiv: introducing the sedentary sphere. *Med Sci Sports Exerc*. 2014;46:1235–1247. doi: 10.1249/MSS.0000000000000224.
29. Gibbs BB, Hergenroeder AL, Katzmarzyk PT, Lee IM, Jakicic JM. Definition, measurement, and health risks associated with sedentary behavior. *Med Sci Sports Exerc*. 2014;47:1295–1300. doi: 10.1249/MSS.0000000000000517.
30. Levine J, Melanson EL, Westerterp KR, Hill JO. Tracmor system for measuring walking energy expenditure. *Eur J Clin Nutr*. 2003;57:1176–1180. doi: 10.1038/sj.ejcn.1601673.
31. Zhang K, Pi-Sunyer FX, Boozer CN. Improving energy expenditure estimation for physical activity. *Med Sci Sports Exerc*. 2004;36:883–889.
32. Grant PM, Ryan CG, Tigbe WW, Granat MH. The validation of a novel activity monitor in the measurement of posture and motion during everyday activities. *Br J Sports Med*. 2006;40:992–997. doi: 10.1136/bjsm.2006.030262.
33. Carr LJ, Mahar MT. Accuracy of intensity and inclinometer output of three activity monitors for identification of sedentary behavior and light-intensity activity. *J Obes*. 2012;2012:460271. doi: 10.1155/2012/460271.
34. Kerr J, Marshall SJ, Godbole S, Chen J, Legge A, Doherty AR, Kelly P, Oliver M, Badland HM, Foster C. Using the SenseCam to improve classifications of sedentary behavior in free-living settings. *Am J Prev Med*. 2013;44:290–296. doi: 10.1016/j.amepre.2012.11.004.
35. Tudor-Locke C, Camhi SM, Troiano RP. A catalog of rules, variables, and definitions applied to accelerometer data in the National Health and Nutrition Examination Survey, 2003-2006. *Prev Chronic Dis*. 2012;9: 110332.
36. Kim Y, Lee JM, Peters BP, Gaesser GA, Welk GJ. Examination of different accelerometer cut-points for assessing sedentary behaviors in children. *PLoS One*. 2014;9:e90630. doi: 10.1371/journal.pone.0090630.
37. Winkler EA, Gardiner PA, Clark BK, Matthews CE, Owen N, Healy GN. Identifying sedentary time using automated estimates of accelerometer wear time. *Br J Sports Med*. 2012;46:436–442. doi: 10.1136/bjsm.2010.079699.
38. Church TS, Thomas DM, Tudor-Locke C, Katzmarzyk PT, Earnest CP, Rodarte RQ, Martin CK, Blair SN, Bouchard C. Trends over 5 decades in U.S. occupation-related physical activity and their associations with obesity. *PLoS One*. 2011;6:e19657. doi: 10.1371/journal.pone.0019657.
39. Ng SW, Popkin BM. Time use and physical activity: a shift away from movement across the globe. *Obes Rev*. 2012;13:659–680. doi: 10.1111/j.1467-789X.2011.00982.x.
40. Ekelund U, Brage S, Griffin SJ, Wareham NJ; ProActive UK Research Group. Objectively measured moderate- and vigorous-intensity physical activity but not sedentary time predicts insulin resistance in high-risk individuals. *Diabetes Care*. 2009;32:1081–1086. doi: 10.2337/dc08-1895.
41. Stamatakis E, Coombs N, Rowlands A, Shelton N, Hillsdon M. Objectively-assessed and self-reported sedentary time in relation to multiple socioeconomic status indicators among adults in England: a cross-sectional study. *BMJ Open*. 2014;4:e006034. doi: 10.1136/bmjopen-2014-006034.
42. Clemes SA, O'Connell SE, Edwardson CL. Office workers' objectively measured sedentary behavior and physical activity during and outside working hours. *J Occup Environ Med*. 2014;56:298–303. doi: 10.1097/JOM.0000000000000101.
43. Evenson KR, Buchner DM, Morland KB. Objective measurement of physical activity and sedentary behavior among US adults aged 60 years or older. *Prev Chronic Dis*. 2012;9:E26.
44. Gennuso KP, Gangnon RE, Matthews CE, Thraen-Borowski KM, Colbert LH. Sedentary behavior, physical activity, and markers of health in older adults. *Med Sci Sports Exerc*. 2013;45:1493–1500. doi: 10.1249/MSS.0b013e318288a1e5.
45. Bankoski A, Harris TB, McClain JJ, Brychta RJ, Caserotti P, Chen KY, Berrigan D, Troiano RP, Koster A. Sedentary activity associated with metabolic syndrome independent of physical activity. *Diabetes Care*. 2011;34:497–503. doi: 10.2337/dc10-0987.
46. Santos DA, Silva AM, Baptista F, Santos R, Vale S, Mota J, Sardinha LB. Sedentary behavior and physical activity are independently related to functional fitness in older adults. *Exp Gerontol*. 2012;47:908–912. doi: 10.1016/j.exger.2012.07.011.
47. Harvey JA, Chastin SF, Skelton DA. Prevalence of sedentary behavior in older adults: a systematic review. *Int J Environ Res Public Health*. 2013;10:6645–6661. doi: 10.3390/ijerph10126645.
48. Gorman E, Hanson HM, Yang PH, Khan KM, Liu-Ambrose T, Ashe MC. Accelerometry analysis of physical activity and sedentary behavior in older adults: a systematic review and data analysis. *Eur Rev Aging Phys Act*. 2014;11:35–49. doi: 10.1007/s11556-013-0132-x.
49. Rhodes RE, Mark RS, Temmel CP. Adult sedentary behavior: a systematic review. *Am J Prev Med*. 2012;42:e3–e28. doi: 10.1016/j.amepre.2011.10.020.
50. Bennett GG, Wolin KY, Viswanath K, Askew S, Puleo E, Emmons KM. Television viewing and pedometer-determined physical activity among multiethnic residents of low-income housing. *Am J Public Health*. 2006;96:1681–1685. doi: 10.2105/AJPH.2005.080580.
51. Larsen BA, Martin L, Strong DR. Sedentary behavior and prevalent diabetes in Non-Latino Whites, Non-Latino Blacks and Latinos: findings from the National Health Interview Survey. *J Public Health (Oxf)*. 2015;37:634–640. doi: 10.1093/pubmed/fdu103.
52. Bauman A, Ainsworth BE, Sallis JF, Hagströmer M, Craig CL, Bull FC, Pratt M, Venugopal K, Chau J, Sjöström M; IPS Group. The descriptive epidemiology of sitting: a 20-country comparison using the International Physical Activity Questionnaire (IPAQ). *Am J Prev Med*. 2011;41:228–235. doi: 10.1016/j.amepre.2011.05.003.

53. Bennie JA, Chau JY, van der Ploeg HP, Stamatakis E, Do A, Bauman A. The prevalence and correlates of sitting in European adults: a comparison of 32 Eurobarometer-participating countries. *Int J Behav Nutr Phys Act*. 2013;10:107. doi: 10.1186/1479-5868-10-107.
54. Dempsey PC, Howard BJ, Lynch BM, Owen N, Dunstan DW. Associations of television viewing time with adults' well-being and vitality. *Prev Med*. 2014;69:69–74. doi: 10.1016/j.ypmed.2014.09.007.
55. Clemes SA, Houdmont J, Munir F, Wilson K, Kerr R, Addley K. Descriptive epidemiology of domain-specific sitting in working adults: the Stormont study. *J Public Health (Oxf)*. 2016;38:53–60. doi: 10.1093/pubmed/fdu114.
56. Bowman SA. Television-viewing characteristics of adults: correlations to eating practices and overweight and health status. *Prev Chronic Dis*. 2006;3:A38.
57. Shields M, Tremblay MS. Screen time among Canadian adults: a profile. *Health Rep*. 2008;19:31–43.
58. 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;289:1785–1791. doi: 10.1001/jama.289.14.1785.
59. Proper KI, Cerin E, Brown WJ, Owen N. Sitting time and socioeconomic differences in overweight and obesity. *Int J Obes (Lond)*. 2007;31:169–176. doi: 10.1038/sj.ijo.0803357.
60. Ballard M, Gray M, Reilly J, Noggle M. Correlates of video game screen time among males: body mass, physical activity, and other media use. *Eat Behav*. 2009;10:161–167. doi: 10.1016/j.eatbeh.2009.05.001.
61. Banks E, Jorm L, Rogers K, Clements M, Bauman A. Screen-time, obesity, ageing and disability: findings from 91 266 participants in the 45 and Up Study. *Public Health Nutr*. 2011;14:34–43. doi: 10.1017/S1368980010000674.
62. Beunza JJ, Martínez-González MA, Ebrahim S, Bes-Rastrollo M, Núñez J, Martínez JA, Alonso A. Sedentary behaviors and the risk of incident hypertension: the SUN Cohort. *Am J Hypertens*. 2007;20:1156–1162. doi: 10.1016/j.amjhyper.2007.06.007.
63. Buckworth J, Nigg C. Physical activity, exercise, and sedentary behavior in college students. *J Am Coll Health*. 2004;53:28–34. doi: 10.3200/JACH.53.1.28-34.
64. Ekelund U, Brage S, Besson H, Sharp S, Wareham NJ. Time spent being sedentary and weight gain in healthy adults: reverse or bidirectional causality? *Am J Clin Nutr*. 2008;88:612–617.
65. Kronenberg F, Pereira MA, Schmitz MK, Arnett DK, Evenson KR, Crapo RO, Jensen RL, Burke GL, Sholinsky P, Ellison RC, Hunt SC. Influence of leisure time physical activity and television watching on atherosclerosis risk factors in the NHLBI Family Heart Study. *Atherosclerosis*. 2000;153:433–443.
66. Ogletree SM, Drake R. College students' video game participation and perceptions: gender differences and implications. *Sex Roles*. 2007;56:537–542. doi: 10.1007/s11199-007-9193-5.
67. Rastogi T, Vaz M, Spiegelman D, Reddy KS, Bharathi AV, Stampfer MJ, Willett WC, Ascherio A. Physical activity and risk of coronary heart disease in India. *Int J Epidemiol*. 2004;33:759–767. doi: 10.1093/ije/dyh042.
68. 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;14:1816–1824. doi: 10.1038/oby.2006.209.
69. 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;24:600–606.
70. Yang H, Oliver MB. Exploring the effects of television viewing on perceived life quality: a combined perspective of material value and upward social comparison. *Mass Commun Soc*. 2010;13:118–138. doi: 10.1080/15205430903180685.
71. King AC, Goldberg JH, Salmon J, Owen N, Dunstan D, Weber D, Doyle C, Robinson TN. Identifying subgroups of U.S. adults at risk for prolonged television viewing to inform program development. *Am J Prev Med*. 2010;38:17–26. doi: 10.1016/j.amepre.2009.08.032.
72. Evenson KR, McGinn AP. Test-retest reliability of adult surveillance measures for physical activity and inactivity. *Am J Prev Med*. 2005;28:470–478. doi: 10.1016/j.amepre.2005.02.005.
73. Sirgy MJ, Lee D, Kosenko R, Kosenko R, Meadow HL, Rahtz D, Cicic M, Jin GX, Yarsuvat D, Blenkhorn DI, Wright N. Does television viewership play a role in the perception of quality of life? *J Advert*. 1998;27:125–142.
74. Owen N, Sugiyama T, Eakin EE, Gardiner PA, Tremblay MS, Sallis JF. Adults' sedentary behavior determinants and interventions. *Am J Prev Med*. 2011;41:189–196. doi: 10.1016/j.amepre.2011.05.013.
75. Buman MP, Hekler EB, Haskell WL, Pruitt L, Conway TL, Cain KL, Sallis JF, Saelens BE, Frank LD, King AC. Objective light-intensity physical activity associations with rated health in older adults. *Am J Epidemiol*. 2010;172:1155–1165. doi: 10.1093/aje/kwq249.
76. Davies CA, Vandelanotte C, Duncan MJ, van Uffelen JG. Associations of physical activity and screen-time on health related quality of life in adults. *Prev Med*. 2012;55:46–49. doi: 10.1016/j.ypmed.2012.05.003.
77. Rebar AL, Duncan MJ, Short C, Vandelanotte C. Differences in health-related quality of life between three clusters of physical activity, sitting time, depression, anxiety, and stress. *BMC Public Health*. 2014;14:1088. doi: 10.1186/1471-2458-14-1088.
78. van Uffelen JG, van Gellecum YR, Burton NW, Peeters G, Heesch KC, Brown WJ. Sitting-time, physical activity, and depressive symptoms in mid-aged women. *Am J Prev Med*. 2013;45:276–281. doi: 10.1016/j.amepre.2013.04.009.
79. 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;22:178–188.
80. Van Holle V, McNaughton SA, Teychenne M, Timperio A, Van Dyck D, De Bourdeaudhuij I, Salmon J. Social and physical environmental correlates of adults' weekend sitting time and moderating effects of retirement status and physical health. *Int J Environ Res Public Health*. 2014;11:9790–9810. doi: 10.3390/ijerph110909790.
81. Van Dyck D, Cardon G, Deforche B, Owen N, De Cocker K, Wijndaele K, De Bourdeaudhuij I. Socio-demographic, psychosocial and home-environmental attributes associated with adults' domestic screen time. *BMC Public Health*. 2011;11:668. doi: 10.1186/1471-2458-11-668.
82. De Cocker K, Duncan MJ, Short C, van Uffelen JG, Vandelanotte C. Understanding occupational sitting: prevalence, correlates and moderating effects in Australian employees. *Prev Med*. 2014;67:288–294. doi: 10.1016/j.ypmed.2014.07.031.
83. Koohsari MJ, Sugiyama T, Sahlqvist S, Mavoa S, Hadgraft N, Owen N. Neighborhood environmental attributes and adults' sedentary behaviors: review and research agenda. *Prev Med*. 2015;77:141–149. doi: 10.1016/j.ypmed.2015.05.027.
84. Roemmich JN, Beeler JE, Johnson L. A microenvironment approach to reducing sedentary time and increasing physical activity of children and adults at a playground. *Prev Med*. 2014;62:108–112. doi: 10.1016/j.ypmed.2014.01.018.
85. Lee RE, Mama SK, Adamus-Leach HJ. Neighborhood street scale elements, sedentary time and cardiometabolic risk factors in inactive ethnic minority women. *PLoS One*. 2012;7:e51081. doi: 10.1371/journal.pone.0051081.
86. Van Dyck D, Cerin E, Conway TL, De Bourdeaudhuij I, Owen N, Kerr J, Cardon G, Frank LD, Saelens BE, Sallis JF. Associations between perceived neighborhood environmental attributes and adults' sedentary behavior: findings from the U.S.A., Australia and Belgium. *Soc Sci Med*. 2012;74:1375–1384. doi: 10.1016/j.socscimed.2012.01.018.

87. Ding D, Sugiyama T, Winkler E, Cerin E, Wijndaele K, Owen N. Correlates of change in adults' television viewing time: a four-year follow-up study. *Med Sci Sports Exerc*. 2012;44:1287–1292. doi: 10.1249/MSS.0b013e31824ba87e.
88. den Hoed M, Brage S, Zhao JH, Westgate K, Nessa A, Ekelund U, Spector TD, Wareham NJ, Loos RJ. Heritability of objectively assessed daily physical activity and sedentary behavior. *Am J Clin Nutr*. 2013;98:1317–1325. doi: 10.3945/ajcn.113.069849.
89. de Vilhena e Santos DM, Katzmarzyk PT, Seabra AF, Maia JA. Genetics of physical activity and physical inactivity in humans. *Behav Genet*. 2012;42:559–578. doi: 10.1007/s10519-012-9534-1.
90. Lightfoot JT. Current understanding of the genetic basis for physical activity. *J Nutr*. 2011;141:526–530. doi: 10.3945/jn.110.127290.
91. Healy GN, Matthews CE, Dunstan DW, Winkler EA, Owen N. Sedentary time and cardio-metabolic biomarkers in US adults: NHANES 2003-06. *Eur Heart J*. 2011;32:590–597. doi: 10.1093/eurheartj/ehq451.
92. Buman MP, Winkler EA, Kurka JM, Hekler EB, Baldwin CM, Owen N, Ainsworth BE, Healy GN, Gardiner PA. Reallocating time to sleep, sedentary behaviors, or active behaviors: associations with cardiovascular disease risk biomarkers, NHANES 2005-2006. *Am J Epidemiol*. 2014;179:323–334. doi: 10.1093/aje/kwt292.
93. Matthews CE, Moore SC, Sampson J, Blair A, Xiao Q, Keadle SK, Hollenbeck A, Park Y. Mortality benefits for replacing sitting time with different physical activities. *Med Sci Sports Exerc*. 2015;47:1833–1840. doi: 10.1249/MSS.0000000000000621.
94. Roger VL, Go AS, Lloyd-Jones DM, Benjamin EJ, Berry JD, Borden WB, Bravata DM, Dai S, Ford ES, Fox CS, Fullerton HJ, Gillespie C, Hailpern SM, Heit JA, Howard VJ, Kissela BM, Kittner SJ, Lackland DT, Lichtman JH, Lisabeth LD, Makuc DM, Marcus GM, Marelli A, Matchar DB, Moy CS, Mozaffarian D, Mussolino ME, Nichol G, Paynter NP, Soliman EZ, Sorlie PD, Sotoodehnia N, Turan TN, Virani SS, Wong ND, Woo D, Turner MB; on behalf of the American Heart Association Statistics Committee and Stroke Statistics Subcommittee. Heart disease and stroke statistics—2012 update: a report from the American Heart Association [published correction appears in *Circulation*. 2012;125:e1002. doi: 10.1161/CIR.0b013e31825e7519]. *Circulation*. 2012;125:e2–e220. doi: 10.1161/CIR.0b013e31823ac046.
95. Edwardson CL, Gorely T, Davies MJ, Gray LJ, Khunti K, Wilmot EG, Yates T, Biddle SJ. Association of sedentary behaviour with metabolic syndrome: a meta-analysis. *PLoS One*. 2012;7:e34916. doi: 10.1371/journal.pone.0034916.
96. Petersen CB, Nielsen AJ, Bauman A, Tolstrup JS. Joint association of physical activity in leisure and total sitting time with metabolic syndrome amongst 15,235 Danish adults: a cross-sectional study. *Prev Med*. 2014;69:5–7. doi: 10.1016/j.ypmed.2014.08.022.
97. Gardiner PA, Healy GN, Eakin EG, Clark BK, Dunstan DW, Shaw JE, Zimmet PZ, Owen N. Associations between television viewing time and overall sitting time with the metabolic syndrome in older men and women: the Australian Diabetes, Obesity and Lifestyle study. *J Am Geriatr Soc*. 2011;59:788–796. doi: 10.1111/j.1532-5415.2011.03390.x.
98. Wagner A, Dallongeville J, Haas B, Ruidavets JB, Amouyel P, Ferrières J, Simon C, Arveiler D. Sedentary behaviour, physical activity and dietary patterns are independently associated with the metabolic syndrome. *Diabetes Metab*. 2012;38:428–435. doi: 10.1016/j.diabet.2012.04.005.
99. Mabry RM, Winkler EA, Reeves MM, Eakin EG, Owen N. Associations of physical activity and sitting time with the metabolic syndrome among Omani adults. *Obesity (Silver Spring)*. 2012;20:2290–2295. doi: 10.1038/oby.2012.26.
100. Chu AH, Moy FM. Joint association of sitting time and physical activity with metabolic risk factors among middle-aged Malays in a developing country: a cross-sectional study. *PLoS One*. 2013;8:e61723. doi: 10.1371/journal.pone.0061723.
101. Wijndaele K, Healy GN, Dunstan DW, Barnett AG, Salmon J, Shaw JE, Zimmet PZ, Owen N. Increased cardiometabolic risk is associated with increased TV viewing time. *Med Sci Sports Exerc*. 2010;42:1511–1518. doi: 10.1249/MSS.0b013e3181d322ac.
102. Shuval K, Finley CE, Barlow CE, Gabriel KP, Leonard D, Kohl HW 3rd. Sedentary behavior, cardiorespiratory fitness, physical activity, and cardiometabolic risk in men: the Cooper Center Longitudinal Study. *Mayo Clin Proc*. 2014;89:1052–1062. doi: 10.1016/j.mayocp.2014.04.026.
103. Ford ES, Schulze MB, Kröger J, Pischon T, Bergmann MM, Boeing H. Television watching and incident diabetes: Findings from the European Prospective Investigation into Cancer and Nutrition-Potsdam Study. *J Diabetes*. 2010;2:23–27. doi: 10.1111/j.1753-0407.2009.00047.x.
104. Hu FB, Leitzmann MF, Stampfer MJ, Colditz GA, Willett WC, Rimm EB. Physical activity and television watching in relation to risk for type 2 diabetes mellitus in men. *Arch Intern Med*. 2001;161:1542–1548.
105. Krishnan S, Rosenberg L, Palmer JR. Physical activity and television watching in relation to risk of type 2 diabetes: the Black Women's Health Study. *Am J Epidemiol*. 2009;169:428–434. doi: 10.1093/aje/kwn344.
106. Biswas A, Oh PI, Faulkner GE, Bajaj RR, Silver MA, Mitchell MS, Alter DA. Sedentary time and its association with risk for disease incidence, mortality, and hospitalization in adults: a systematic review and meta-analysis. *Ann Intern Med*. 2015;162:123–132. doi: 10.7326/M14-1651.
107. Grøntved A, Hu FB. Television viewing and risk of type 2 diabetes, cardiovascular disease, and all-cause mortality: a meta-analysis. *JAMA*. 2011;305:2448–2455. doi: 10.1001/jama.2011.812.
108. Proper KI, Singh AS, van Mechelen W, Chinapaw MJ. Sedentary behaviors and health outcomes among adults: a systematic review of prospective studies. *Am J Prev Med*. 2011;40:174–182. doi: 10.1016/j.amepre.2010.10.015.
109. Ford ES, Caspersen CJ. Sedentary behaviour and cardiovascular disease: a review of prospective studies. *Int J Epidemiol*. 2012;41:1338–1353. doi: 10.1093/ije/dys078.
110. Wilmot EG, Edwardson CL, Achana FA, Davies MJ, Gorely T, Gray LJ, Khunti K, Yates T, Biddle SJ. Sedentary time in adults and the association with diabetes, cardiovascular disease and death: systematic review and meta-analysis [published correction appears in *Diabetologia*. 2013;56:942–943]. *Diabetologia*. 2012;55:2895–2905. doi: 10.1007/s00125-012-2677-z.
111. Wijndaele K, Brage S, Besson H, Khaw KT, Sharp SJ, Luben R, Bhaniani A, Wareham NJ, Ekelund U. Television viewing and incident cardiovascular disease: prospective associations and mediation analysis in the EPIC Norfolk Study. *PLoS One*. 2011;6:e20058. doi: 10.1371/journal.pone.0020058.
112. Stamatakis E, Hamer M, Dunstan DW. Screen-based entertainment time, all-cause mortality, and cardiovascular events: population-based study with ongoing mortality and hospital events follow-up [published correction appears in *J Am Coll Cardiol*. 2011;57:1717]. *J Am Coll Cardiol*. 2011;57:292–299. doi: 10.1016/j.jacc.2010.05.065.
113. Chomistek AK, Manson JE, Stefanick ML, Lu B, Sands-Lincoln M, Going SB, Garcia L, Allison MA, Sims ST, LaMonte MJ, Johnson KC, Eaton CB. Relationship of sedentary behavior and physical activity to incident cardiovascular disease: results from the Women's Health Initiative. *J Am Coll Cardiol*. 2013;61:2346–2354. doi: 10.1016/j.jacc.2013.03.031.
114. Basterra-Gortari FJ, Bes-Rastrollo M, Gea A, Núñez-Córdoba JM, Toledo E, Martínez-González MÁ. Television viewing, computer use, time driving and all-cause mortality: the SUN

cohort. *J Am Heart Assoc*. 2014;3:e000864. doi: 10.1161/JAHA.114.000864.
115. Dunstan DW, Barr EL, Healy GN, Salmon J, Shaw JE, Balkau B, Magliano DJ, Cameron AJ, Zimmet PZ, Owen N. Television viewing time and mortality: the Australian Diabetes, Obesity and Lifestyle Study (AusDiab). *Circulation*. 2010;121:384–391. doi: 10.1161/CIRCULATIONAHA.109.894824.
116. Holtermann A, Mork PJ, Nilsen TI. Hours lying down per day and mortality from all-causes and cardiovascular disease: the HUNT Study, Norway. *Eur J Epidemiol*. 2014;29:559–565. doi: 10.1007/s10654-014-9939-7.
117. Katzmarzyk PT, Church TS, Craig CL, Bouchard C. Sitting time and mortality from all causes, cardiovascular disease, and cancer. *Med Sci Sports Exerc*. 2009;41:998–1005. doi: 10.1249/MSS.0b013e3181930355.
118. Matthews CE, Cohen SS, Fowke JH, Han X, Xiao Q, Buchowski MS, Hargreaves MK, Signorello LB, Blot WJ. Physical activity, sedentary behavior, and cause-specific mortality in black and white adults in the Southern Community Cohort Study. *Am J Epidemiol*. 2014;180:394–405. doi: 10.1093/aje/kwu142.
119. Matthews CE, George SM, Moore SC, Bowles HR, Blair A, Park Y, Troiano RP, Hollenbeck A, Schatzkin A. Amount of time spent in sedentary behaviors and cause-specific mortality in US adults. *Am J Clin Nutr*. 2012;95:437–445. doi: 10.3945/ajcn.111.019620.
120. Seguin R, Buchner DM, Liu J, Allison M, Manini T, Wang CY, Manson JE, Messina CR, Patel MJ, Moreland L, Stefanick ML, Lacroix AZ. Sedentary behavior and mortality in older women: the Women's Health Initiative. *Am J Prev Med*. 2014;46:122–135. doi: 10.1016/j.amepre.2013.10.021.
121. Warren TY, Barry V, Hooker SP, Sui X, Church TS, Blair SN. Sedentary behaviors increase risk of cardiovascular disease mortality in men. *Med Sci Sports Exerc*. 2010;42:879–885. doi: 10.1249/MSS.0b013e3181c3aa7e.
122. Ensrud KE, Blackwell TL, Cauley JA, Dam TT, Cawthon PM, Schousboe JT, Barrett-Connor E, Stone KL, Bauer DC, Shikany JM, Mackey DC; Osteoporotic Fractures in Men Study Group. Objective measures of activity level and mortality in older men. *J Am Geriatr Soc*. 2014;62:2079–2087. doi: 10.1111/jgs.13101.
123. Koster A, Caserotti P, Patel KV, Matthews CE, Berrigan D, Van Domelen DR, Brychta RJ, Chen KY, Harris TB. Association of sedentary time with mortality independent of moderate to vigorous physical activity. *PLoS One*. 2012;7:e37696. doi: 10.1371/journal.pone.0037696.
124. de Rezende LF, Rodrigues Lopes M, Rey-López JP, Matsudo VK, Luiz Odo C. Sedentary behavior and health outcomes: an overview of systematic reviews. *PLoS One*. 2014;9:e105620. doi: 10.1371/journal.pone.0105620.
125. 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;41:207–215. doi: 10.1016/j.amepre.2011.05.004.
126. van Uffelen JG, Wong J, Chau JY, van der Ploeg HP, Riphagen I, Gilson ND, Burton NW, Healy GN, Thorp AA, Clark BK, Gardiner PA, Dunstan DW, Bauman A, Owen N, Brown WJ. Occupational sitting and health risks: a systematic review. *Am J Prev Med*. 2010;39:379–388. doi: 10.1016/j.amepre.2010.05.024.
127. Powell KE, Paluch AE, Blair SN. Physical activity for health: What kind? How much? How intense? On top of what? *Annu Rev Public Health*. 2011;32:349–365. doi: 10.1146/annurev-publhealth-031210-101151.
128. Thyfault JP, Du M, Kraus WE, Levine JA, Booth FW. Physiology of sedentary behavior and its relationship to health outcomes. *Med Sci Sports Exerc*. 2015;47:1301–1305. doi: 10.1249/MSS.0000000000000518.
129. Garland T Jr, Schutz H, Chappell MA, Keeney BK, Meek TH, Copes LE, Acosta W, Drenowatz C, Maciel RC, van Dijk G, Kotz CM, Eisenmann JC. The biological control of voluntary exercise, spontaneous physical activity and daily energy expenditure in relation to obesity: human and rodent perspectives. *J Exp Biol*. 2011;214(pt 2):206–229. doi: 10.1242/jeb.048397.
130. Fuss J, Gass P. Endocannabinoids and voluntary activity in mice: runner's high and long-term consequences in emotional behaviors. *Exp Neurol*. 2010;224:103–105. doi: 10.1016/j.expneurol.2010.03.016.
131. Ceccarini G, Maffei M, Vitti P, Santini F. Fuel homeostasis and locomotor behavior: role of leptin and melanocortin pathways. *J Endocrinol Invest*. 2015;38:125–131. doi: 10.1007/s40618-014-0225-z.
132. Park Y, Booth FW, Lee S, Laye MJ, Zhang C. Physical activity opposes coronary vascular dysfunction induced during high fat feeding in mice. *J Physiol*. 2012;590:4255–4268. doi: 10.1113/jphysiol.2012.234856.
133. Raschke S, Eckel J. Adipo-myokines: two sides of the same coin: mediators of inflammation and mediators of exercise. *Mediators Inflamm*. 2013;2013:320724. doi: 10.1155/2013/320724.
134. Booth FW, Laye MJ, Lees SJ, Rector RS, Thyfault JP. Reduced physical activity and risk of chronic disease: the biology behind the consequences. *Eur J Appl Physiol*. 2008;102:381–390. doi: 10.1007/s00421-007-0606-5.
135. de Luca C, Olefsky JM. Stressed out about obesity and insulin resistance. *Nat Med*. 2006;12:41–42. doi: 10.1038/nm0106-41.
136. Gregor MF, Hotamisligil GS. Inflammatory mechanisms in obesity. *Annu Rev Immunol*. 2011;29:415–445. doi: 10.1146/annurev-immunol-031210-101322.
137. O'Keefe JH, Bell DS. Postprandial hyperglycemia/hyperlipidemia (postprandial dysmetabolism) is a cardiovascular risk factor. *Am J Cardiol*. 2007;100:899–904. doi: 10.1016/j.amjcard.2007.03.107.
138. Ceriello A. The post-prandial state and cardiovascular disease: relevance to diabetes mellitus. *Diabetes Metab Res Rev*. 2000;16:125–132.
139. Heine RJ, Balkau B, Ceriello A, Del Prato S, Horton ES, Taskinen MR. What does postprandial hyperglycaemia mean? *Diabet Med*. 2004;21:208–213.
140. Mikus CR, Oberlin DJ, Libla JL, Taylor AM, Booth FW, Thyfault JP. Lowering physical activity impairs glycemic control in healthy volunteers. *Med Sci Sports Exerc*. 2012;44:225–231. doi: 10.1249/MSS.0b013e31822ac0c0.
141. Stephens BR, Granados K, Zderic TW, Hamilton MT, Braun B. Effects of 1 day of inactivity on insulin action in healthy men and women: interaction with energy intake. *Metabolism*. 2011;60:941–949. doi: 10.1016/j.metabol.2010.08.014.
142. Dunstan DW, Howard B, Healy GN, Owen N. Too much sitting: a health hazard. *Diabetes Res Clin Pract*. 2012;97:368–376. doi: 10.1016/j.diabres.2012.05.020.
143. Hellsten Y, Nyberg M, Jensen LG, Mortensen SP. Vasodilator interactions in skeletal muscle blood flow regulation. *J Physiol*. 2012;590:6297–6305. doi: 10.1113/jphysiol.2012.240762.
144. Zderic TW, Hamilton MT. Identification of hemostatic genes expressed in human and rat leg muscles and a novel gene (LPP1/PAP2A) suppressed during prolonged physical inactivity (sitting). *Lipids Health Dis*. 2012;11:137. doi: 10.1186/1476-511X-11-137.
145. Boyle LJ, Credeur DP, Jenkins NT, Padilla J, Leidy HJ, Thyfault JP, Fadel PJ. Impact of reduced daily physical activity on conduit artery flow-mediated dilation and circulating endothelial microparticles. *J Appl Physiol (1985)*. 2013;115:1519–1525. doi: 10.1152/japplphysiol.00837.2013.
146. Thosar SS, Bielko SL, Mather KJ, Johnston JD, Wallace JP. Effect of prolonged sitting and breaks in sitting time on endothelial function. *Med Sci Sports Exerc*. 2015;47:843–849. doi: 10.1249/MSS.0000000000000479.

147. Manini TM, Carr LJ, King AC, Marshall S, Robinson TN, Rejeski WJ. Interventions to reduce sedentary behavior. *Med Sci Sports Exerc*. 2015;47:1306–1310. doi: 10.1249/MSS.0000000000000519.
148. Prince SA, Saunders TJ, Gresty K, Reid RD. A comparison of the effectiveness of physical activity and sedentary behaviour interventions in reducing sedentary time in adults: a systematic review and meta-analysis of controlled trials. *Obes Rev*. 2014;15:905–919. doi: 10.1111/obr.12215.
149. Neuhaus M, Eakin EG, Straker L, Owen N, Dunstan DW, Reid N, Healy GN. Reducing occupational sedentary time: a systematic review and meta-analysis of evidence on activity-permissive workstations. *Obes Rev*. 2014;15:822–838. doi: 10.1111/obr.12201.
150. King AC, Hekler EB, Grieco LA, Winter SJ, Sheats JL, Buman MP, Banerjee B, Robinson TN, Cirimele J. Harnessing different motivational frames via mobile phones to promote daily physical activity and reduce sedentary behavior in aging adults. *PLoS One*. 2013;8:e62613. doi: 10.1371/journal.pone.0062613.
151. Spring B, Schneider K, McFadden HG, Vaughn J, Kozak AT, Smith M, Moller AC, Epstein LH, Demott A, Hedeker D, Siddique J, Lloyd-Jones DM. Multiple behavior changes in diet and activity: a randomized controlled trial using mobile technology. *Arch Intern Med*. 2012;172:789–796. doi: 10.1001/archinternmed.2012.1044.
152. Pellegrini CA, Duncan JM, Moller AC, Buscemi J, Sularz A, DeMott A, Pictor A, Pagoto S, Siddique J, Spring B. A smartphone-supported weight loss program: design of the ENGAGED randomized controlled trial. *BMC Public Health*. 2012;12:1041. doi: 10.1186/1471-2458-12-1041.
153. Bond DS, Thomas JG, Raynor HA, Moon J, Sieling J, Trautvetter J, Leblond T, Wing RR. B-MOBILE: a smartphone-based intervention to reduce sedentary time in overweight/obese individuals: a within-subjects experimental trial. *PLoS One*. 2014;9:e100821. doi: 10.1371/journal.pone.0100821.
154. Dantzig S, Geleijnse G, van Halteren AT. Toward a persuasive mobile application to reduce sedentary behavior. *Pers Ubiquit Comput*. 2013;17:1237–1246. doi: 10.1007/s00779-012-0588-0.
155. Haskell WL. Physical activity by self-report: a brief history and future issues. *J Phys Act Health*. 2012;9(suppl 1):S5–S10.

Circulation

American Heart Association

Sedentary Behavior and Cardiovascular Morbidity and Mortality: A Science Advisory From the American Heart Association

Endorsed by The Obesity Society, Deborah Rohm Young, Marie-France Hivert, Sofiya Alhassan, Sarah M. Camhi, Jane F. Ferguson, Peter T. Katzmarzyk, Cora E. Lewis, Neville Owen, Cynthia K. Perry, Juned Siddique and Celina M. Yong
On behalf of the Physical Activity Committee of the Council on Lifestyle and Cardiometabolic Health; Council on Clinical Cardiology; Council on Epidemiology and Prevention; Council on Functional Genomics and Translational Biology; and Stroke Council

Circulation. 2016;134:e262-e279; originally published online August 15, 2016;
doi: 10.1161/CIR.0000000000000440
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231

Print ISSN: 0009-7322. Online ISSN: 1524-4539