

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.

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.

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CLINICAL STATEMENTS AND GUIDELINES

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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 al¹⁴ 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

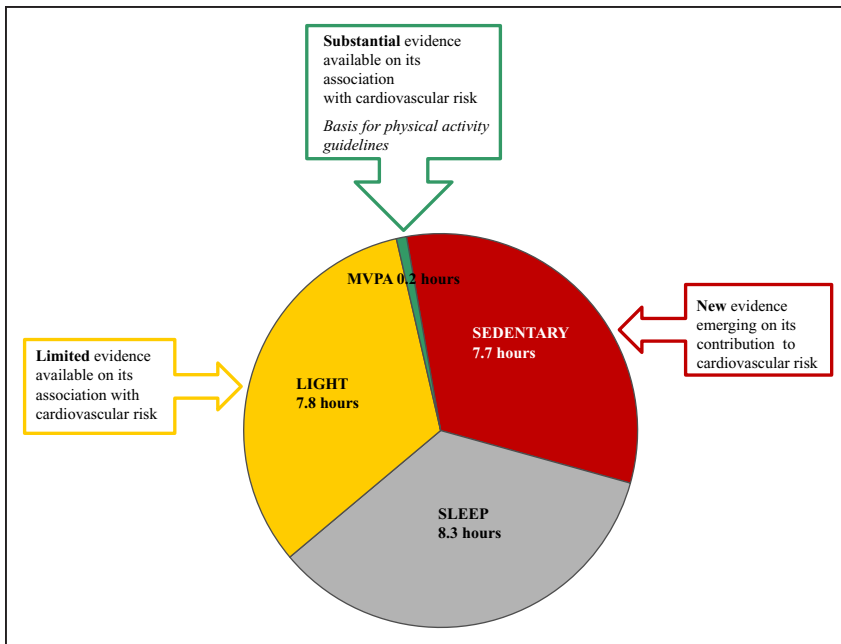


Figure. Estimated daily time spent in different contexts of energy expenditure among adults, based on the National Health and Nutrition Examination Survey.^{6,7}

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 veloc-

ity. 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.

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 accelerometers²⁸ 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, Bowman⁵⁶ 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 groups¹⁸; 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-

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 associations⁸⁵ 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, $\approx 34\%$ 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 al¹⁰¹ found

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 al¹⁰² 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 men¹⁰⁴ and women⁵⁸ 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, 1.44–4.24¹¹⁰) and for CVD mortality (pooled HR, 1.90; 95% CI, 1.36–2.66¹¹⁰). In an analysis of data from the EPIC (European Prospective Investigation Into Cancer and Nutrition) Norfolk study, Wijndaele et al¹¹¹ 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 al¹¹² 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 al¹¹³ 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 Study¹¹⁹ 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-

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 Navarra 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 al¹²³ 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 in-

active. 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 non-exercise 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 \approx 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 al¹⁴¹ 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 evi-

dence 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 al¹⁴⁸ performed a meta-analysis of 7 interventions, the primary focus of which

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 al¹⁴⁹ 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 networking¹⁵² 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 al¹⁵³ 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. Inter-

ventions 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.

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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.

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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
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*Modest.

†Significant.

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