AMERICAN COLLEGE of SPORTS MEDICINE
PRONOUNCEMENT

Sedentary Behavior and Health: Update from the 2018 Physical Activity Guidelines Advisory Committee

PETER T. KATZMARZYK[1], KENNETH E. POWELL[2], JOHN M. JAKICIC[3], RICHARD P. TROIANO[4], KATRINA PIERCY[5], and BETHANY TENNANT[6], FOR THE 2018 PHYSICAL ACTIVITY GUIDELINES ADVISORY COMMITTEE*

[1]Pennington Biomedical Research Center, Baton Rouge, LA; [2]Centers for Disease Control and Prevention, Atlanta, GA; [3]Department of Health and Physical Activity, University of Pittsburgh, Pittsburgh, PA; [4]Division of Cancer Control and Population Sciences, National Cancer Institute, U.S. Department of Health and Human Services, Rockville, MD; [5]Office of Disease Prevention and Health Promotion, US Department of Health and Human Services, Rockville, MD; and [6]ICF, Fairfax, VA

ABSTRACT

KATZMARZYK, P. T., K. E. POWELL, J. M. JAKICIC, R. P. TROIANO, K. PIERCY, and B. TENNANT, FOR THE 2018 PHYSICAL ACTIVITY GUIDELINES ADVISORY COMMITTEE. Sedentary Behavior and Health: Update from the 2018 Physical Activity Guidelines Advisory Committee. *Med. Sci. Sports Exerc.*, Vol. 51, No. 6, pp. 1227–1241, 2019. **Purpose:** To provide an overview of relationships between sedentary behavior and mortality as well as incidence of several noncommunicable diseases and weight status reported in the *2018 Physical Activity Guidelines Advisory Committee Scientific Report* (2018 PAGAC Scientific Report), and to update the evidence from recent studies. **Methods:** Evidence related to sedentary behavior in the 2018 PAGAC Scientific Report was summarized, and a systematic review was undertaken to identify original studies published between January 2017 and February 2018. **Results:** The 2018 PAGAC Scientific Report concluded there was strong evidence that high amounts of sedentary behavior increase the risk for all-cause and cardiovascular disease (CVD) mortality and incident CVD and type 2 diabetes. Moderate evidence indicated sedentary behavior is associated with incident endometrial, colon and lung cancer. Limited evidence suggested sedentary behavior is associated with cancer mortality and weight status. There was strong evidence that the hazardous effects of sedentary behavior are more pronounced in physically inactive people. Evidence was insufficient to determine if bout length or breaks in sedentary behavior are associated with health outcomes. The new literature search yielded seven new studies for all-cause mortality, two for CVD mortality, two for cancer mortality, four for type 2 diabetes, one for weight status, and four for cancer; no new studies were identified for CVD incidence. Results of the new studies supported the conclusions in the 2018 PAGAC Scientific Report. **Conclusions:** The results of the updated search add further evidence on the association between sedentary behavior and health. Further research is required on how sex, age, race/ethnicity, socioeconomic status, and weight status may modify associations between sedentary behavior and health outcomes. **Key Words:** SITTING, MORTALITY, COHORT, CHRONIC DISEASE

Address for correspondence: Peter T. Katzmarzyk, Ph.D., Pennington Biomedical Research Center, 6400 Perkins Rd, Baton Rouge, LA, 70808-4124; E-mail: Peter.Katzmarzyk@pbrc.edu.

*The 2018 Physical Activity Guidelines Advisory Committee includes David M. Buchner, Wayne W. Campbell, Loretta DiPietro, Kirk I. Erickson, Charles H. Hillman, John M. Jakicic, Kathleen F. Janz, Peter T. Katzmarzyk, Abby C. King, William E. Kraus, Richard F. Macko, David X. Marquez, Anne McTiernan, Russell R. Pate, Linda S. Pescatello, Kenneth E. Powell, and Melicia C. Whitt-Glover.

Submitted for publication: June 2018.
Accepted for publication: October 2018.
Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.acsm-msse.org).

0195-9131/19/5106-1227/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/MSS.0000000000001935

Sedentary behavior is defined as any waking behavior characterized by the expenditure of 1.5 METs or less of energy while in a sitting, reclining, or lying posture (1). On an absolute scale of intensity, sedentary behaviors are at the low end of the physical activity continuum; however, the postural component of the definition suggests that sedentary pursuits may represent distinct behaviors (2). In most research studies, sedentary behavior has been operationalized as daily sitting time, television (TV) viewing, or low counts on an activity monitor such as an accelerometer. Representative data collected by accelerometry in the U.S. National Health and Nutrition Examination Survey (NHANES) indicate that children and adults spend approximately 55% of their awake time (7.7 $h \cdot d^{-1}$) being sedentary (3).

Given that much of the evidence on the negative health effects associated with sedentary behavior has been published in the last decade, the *2008 Physical Activity Guidelines for Americans* (4) did not specifically address this (5). However, given the emerging evidence on the negative health effects and the potential public health burden associated with high levels of sedentary behavior in the population, the 2018 Physical Activity Guidelines Advisory Committee decided to review this evidence. In this regard, the interplay between sedentary behavior and physical activity on health were of particular interest.

The purpose of this article is to summarize the evidence on the associations between sedentary behavior and health reviewed by the 2018 Physical Activity Guidelines Advisory Committee and to perform a systematic review of prospective observational studies published subsequently. In addition to updating the systematic review, we identified articles from the searches to provide evidence on the relationship between changes in sedentary behavior and risk of mortality.

2018 PHYSICAL ACTIVITY GUIDELINES ADVISORY COMMITTEE SCIENTIFIC REPORT

The 2018 Physical Activity Guidelines Advisory Committee (Committee) recently conducted a systematic review of the associations between sedentary behavior and several health outcomes (6). The Committee reviewed the scientific evidence on the associations between sedentary behavior and all-cause mortality, cardiovascular disease (CVD) mortality, cancer mortality, type 2 diabetes, weight status, CVD and cancer published through early 2017. Table 1 provides the specific questions addressed by the Committee in its report.

A single literature search was conducted to answer questions 1, 2, and 3. Subsets of the resulting body of evidence were used to answer each question and relevant subquestions. The search strategy included 1) a search for systematic reviews and meta-analyses, 2) reviewing the original research articles contained in the systematic reviews and meta-analyses, and 3) a search for more recent original research studies published after the systematic reviews and meta-analyses. The systematic literature search to address question 4 included 1) a search for systematic reviews and meta-analyses, and 2) a search of more recent original research studies published after the systematic reviews and meta-analyses. The evidence used to address question 5 was obtained from the articles retrieved for question 1.

TABLE 1. Questions related to sedentary behavior and health outcomes in adults addressed by the 2018 physical activity guidelines advisory committee.

Major questions
1. What is the relationship between sedentary behavior and all-cause mortality?
2. What is the relationship between sedentary behavior and cardiovascular disease mortality?
3. What is the relationship between sedentary behavior and cancer mortality?
4. What is the relationship between sedentary behavior and 1) type 2 diabetes, 2) weight status, 3) cardiovascular disease, and 4) cancer?
5. Does the effect of moderate-to-vigorous physical activity on all-cause mortality vary by amount of sedentary behavior?
Subquestions[a]
a) Is there a dose–response relationship? If yes, what is the shape of the relationship?
b) Does the relationship vary by age, sex, race/ethnicity, socioeconomic status, or weight status?
c) Is the relationship independent of amounts of light, moderate, or vigorous physical activity?
d) Is there any evidence that bouts or breaks in sedentary behavior are important factors?

[a]The subquestions apply to questions 1 through 4 only.

Evidence to inform each question was graded as strong, moderate, limited, or not assignable based on several grading criteria, including applicability, generalizability, risk of bias/study limitations, quantity and consistency of results across studies, and magnitude and precision of effect (See Supplemental Table 1; Supplemental Digital Content 1, 2018 Physical Activity Guidelines Advisory Committee Grading Criteria, http://links.lww.com/MSS/B535) (6). Table 2 provides a summary of the relationships and level of evidence for each health outcome. Overall, there was strong evidence for a direct association between greater amounts of sedentary behavior and higher risk of mortality from all-causes and CVD, and for higher risk of incident type 2 diabetes and CVD. There was moderate evidence for an association between sedentary behavior and incident cancer (especially colon, endometrial, and lung cancer), and limited evidence for associations between sedentary behavior and cancer mortality and weight status. For a detailed summary of the meta-analyses, systematic reviews and original research studies that contributed evidence to these conclusions, please see the PAGAC Scientific Report (Part F, Chapter 2) (6). Specific details on each study can be found in the online supplemental tables (https://health.gov/paguidelines/second-edition/report/supplementary-material.aspx).

There was strong evidence for the existence of dose–response associations between sedentary behavior and all-cause mortality, CVD mortality, and incident CVD, whereas there was limited evidence for cancer mortality, incident type 2 diabetes, weight status, and incident cancer. Two meta-analyses were identified that reported significant dose–response relationships between daily sitting (7), TV viewing (8), and all-cause mortality. Further, 24 of the 29 original studies that tested for the existence of a dose–response relationship with all-cause mortality reported statistical significance (6). Two meta-analyses tested for dose–response associations between sedentary behavior and incident CVD (9,10). Grontved and Hu (9) reported a significant linear dose–response association between TV viewing and

TABLE 2. Summary of relationships between sedentary behavior and health outcomes in the *2018 Physical Activity Guidelines Advisory Committee Scientific Report.*

Health Outcomes	Level of Evidence for Association	Level of Evidence for Dose–Response	Level of Evidence for Variation in Association by Physical Activity	Level of Evidence for Variation in Association by Age, Sex, Race/Ethnicity, Socioeconomic Status or Weight Status?	Level of Evidence for Bouts or Breaks as Important Factors
All-cause mortality	Strong	Strong	Strong	Limited for no interaction by age, sex, race/ethnicity and weight status; not assignable for socioeconomic status	Not assignable
CVD mortality	Strong	Strong	Moderate	Limited for no interaction by age, sex, race/ethnicity and weight status; not assignable for socioeconomic status	Not assignable
Cancer mortality	Limited	Limited	Not assignable	Not assignable	Not assignable
Incident type 2 diabetes	Strong	Limited	Not assignable	Not assignable	Not assignable
Weight status	Limited	Limited	Not assignable	Not assignable	Not assignable
Incident CVD	Strong	Strong	Not assignable	Not assignable	Not assignable
Incident cancer	Moderate	Limited	Not assignable	Not assignable	Not assignable

incident fatal and nonfatal CVD, whereas Pandey et al. (10) reported a significant, curvilinear dose–response association with increasing slope of risk for CVD at increasingly higher levels of sedentary time.

An important subquestion addressed by the Committee was the degree to which the observed relationships vary by age, sex, race/ethnicity, socioeconomic status, or weight status. For all outcomes, there was insufficient evidence to inform the degree to which socioeconomic status was an effect modifier in the associations with sedentary behavior. For both all-cause and CVD mortality, studies generally reported no significant effect modification by age, sex, race/ethnicity, or weight status. Further age-, sex-, race/ethnicity-, and weight status-stratified analyses were generally significant in all strata examined. Evidence was insufficient for other outcomes to determine whether the relationships varied by these factors.

A bout of sedentary behavior can be operationalized as a period of uninterrupted sedentary time, whereas a break in sedentary behavior can be operationalized as a nonsedentary bout in between two sedentary bouts (1). The degree to which bouts and breaks in sedentary behavior are related to health outcomes is of interest. Unfortunately, there was insufficient evidence to inform the degree to which bouts and breaks in sedentary behavior are important factors in the major questions addressed by the Committee. At the time of the review, only one study was identified that included bouts of sedentary time as a variable in a latent class analysis prediction of all-cause mortality (11); no studies could be identified for the other health outcomes. This resulted in a grade of "not assignable" for this subquestion.

The degree to which sedentary behavior and physical activity interact in their associations with health outcomes was of particular interest to the Committee. There was evidence that the associations between sedentary behavior and all-cause mortality (strong) and CVD mortality (moderate) vary by level of moderate-to-vigorous physical activity. The effect of sedentary behavior on all-cause and CVD mortality is stronger among people who have low amounts of moderate-to-vigorous physical activity. In the meta-analysis of Biswas et al. (12), the summary hazard ratio (HR) for all-cause mortality associated with sedentary time was 1.16 (95% confidence interval [CI, 0.84–1.56) among those with high physical activity and 1.46 (95% CI, 1.22–1.75) among those with low physical activity. Further, Ekelund et al. (13) conducted a harmonized meta-analysis using individual-level data from more than 1 million adults and reported that increasingly higher amounts of moderate-to-vigorous physical activity attenuated the relationships between sedentary behavior and all-cause and CVD mortality. At the highest amounts of moderate-to-vigorous physical activity, the HR for all-cause mortality associated with the four levels of sedentary behavior appear to converge at about 1 (reference value). The number of minutes per day needed to achieve this estimated volume of moderate-to-vigorous physical activity (35.5 $MET \cdot h \cdot wk^{-1}$) varies inversely with the MET value of the activity, ranging from approximately 40 $min \cdot d^{-1}$ at 8 METs to 50 $min \cdot d^{-1}$ at 6 METs to 100 $min \cdot d^{-1}$ at 3 METs. According to data from the 2015 National Health Interview Survey, the prevalence of people participating in more than 300 $min \cdot wk^{-1}$ (~43 $min \cdot d^{-1}$) of moderate-to-vigorous physical activity is approximately 33%, whereas the prevalence of people participating in more than 700 $min \cdot wk^{-1}$ (~100 $min \cdot d^{-1}$) is approximately 11% (2018 PAGAC Scientific Report, Figure D1 (6,14)).

Evidence to inform question 5 was largely derived from the meta-analysis of Ekelund et al. (13). The overall shape of the dose–response relationships between moderate-to-vigorous physical activity and all-cause mortality are generally similar when stratified by level of sitting or TV viewing. However, the relative risks are consistently higher in the high sitting and high TV viewing groups. The reduction in risk of all-cause mortality associated with moderate-to-vigorous physical activity is relatively greater for those who are the most sedentary. This is especially apparent at the lower amounts of moderate-to-vigorous physical activity.

To visually describe the joint associations among sedentary behavior, moderate-to-vigorous physical activity and all-cause mortality, the Committee developed a heat map figure which depicts the risk of all-cause mortality associated with various combinations of sitting time and moderate-to-vigorous physical activity (Fig. 1). Linear and nonlinear regression techniques were used to interpolate the hazard ratios between four levels of sitting time and four levels of moderate-to-vigorous physical activity reported in Ekelund et al. (13). In the heat map, red represents higher risk of all-cause mortality, and green represents lower risk. The greatest risk of mortality is borne by those who sit the most and who do the least moderate-to-vigorous physical activity, whereas the lowest risk of mortality is achieved

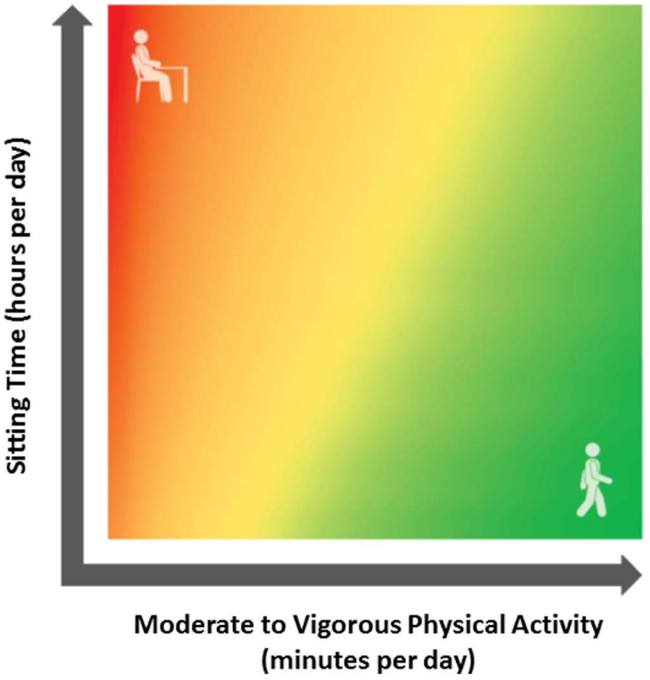

FIGURE 1—Joint associations of sitting time and moderate-to-vigorous physical activity with risk of all-cause mortality. From the *2018 Physical Activity Guidelines Advisory Committee Scientific Report* (6), and based on data presented by Ekelund et al. (13).

by individuals who sit the least and do the most moderate-to-vigorous physical activity.

METHODS FOR UPDATED LITERATURE SEARCH

This systematic review is reported according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses guidelines (15). The systematic review followed an established protocol, and was registered prospectively at PROSPERO (CRD42018092817). Our aim was to update the systematic review conducted by the 2018 Physical Activity Guidelines Advisory Committee and to additionally examine the association between changes in sedentary behavior and risk of all-cause mortality.

Literature search strategy. We searched the PubMed, Cochrane, and CINAHL bibliographic databases for studies published in English between January 1, 2017, and February 28, 2018. Two separate searches were conducted for 1) all-cause, CVD and cancer mortality, and 2) type 2 diabetes, weight status, CVD and cancer. Our search strategy was similar to that employed by the 2018 Physical Activity Guidelines Advisory Committee, and included a comprehensive list of search terms including several combinations of sedentary, sitting, screen time, television, TV, inactivity, physically inactive, sedentarism, and so on, along with relevant terms to identify the mortality and disease outcomes of interest (see *2018 Physical Activity Guidelines Advisory Committee Scientific Report* (6) for a full list of specific search terms).

Study selection criteria. The inclusion criteria were predefined, and studies were considered potentially eligible if they were original prospective observational studies, only involved adults 18 yr and older, were published in English, and investigated the association between sedentary behavior and one of the health outcomes of interest. Studies of nonambulatory adults, hospitalized patients, or samples with preexisting health conditions were excluded. A sample size of at least 1000 people was required for the mortality outcomes. Two authors independently reviewed the titles, abstracts and full-text articles, and disagreements about eligibility were resolved through consensus. Although intervention studies that examine changes in chronic disease risk factors in response to alterations in sedentary behavior provide valuable information about potential mechanisms, this type of evidence was beyond the scope of this review which focused on mortality and noncommunicable disease outcomes.

The systematic search for the mortality outcomes (all-cause, CVD, cancer) identified 780 unique records after duplicates were removed. Of these, 770 were excluded after a review of the titles and abstracts. Based on full-text reviews, four were excluded for all-cause mortality, nine were excluded for CVD mortality, and nine were excluded for cancer mortality. One additional study that was relevant for CVD and cancer mortality was identified in the search for disease outcomes, and was added at this stage. Thus, the final number of eligible studies was seven for all-cause mortality, two for CVD mortality, and two for cancer mortality (see Supplemental Figure 1, Supplemental Digital Content 2, article selection process for mortality studies, http://links.lww.com/MSS/B536). The systematic search for disease outcomes identified 922 unique records after duplicates were removed. Of these, 910 were excluded after a review of the titles and abstracts. Based on full-text reviews, an additional five studies were excluded, leaving a total of two studies of type 2 diabetes, one study for weight status, and four studies for incident cancer; no studies were identified for incident CVD (see Supplemental Figure 2, Supplemental Digital Content 3, article selection process for incident condition studies, http://links.lww.com/MSS/B537).

Data extraction and quality assessment. The following information was extracted from each eligible article: name of the first author, year of publication, study sample, sample size, age (range or mean), definition of sedentary behavior, dates and length of follow-up, risk estimates with corresponding 95% CI comparing levels of sedentary behavior, and whether the study tested and reported a dose–response association. If a study provided several risk estimates, we used the fully adjusted estimate. Extraction of data was performed by one author, and the resulting table was checked by another author.

Quality assessment and risk of bias in the eligible studies was done using the USDA Nutrition Evidence Library (NEL) Bias Assessment Tool (BAT) (16). The NEL BAT uses a domain-based evaluation to help determine whether any systematic error exists that could either over- or underestimate the study results. Selection, performance, detection, and attrition bias are addressed in the NEL BAT. The results of studies' risk of bias assessments were used to develop a risk of bias summary chart (see Supplemental Table 2, Supplemental Digital Content 4, original research bias assessment chart,

http://links.lww.com/MSS/B538). The NEL BAT assessment was performed by one author, and the resulting table was checked by another author.

RESULTS

Study characteristics. The main characteristics of the eligible studies identified in the updated search are presented in Table 3 for all-cause, CVD and cancer mortality, and in Table 4 for incident type 2 diabetes, weight status, incident CVD and incident cancer. All studies used prospective cohort designs, with follow-up periods ranging from 2.3 to 19.4 yr. The sedentary exposures varied across studies: five studies used self-reported sitting time (19,26,28–30), seven studies used self-reported TV viewing time (18,21,24–26,28,31), and five studies used accelerometer-derived estimates of sedentary time (17,20,22,23,27). All studies included an estimate of duration of sedentary behavior (sedentary time) as an exposure, whereas three studies also included a marker of bouts or breaks in sedentary time as an exposure (17,22,27).

Mortality outcomes. Seven studies reported on the association between sedentary behavior and all-cause mortality (Table 3) (17–23). Six of the studies reported a statistically significant association (17–22). For example, an analysis from the Women's Health Initiative reported a significant ($P < 0.05$) association between self-reported daily sitting time and all-cause mortality (odds ratio for dying before age 85 yr for ≥ 10 h·d^{-1} vs <5 h·d^{-1} = 1.16; 95% CI, 1.04–1.29) over 13.7 yr of follow-up (19). Two additional studies, one from the United Kingdom and one among African Americans, demonstrated significant associations between daily TV viewing and all-cause mortality (18,21). Hamer et al. (18) reported a HR for all-cause mortality of 1.98 (95% CI, 1.25–3.15) comparing ≥ 6 h·d^{-1} versus <2 h·d^{-1} of TV viewing, whereas Imran et al. (21) reported a HR for all-cause mortality of 1.48 (95% CI, 1.19–1.83) comparing ≥ 4 h·d^{-1} < 2 h·d^{-1} of TV viewing. Three studies that used accelerometer-derived estimates of sedentary time as the exposure reported a significant association with all-cause mortality (17,20,22), whereas one did not (23). The three positive studies were in samples of US and UK adults and had follow-up period ranging from 4.0 to 6.5 yr, whereas the negative study was conducted among older US women (mean age, 72 yr), with a mean follow-up time of 2.3 yr (Table 3). Among the three positive studies, Diaz et al. (17) and Jefferis et al. (22) reported HR of 2.63 (95% CI, 1.60–4.30) and 2.73 (95% CI, 1.50–4.95), respectively, for the upper versus lowest quartiles of sedentary time, whereas Theou et al. (20) reported an HR of 1.15 (95% CI, 1.11–1.20) per each additional hour of sedentary time.

In addition to total duration of sedentary behavior, two studies examined the effects of bouts or breaks in sedentary behavior in relation to all-cause mortality (17,22). Diaz and colleagues reported a significant association (P for trend <0.001) between bout duration and all-cause mortality in US adults, and participants classified as both highly sedentary (≥ 12 h·d^{-1}) and with high bout duration (≥ 10 min per bout) had the highest risk of death (17). On the other hand, Jefferis and colleagues reported that neither breaks in sedentary behavior nor sedentary bout duration were related to all-cause mortality in a sample of older men (ages 71–92 yr) from the UK (22).

Two studies reported on the association between sedentary behavior and CVD mortality (18,24). Grace and colleagues reported a significant association between TV viewing and CVD mortality among smokers (but not nonsmokers) after adjustment for age and sex in the Australian Diabetes, Obesity and Lifestyle Study (AusDiab) (24). However, this association was no longer significant after the inclusion of additional covariates in the model. On the other hand, Hamer and colleagues reported a multivariable-adjusted HR of 1.22 (95% CI, 1.00–1.49) per standard deviation of daily TV viewing for CVD mortality in the English Longitudinal Study of Ageing (18).

Two studies reported on the association between sedentary behavior and cancer mortality (18,24). Hamer and colleagues reported a nonsignificant HR of 1.16 (95% CI, 0.96–1.39) per standard deviation of daily TV viewing for cancer mortality in the English Longitudinal Study of Ageing (15). Results from the AusDiab study indicated a significant association between TV viewing and cancer mortality among smokers (P for trend = 0.02) but not among nonsmokers (P for trend = 0.52) (24).

A total of six of seven studies reported a dose–response association between sedentary behavior and all-cause mortality (Table 3). Only one of two studies of CVD mortality and one of two studies of cancer mortality reported dose–response associations. Few studies formally tested for interactions between sedentary behavior and demographic characteristics on mortality outcomes; however, Rillamas-Sun et al. (19) reported no interaction by race/ethnicity on all-cause mortality in the Women's Health Initiative (19). Diaz and colleagues reported that the positive associations of sedentary time and bout duration with all-cause mortality did not vary by age, sex, race, body mass index (BMI) or moderate-to-vigorous physical activity (17). Further, Imran et al. (21) reported that in African Americans the results were similar when they excluded those with high and low BMI, those with low leisure physical activity, and those without a high school diploma. Theou and colleagues (20) reported a significant association between accelerometer-derived sedentary time and all-cause mortality in NHANES; the association was statistically significant in physically inactive adults but not in physically active adults.

Diseases and conditions. Two studies were identified that examined the association between sedentary behavior and incident type 2 diabetes (25,26). Stamatakis and colleagues (26) reported a significant association of TV sitting and total sitting with incident diabetes in UK adults enrolled in the Whitehall II study in models adjusting for several covariates, but the results were attenuated and were no longer significant after adjustment for BMI. Joseph and colleagues reported no associations between self-reported TV viewing and incident diabetes in African American adults in the

TABLE 3. Summary of original research studies on sedentary behavior and all-cause, CVD and cancer mortality published between January 1, 2017, and February 28, 2018.

References	Year of Publication	Population	Sample Size	Age	Definition of Sedentary Behavior	Mortality Follow-up Period	Main Results	Dose–Response
All-cause mortality								
Diaz et al. (17)	2017	U.S. Adults; Reasons for Geographic and Racial Differences in Stroke (REGARDS)	7985	≥45 yr	Actical waist accelerometry Total sedentary time: <50 counts per minute Sedentary bout: consecutive minutes <50 counts per minute	2009–13 to 2015 Median of 4.0 yr	HR (95% CI) across quartiles of total sedentary time in fully adjusted model: Q1: 1.00 (reference) Q2: 1.22 (0.74–2.02) Q3: 1.61 (0.99–2.63) Q4: 2.63 (1.60–4.30) *P* for trend <0.001 HR (95% CI) across quartiles of total sedentary bout duration in fully adjusted model: Q1: 1.00 (reference) Q2: 1.03 (0.67–1.60) Q3: 1.22 (0.80–1.85) Q4: 1.96 (1.31–2.93) *P* for trend <0.001 Participants classified as high for both high sedentary time [≥12.5 $h \cdot d^{-1}$] and high bout duration [≥10 min per bout]) had the greatest risk for death. Associations of sedentary time and bout duration did not vary by age, sex, race, BMI or moderate-to-vigorous physical activity ($P > 0.10$).	Yes
Hamer et al. (18)	2017	U.K. Adults: The English Longitudinal Study of Ageing (ELSA)	8451	Mean of 64.8 yr	Self-reported TV viewing	2008–09 to 2012 Mean of 4 yr	HR (95% CI) across levels of TV viewing time in fully adjusted model: <2 $h \cdot d^{-1}$: 1.00 (reference) 2–<4 $h \cdot d^{-1}$: 1.63 (1.02–2.61) 4–<6 $h \cdot d^{-1}$: 1.49 (0.92–2.39) ≥6 $h \cdot d^{-1}$: 1.98 (1.25–3.15) Per SD increase: 1.17 (1.06–1.28)	Yes
Rillamas-Sun et al. (19)	2017	U.S. Women: Women's Health Initiative Observational Study	29,090	62–81 yr	Self-reported daily sitting time	1993–98 to 2015 Mean of 13.7 yr	OR (95% CI) of dying before age 85 yr across daily sitting categories in fully adjusted model: ≤5 $h \cdot d^{-1}$: 1.00 (reference) 6–9 $h \cdot d^{-1}$: 1.02 (0.94–1.11) ≥10 $h \cdot d^{-1}$: 1.16 (1.04–1.29) *P* for trend ≤0.05 No interaction by race/ethnicity.	Yes

Theou et al. (20)	2017	U.S. Adults; 2003–04 & 2005–06 U.S. NHANES	3141	≥50 yr	ActiGraph waist accelerometry (≤100 counts per minute)	2003–2006 to 2011 Mean of 6.5 yr	HR (95% CI) per hour of sedentary time in fully adjusted model: 1.15 (1.11–1.20) HR (95% CI) per hour of sedentary time in fully adjusted models, stratified by physical activity level: Physically Inactive 1.20 (1.12–1.29) Physically Active 0.98 (0.78–1.24) HR (95% CI) per hour of sedentary time in fully adjusted models including physical activity, stratified by level of frailty: Frailty Index Score ≤ 0.1 0.90 (0.70–1.15) Frailty Index Score 0.1 to ≤0.2 1.13 (1.00–1.28) Frailty Index Score 0.2 to ≤0.3 1.27 (1.11–1.46) Frailty Index Score ≥ 0.3 1.36 (1.22–1.52)	Yes
Imran et al. (21)	2018	U.S. African American Adults: Jackson Heart Study (JHS)	5289	Mean of 55 yr	Self-reported TV viewing	Baseline in 2000–04 Median of 9.9 yr	HR (95% CI) across levels of TV viewing time in fully adjusted model: <2 $h \cdot d^{-1}$: 1.00 (reference) 2–<4 $h \cdot d^{-1}$: 1.08 (0.86–1.37) ≥4 $h \cdot d^{-1}$: 1.48 (1.19–1.83) *P* for trend = 0.002 The results were similar in models which excluded those who died in the first 2 yr of follow-up, those with low or high BMI, those with low leisure physical activity, those with low eGFR, and those without a high school diploma.	Yes
Jefferis et al. (22)	2018	U.K. Older Men: British Regional Heart Study	1181	71–92 yr	ActiGraph waist accelerometry Total sedentary time: <100 counts per minute Sedentary breaks: interruption of a sedentary bout lasting >1 min	2010–11 to 2016 Median of 5.0 yr	HR (95% CI) across quartiles of total sedentary time in fully adjusted model: Q1: 1.00 (reference) Q2: 1.14 (0.69–1.91) Q3: 1.55 (0.91–2.64) Q4: 2.73 (1.50–4.95) HR per 30 $min \cdot d^{-1}$: 1.15 (1.06–1.26) HR (95% CI) across quartiles of sedentary breaks per hour in fully adjusted model: Q1: 1.00 (reference) Q2: 1.22 (0.81–1.82) Q3: 0.95 (0.56–1.61) Q4: 1.01 (0.50–2.02) The numbers of minutes spent in sedentary bouts lasting 1–15 min, 16–30, 31–60 and >61 min were all similarly associated with mortality.	Yes

(continued next page)

TABLE 3. *(Continued)*

References	Year of Publication	Population	Sample Size	Age	Definition of Sedentary Behavior	Mortality Follow-up Period	Main Results	Dose–Response
Lee et al. (23)	2018	U.S. Women; Women's Health Study	16,741	Mean of 72 yr	ActiGraph waist accelerometry Total sedentary time: <200 counts per minute	2011–15 to 2015 Mean of 2.3 yr	HR (95% CI) across quartiles of total sedentary time in fully adjusted model: Q1: 1.00 (reference) Q2: 0.97 (0.62–1.50) Q3: 1.18 (0.77–1.82) Q4: 0.92 (0.56–1.50) *P* for trend = 0.99	No
CVD mortality								
Grace et al. (24)	2017	Australian Adults: Australian Diabetes, Obesity and Lifestyle Study (AusDiab)	8907	≥25 yr	Self-reported TV viewing	1999–2000 to 2013 Median of 13.6 yr	HR (95% CI) across levels of TV viewing time in fully adjusted model: Nonsmokers <2 $h \cdot d^{-1}$: 1.00 (reference) 2–<4 $h \cdot d^{-1}$: 0.93 (0.69–1.26) ≥4 $h \cdot d^{-1}$: 1.04(0.69–1.57) *P* for trend = 0.99 Current Smokers <2 $h \cdot d^{-1}$: 1.00 (reference) 2–<4 $h \cdot d^{-1}$: 1.11 (0.46–2.63) ≥4 $h \cdot d^{-1}$: 2.02 (0.80–5.12) *P* for trend = 0.16	No
Hamer et al. (18)	2017	U.K. Adults: The English Longitudinal Study of Ageing (ELSA)	8451	Mean of 64.8 yr	Self-reported TV viewing	2008–09 to 2012 Mean of 4 yr	HR per SD increase in daily TV viewing: 1.22 (1.00–1.49).	Yes
Cancer mortality								
Grace et al. (24)	2016	Australian Adults: Australian Diabetes, Obesity and Lifestyle Study (AusDiab)	8907	≥25 yr	Self-reported TV viewing	1999/2000 to 2013 Median of 13.6 yr	HR (95% CI) across levels of TV viewing time in fully adjusted model: Nonsmokers <2 $h \cdot d^{-1}$: 1.00 (reference) 2–<4 $h \cdot d^{-1}$: 0.92 (0.72–1.19) ≥4 $h \cdot d^{-1}$: 0.91(0.61–1.34) *P* for trend = 0.52 Current Smokers <2 $h \cdot d^{-1}$: 1.00 (reference) 2–<4 $h \cdot d^{-1}$: 1.44 (0.77–2.69) ≥4 $h \cdot d^{-1}$: 2.27 (1.11–4.67) *P* for trend = 0.02	Yes: in current smokers only
Hamer et al. (18)	2017	U.K. Adults: The English Longitudinal Study of Ageing (ELSA)	8451	Mean of 64.8 yr	Self-reported TV viewing	2008–09 to 2012 Mean of 4 yr	HR per SD increase in daily TV viewing: 1.16 (0.96–1.39).	No

eGFR, estimated glomerular filtration rate; OR, odds ratio; SD, standard deviation.

TABLE 4. Summary of original studies on sedentary behavior and type 2 diabetes, weight status, and cancer published between January 1, 2017 and February 28, 2018.[a]

Reference	Year of Publication	Population	Sample Size	Age	Definition of Sedentary Behavior	Follow-up Period	Main Results	Dose–Response
Type 2 diabetes								
Joseph et al. (25)	2017	U.S. African American Adults; Jackson Heart Study (JHS)	3252	21–94 yr	Self-reported TV viewing	2000–04 to 2005–12 Median of 7.5 yr	IRR (95% CI) across levels of daily TV viewing time in fully adjusted models: ≥4 h·d^{-1}: 1.00 (reference) 1–3.9 h·d^{-1}: 0.99 (0.82–1.18) <1 h·d^{-1}: 0.95 (0.72–1.25) Continuous IRR = 0.98 (0.86–1.11)	No
Stamatakis et al. (26)	2017	U.K. Adults: Whitehall II Study	4811	Mean of 44 yr	Self-reported work-related sitting time, TV viewing time, non-TV leisure time sitting, total leisure sitting time, total sitting time, non-TV total sitting time	1997–99 to 2011 Mean of 13.0 yr	HR (95% CI) across levels of sedentary behavior in fully adjusted models: Work Sitting <15 h·wk^{-1}: 1.00 (reference) 15–<35 h·wk^{-1}: 1.14 (0.87–1.51) ≥35 h·wk^{-1}: 1.17 (0.89–1.53) *P* for trend = 0.48 TV Sitting <11 h·wk^{-1}: 1.00 (reference) 11–<16 h·wk^{-1}: 1.33 (1.00–1.77) ≥16 h·wk^{-1}: 1.39 (1.03–1.88) *P* for trend = 0.05 Non-TV Leisure Sitting at Home <8 h·wk^{-1}: 1.00 (reference) 8–<16 h·wk^{-1}: 0.78 (0.57–1.05) ≥16 h·wk^{-1}: 0.98 (0.70–1.36) *P* for trend = 0.15 Leisure Sitting at Home <15 h·wk^{-1}: 1.00 (reference) 15–<25 h·wk^{-1}: 1.26 (0.97–1.64) ≥25 h·wk^{-1}: 1.27 (0.98–1.66) *P* for trend = 0.15 Total Sitting <15 h·wk^{-1}: 1.00 (reference) 15–<25 h·wk^{-1}: 0.87 (0.67–1.13) ≥25 h·wk^{-1}: 1.26 (1.00–1.62) *P* for trend = 0.01 Total Sitting Excluding TV <15 h·wk^{-1}: 1.00 (reference) 15–<25 h·wk^{-1}: 0.93 (0.68–1.27) ≥25 h·wk^{-1}: 1.23 (0.91–1.66) *P* for trend = 0.15 After additional adjustment for BMI the results were attenuated and no longer significant for TV sitting and total sitting.	Yes – for TV sitting and total sitting before adjustment for BMI No – after adjustment for BMI

(continued next page)

TABLE 4. *(Continued)*

Reference	Year of Publication	Population	Sample Size	Age	Definition of Sedentary Behavior	Follow-up Period	Main Results	Dose–Response
Weight status								
Barone Gibbs et al. (27)	2017	U.S. Adults; Coronary Artery and Risk Development in Young Adults (CARDIA)	1826	38–50 yr	ActiGraph waist accelerometry (<100 counts per minute) Total sedentary time and bouts of ≥10 min	2005–06 to 2010–11 ~5 yr	Higher total sedentary time at baseline was not associated with 5-yr changes in BMI and waist circumference. Each hour of sedentary time at baseline accumulated in bouts of ≥10 min was associated with 0.077 $kg \cdot m^{-2}$ higher gain in BMI ($P = 0.033$) and 0.198 cm higher gain in waist circumference ($P = 0.028$).	Yes
Cancer								
Eaglehouse et al. (28)	2017	Chinese Adults Living in Singapore: Singapore Chinese Health Study	61,321	45–74 yr	Self-reported TV viewing and "other" sitting activities	1993–1998 to 2014 Mean of 16.8 yr	HR (95% CI) for incident colorectal cancer across levels of TV viewing in fully adjusted model: <2 $h \cdot d^{-1}$: 1.00 (reference) ≥3 $h \cdot d^{-1}$: 1.04 (0.95–1.14) HR (95% CI) for incident colorectal cancer across levels of "other" sitting activities in fully adjusted model: None: 1.00 (reference) <1 $h \cdot d^{-1}$: 0.99 (0.87–1.13) 1–2 $h \cdot d^{-1}$: 1.00 (0.87–1.15) ≥3 $h \cdot d^{-1}$ 0.99 (0.84–1.17) P for trend = 0.99	No
Gorczca et al. (29)	2017	U.S. Women: Women's Health Initiative Observational Study	74,870	50–79 yr	Self-reported daily sitting time	Median of 13.4 yr	HR (95% CI) for incident colorectal cancer across levels of daily sitting time in fully adjusted model: ≤5 $h \cdot d^{-1}$: 1.00 (reference) 5.1–9.9 $h \cdot d^{-1}$: 1.10 (0.95–1.26) ≥10 $h \cdot d^{-1}$: 1.12 (0.92–1.35) P for trend = 0.29 HR (95% CI) for incident rectal cancer across levels of daily sitting time in fully adjusted model: ≤5 $h \cdot d^{-1}$: 1.00 (reference) 5.1–9.9 $h \cdot d^{-1}$: 1.08 (0.78–1.51) ≥10 $h \cdot d^{-1}$: 0.94 (0.59–1.48) P for trend = 0.74 HR (95% CI) for incident colon cancer across levels of daily sitting time in fully adjusted model: ≤5 $h \cdot d^{-1}$: 1.00 (reference) 5.1–9.9 $h \cdot d^{-1}$: 1.10 (0.95–1.28) ≥10 $h \cdot d^{-1}$: 1.14 (0.92–1.40) P for trend = 0.25 No interaction between sitting time and physical activity ($P = 0.62$), age group ($P = 0.97$), BMI ($P = 0.66$) or employment status ($P = 0.99$).	No

Nomura et al. (30)	2017	U.S. Women; Women's Health Initiative Observational Study	70,233	50–79 yr	Self-reported daily sitting time and total sedentary time	1994–98 to 2015	HR (95% CI) for incident postmenopausal breast cancer across levels of daily sitting time in fully adjusted model: ≤5 h·d^{-1}: 1.00 (reference) 6–9 h·d^{-1}: 1.03 (0.96–1.11) ≥10 h·d^{-1}: 1.00 (0.92–1.09) *P* for trend = 0.88 Continuous HR (h·d^{-1}) = 1.00 (0.98–1.02). No interactions between sitting and race/ethnicity, hormone receptor status, BMI, weight gain since age 18, waist circumference, or wait-to-hip ratio.	No
Ukawa et al. (31)	2018	Japanese Women; Japan Collaborative Cohort Study for Evaluation of Cancer Risk (JACC Study)	34,758	40–79 yr	Self-reported TV viewing	1988–90 to 2009 Median of 19.4 yr	HR (95% CI) for incident ovarian cancer across levels of TV viewing time in fully adjusted model: <2 h·d^{-1}: 1.00 (reference) 2–2.9 h·d^{-1}: 1.03 (0.70–1.50) 3–3.9 h·d^{-1}: 1.18 (0.82–1.70) 4–4.9 h·d^{-1}: 0.81 (0.54–1.21) ≥5 h·d^{-1}: 2.15 (1.54–2.99)	Not tested

[a]No studies were identified for incident CVD.

Jackson Heart Study, both before and after including BMI as a covariate (25).

A single study was identified that examined the association between sedentary behavior and weight status (27). Among adults in the CARDIA Study, there was no association between total duration of sedentary behavior and 5-yr changes in BMI or waist circumference. However, each additional hour of sedentary time accumulated in bouts of greater than or equal to 10 min was associated with greater gain in BMI ($P = 0.033$) and waist circumference ($P = 0.028$) (Table 4).

Four studies were identified that addressed the association between sedentary behavior and incident cancer: two studied colorectal cancer (28,29), one studied breast cancer (30), and one studied ovarian cancer (31). Neither of the two studies of colorectal cancer reported a significant effect of sedentary behavior (TV viewing or sitting time) on cancer incidence (Table 4). Nomura and colleagues (30) reported no significant association between sedentary behavior and incident breast cancer in post-menopausal US women in the Women's Health Initiative Observational Study (30). On the other hand, Ukawa and colleagues reported that Japanese women who watched TV for greater than or equal to 5 h·d^{-1} were more likely to develop ovarian cancer than those who watched TV for less than 2 h·d^{-1} (HR, 2.15; 95% CI, 1.54–2.99). Two studies tested for interactions, and reported no interactions between sedentary behavior and race/ethnicity, age, hormone receptor status, BMI, weight gain since age 18 yr, waist circumference, waist-to-hip ratio, employment status or physical activity (29,30).

A total of six of the seven studies of sedentary behavior, disease incidence or weight status tested for dose–response associations (25–30). Only Barone-Gibbs and colleagues reported significant dose–response associations - between sedentary time and weight status (BMI and waist circumference) (27).

Changes in sedentary behavior and risk of mortality. We identified several papers from the original systematic review search (32–35) and the updated search (36) that addressed changes in sedentary behavior over time and risk of mortality ($n = 4$ for all-cause mortality, $n = 1$ for CVD mortality) (Table 5). In each of the studies, mortality rates were compared across categories of changes in sitting time (consistently sedentary, increased or decreased sedentary time, or consistently nonsedentary). Changes in sedentary time were evaluated over approximately 2 to 11 yr, and the mean or median follow-up time for mortality surveillance ranged from approximately 5 to 9 yr after the second assessment of sedentary behavior. In all studies, the risk of mortality was significantly lower in those who were consistently nonsedentary over time, compared to those who were consistently sedentary. In general, those who decreased sedentary behavior over time had an intermediate risk of mortality, compared to those who were consistently sedentary or nonsedentary. Three studies reported lower risk of mortality associated with increased sedentary behavior over time, compared to those who were consistently sedentary (32,33,36), whereas two studies reported an increased risk of mortality among those who increased sedentary

TABLE 5. Summary of original studies on changes in sedentary behavior and mortality.

Authors	Year of Publication	Population	Sample Size	Age (yr)	Definition of Sedentary Behavior	Mortality Follow-up Period	Main Results
Leon-Munoz et al. (32)	2013	Spanish Adults	2635	≥60 yr	Changes in daily sitting time between 2001–2003	2003 to 2011	HR (95% CI) for all-cause mortality across categories of sitting time in fully adjusted model: Consistently sedentary: 1.00 (reference) Newly sedentary: 0.91 (0.76–1.10) Formerly sedentary: 0.86 (0.70–1.05) Consistently nonsedentary: 0.75 (0.62–0.90)
Lee et al. (33)	2015	U.S. Women; Women's Health Initiative (WHI)	77,801	50–79 yr	Changes in daily sitting time from baseline and year 6	1998 to 2008 Mean of 5.1 yr	HR (95% CI) for all-cause mortality across categories of sitting time in fully adjusted model: Consistently high sitting: 1.00 (reference) Increased sitting: 0.79 (0.58–1.07) Decreased sitting: 0.71 (0.54–0.95) Consistently low sitting: 0.49 (0.39–0.63)
Keadle et al. (34)	2015	U.S. Adults; NIH-AARP Diet and Health Study	165,087	50–71 yr	Changes in TV viewing time between 1994–96 and 2004–06	2004–2006 to 2011 Mean of 6.6 yr	HR (95% CI) for all-cause mortality across categories of TV viewing in fully adjusted model: Consistent 5+ $h \cdot d^{-1}$: 1.28 (1.21–1.34) Decreased from 5+ to 3–4 $h \cdot d^{-1}$: 0.85 (0.80–0.91) Decreased from 5+ to <3 $h \cdot d^{-1}$: 0.88 (0.79–0.97) Increased from <3 to 3.4 $h \cdot d^{-1}$: 1.17 (1.10–1.24) Increased from <3 to 5+ $h \cdot d^{-1}$: 1.45 (1.32–1.58) Consistent <3 $h \cdot d^{-1}$: 1.0 (reference)
Grunseit et al. (35)	2017	Norwegian Adults; Nord-Trondelag Health Study (HUNT)	25,651	≥20 yr	Changes in daily sitting time between 1995–97 and 2006–08	2006–2008 to 2013 Mean of 6.2 yr	HR (95% CI) for all-cause mortality across categories of sitting time in fully adjusted model: Consistently high sitting: 1.26 (1.06–1.51) Increased sitting: 1.51 (1.28–2.78) Decreased sitting: 1.03 (0.88–1.20) Consistently low sitting: 1.00 (reference)
Cabanas-Sanchez et al. (36)	2017	Spanish Adults	2657	≥60 yr	Changes in daily sitting time between 2001 and 2003	2003 to 2014 Mean of 9.2 yr	HR (95% CI) of CVD mortality across categories of sitting time in fully adjusted model: Consistently sedentary: 1.00 (reference) Newly sedentary: 1.18 (0.87–1.59) Formerly sedentary: 0.77 (0.56–1.07) Consistently nonsedentary: 0.67 (0.46–0.96)

behavior over time, compared to those who were consistently sedentary (34,35). It is plausible that using two measurements of sedentary behavior over a period of time may be a better marker of long-term levels of sedentary behavior rather than a measure of precise changes over time given the self-reported nature of the data. Two concordant responses may classify participants more accurately than two discordant responses over time, making the later more susceptible misclassification and inconsistent findings.

DISCUSSION

The results from the updated search provide further evidence of an association between sedentary behavior and all-cause mortality. Further, the new results from studies of changes in sedentary behavior and mortality suggest that individuals who maintain sedentary behavior over time have the highest risk of mortality, those with sustained low levels of sedentary behavior have lowest risk, and those who report changes in sedentary behavior have an intermediate mortality risk. The updated results obtained for CVD mortality (18,24) do not alter the strength of evidence for the strong association with sedentary behavior. Although Grace and colleagues did not find a significant multivariable-adjusted association between TV viewing and CVD mortality when the AusDiab sample was stratified by smoking status (24), these results are in contrast with an earlier report from that cohort that reported a HR of 1.80 (95% CI, 1.00–3.25) between high amounts of TV viewing ($\geq$4 h·d^{-1} vs <2 h·d^{-1}) and CVD mortality in the full sample (8). The smaller sample size and small number of events in the sub-group analyses likely contributed to the nonsignificant results. The two new studies identified for cancer mortality (18,24) do not alter the conclusion of the Committee that the evidence for an association between sedentary behavior and cancer mortality is limited. Associations between sedentary behavior and cancer mortality are affected by cancer screening and treatment availability and efficacy. A limitation of most studies is a failure to take these factors into account.

Similar to the results of previous studies on the association between sedentary behavior and type 2 diabetes, the observed associations in the updated review are not statistically significant in fully-adjusted models where BMI is included as a covariate (25,26). The effects of sedentary behavior on risk of type 2 diabetes may be operating, in part, through its association with BMI; however, whether or not BMI is in the causal pathway between sedentary behavior and type 2 diabetes is not known. The extent to which sedentary behavior and BMI represent independent risk factors will require further research to disentangle the effects of BMI and sedentary behavior on risk of incident disease, especially type 2 diabetes.

Strong evidence demonstrates that the association between sedentary behavior and all-cause mortality is more pronounced among physically inactive people. In addition, individuals who are highly sedentary appear to require higher amounts of physical activity to achieve the same level of absolute mortality risk as those who are less sedentary (37). Therefore, moderate-to-vigorous physical activity should be part of every adult's lifestyle, especially for those who are sedentary for large portions of the day. These results also illustrate the need to individualize and tailor lifestyle recommendations for maximum benefit to the individual, which in turn will have a greater impact on population health. Further, the finding that the association between physical activity and health varies by level of sedentary behavior also highlights the importance of integrating sedentary behavior and physical activity guidelines.

US adults spend a large portion of each day engaging in sedentary behavior (3). Therefore, limiting excessive time spent sitting would reduce the population health impact associated with premature mortality and several major chronic diseases such as type 2 diabetes, CVD, and several cancers. For physically inactive adults, replacing sedentary behavior with light intensity physical activities is likely to produce some health benefits; however, among all adults, replacing sedentary behavior with higher intensity physical activities may produce even greater benefits (38–41). The updated systematic review identified several new papers addressing the relationship between sedentary behavior and health outcomes. However, the new studies did not provide results that would change the levels of evidence that addressed the Committee's questions.

Several research recommendations were generated by this work. As described in the introduction, the current consensus definition of sedentary behavior has both an energy expenditure component ($\leq$1.5 METs) and a postural component (sitting, reclining, or lying) (1). There is a pressing need to develop objective field methods to simultaneously assess these two components of the definition that can be applied in both surveillance and research settings to properly quantify time spent in sedentary behavior. Analysis strategies to identify different bout lengths as well as breaks in sedentary behavior vary among studies and are also an important area for future research. Further, research using prospective cohorts is required 1) on the interactive effects of physical activity (especially light intensity activity) and sedentary behavior on mortality and incident CVD, 2) on the role of bouts and breaks in sedentary behavior in relation to mortality and other health outcomes, and 3) on disentangling the independent effects of sedentary behavior and adiposity on risk of type 2 diabetes, and the degree to which adiposity may be in the causal pathway in this association. Further research is also required to determine how sex, age, race/ethnicity, socioeconomic status, and weight status relate to the association between sedentary behavior and CVD incidence and mortality. Finally, randomized controlled trials are required to test the health effects of interventions to replace time spent in sedentary behaviors with standing and light, moderate, and vigorous intensity activity.

The authors gratefully acknowledge the contributions of Emily Bhutiani, MS (National Cancer Institute, National Institutes of Health through June 2017) and Kyle Sprow, MPH (National Cancer Institute, National Institutes of Health) for management support; Anne Brown Rodgers, HHS consultant for technical writing support; and ICF librarians, abstractors, and additional support staff.

The results of this study do not constitute endorsement by ACSM, and are presented clearly, honestly, and without fabrication, falsification, or inappropriate manipulation. The Committee's work was supported by the US Department of Health and Human Services (HHS). Committee members were reimbursed for travel and per diem expenses for the five public meetings; Committee members volunteered their time. Dr. Jakicic received an honorarium for serving on the Scientific Advisory Board for Weight Watchers International and was a co-investigator on a grant awarded to the University of Pittsburgh by Weight Watchers International. The authors report no other potential conflicts of interest.

HHS staff provided general administrative support to the Committee and assured that the Committee adhered to the requirements for Federal Advisory Committees. HHS also contracted with ICF, a global consulting services company, to provide technical support for the literature searches conducted by the Committee. HHS and ICF staff collaborated with the Committee in the design and conduct of the searches by assisting with the development of the analytical frameworks, inclusion/exclusion criteria, and search terms for each primary question; using those parameters, ICF performed the literature searches.

This paper is being published as an official pronouncement of the American College of Sports Medicine. This pronouncement was reviewed for the American College of Sports Medicine by members-at-large and the Pronouncements Committee. *Disclaimer:* Care has been taken to confirm the accuracy of the information present and to describe generally accepted practices. However, the authors, editors, and publisher are not responsible for errors or omissions or for any consequences from application of the information in this publication and make no warranty, expressed or implied, with respect to the currency, completeness, or accuracy of the contents of the publication. Application of this information in a particular situation remains the professional responsibility of the practitioner; the clinical treatments described and recommended may not be considered absolute and universal recommendations.

REFERENCES

1. Tremblay MS, Aubert S, Barnes JD, et al. Sedentary Behavior Research Network (SBRN)—terminology consensus project process and outcome. *Int J Behav Nutr Phys Act*. 2017;14(1):75.
2. Gibbs BB, Hergenroeder AL, Katzmarzyk PT, Lee IM, Jakicic JM. Definition, measurement, and health risks associated with sedentary behavior. *Med Sci Sports Exerc*. 2015;47(6):1295–300.
3. Matthews CE, Chen KY, Freedson PS, et al. Amount of time spent in sedentary behaviors in the United States, 2003-2004. *Am J Epidemiol*. 2008;167:875–81.
4. U.S. Department of Health and Human Services. *2008 Physical Activity Guidelines for Americans*. Washington, DC: US Government Printing Office; 2008. p. 61.
5. Physical Activity Guidelines Advisory Committee. *Physical Activity Guidelines Advisory Committee Report, 2008*. Washington, DC: U.S. Department of Health and Human Services; 2008. 683 p.
6. 2018 Physical Activity Guidelines Advisory Committee. *Physical Activity Guidelines Advisory Committee Scientific Report*. Washington, D.C.: U.S. Department of Health and Human Services; 2018. p. 779.
7. Chau JY, Grunseit AC, Chey T, et al. Daily sitting time and all-cause mortality: a meta-analysis. *PLoS One*. 2013;8(11):e80000.
8. Sun JW, Zhao LG, Yang Y, Ma X, Wang YY, Xiang YB. Association between television viewing time and all-cause mortality: a meta-analysis of cohort studies. *Am J Epidemiol*. 2015;182(11):908–16.
9. Grontved A, Hu FB. Television viewing and risk of type 2 diabetes, cardiovascular disease, and all-cause mortality: a meta-analysis. *JAMA*. 2011;305(23):2448–55.
10. Pandey A, Salahuddin U, Garg S, et al. Continuous dose–response association between sedentary time and risk for cardiovascular disease: a meta-analysis. *JAMA Cardiol*. 2016;1(5):575–83.
11. Evenson KR, Herring AH, Wen F. Accelerometry-assessed latent class patterns of physical activity and sedentary behavior with mortality. *Am J Prev Med*. 2017;52(2):135–43.
12. Biswas A, Oh PI, Faulkner GE, et al. 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(2):123–32.
13. Ekelund U, Steene-Johannessen J, Brown WJ, et al. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality? A harmonised meta-analysis of data from more than 1 million men and women. *Lancet*. 2016;388:1302–10.
14. Centers for Disease Control and Prevention NCfHS. National Health Interview Survey (NHIS), 1997–2015. 2015 data release. https://www.cdc.gov/nchs/nhis/nhis_2015_data_release.htm. Updated November 3, 2017. Accessed January 11, 2018. 2018.
15. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *J Clin Epidemiol*. 2009;62(10):1006–12.
16. 2015 Dietary Guidelines Advisory Committee. *Scientific Report of the 2015 Dietary Guidelines Advisory Committee*. Washington, D.C.: U.S. Department of Health and Human Services and U.S. Department of Agriculture; 2015; p. 436.
17. Diaz KM, Howard VJ, Hutto B, et al. Patterns of sedentary behavior and mortality in U.S. middle-aged and older adults: a national cohort study. *Ann Intern Med*. 2017;167:465–75.
18. Hamer M, Yates T, Demakakos P. Television viewing and risk of mortality: exploring the biological plausibility. *Atherosclerosis*. 2017;263:151–5.
19. Rillamas-Sun E, LaMonte MJ, Evenson KR, et al. The influence of physical activity and sedentary behavior on living to age 85 years without disease and disability in older women. *J Gerontol A Biol Sci Med Sci*. 2018;73(11):1525–31.
20. Theou O, Blodgett JM, Godin J, Rockwood K. Association between sedentary time and mortality across levels of frailty. *CMAJ*. 2017;189(33):E1056–64.
21. Imran TF, Ommerborn M, Clark C, et al. Television viewing time, physical activity, and mortality among African Americans. *Prev Chronic Dis*. 2018;15:E10.
22. Jefferis BJ, Parsons TJ, Sartini C, et al. Objectively measured physical activity, sedentary behaviour and all-cause mortality in older men: does volume of activity matter more than pattern of accumulation? *Br J Sports Med*. 2018; [Epub ahead of print]. doi: 10.1136/bjsports-2017-098733.
23. Lee IM, Shiroma EJ, Evenson KR, Kamada M, LaCroix AZ, Buring JE. Accelerometer-measured physical activity and sedentary behavior in relation to all-cause mortality: the Women's Health Study. *Circulation*. 2018;137(2):203–5.
24. Grace MS, Lynch BM, Dillon F, Barr EL, Owen N, Dunstan DW. Joint associations of smoking and television viewing time on cancer and cardiovascular disease mortality. *Int J Cancer*. 2017;140:1538–44.
25. Joseph JJ, Echouffo-Tcheugui JB, Talegawkar SA, et al. Modifiable lifestyle risk factors and incident diabetes in African Americans. *Am J Prev Med*. 2017;53(5):e165–74.
26. Stamatakis E, Pulsford RM, Brunner EJ, et al. Sitting behaviour is not associated with incident diabetes over 13 years: the Whitehall II cohort study. *Br J Sports Med*. 2017;51(10):818–23.
27. Barone Gibbs B, Pettee Gabriel K, Carnethon MR, et al. Sedentary time, physical activity, and adiposity: cross-sectional and longitudinal associations in CARDIA. *Am J Prev Med*. 2017;53(6):764–71.
28. Eaglehouse YL, Koh WP, Wang R, Aizhen J, Yuan JM, Butler LM. Physical activity, sedentary time, and risk of colorectal cancer: the Singapore Chinese Health Study. *Eur J Cancer Prev*. 2017;26(6):469–75.

29. Gorczyca AM, Eaton CB, LaMonte MJ, et al. Association of physical activity and sitting time with incident colorectal cancer in postmenopausal women. *Eur J Cancer Prev*. 2018;27(4):331–8.
30. Nomura SJO, Dash C, Sheppard VB, et al. Sedentary time and postmenopausal breast cancer incidence. *Cancer Causes Control*. 2017; 28(12):1405–16.
31. Ukawa S, Tamakoshi A, Mori M, et al. Association between average daily television viewing time and the incidence of ovarian cancer: findings from the Japan Collaborative Cohort Study. *Cancer Causes Control*. 2018;29(2):213–9.
32. Leon-Munoz LM, Martinez-Gomez D, Balboa-Castillo T, Lopez-Garcia E, Guallar-Castillon P, Rodriguez-Artalejo F. Continued sedentariness, change in sitting time, and mortality in older adults. *Med Sci Sports Exerc*. 2013;45:1501–7.
33. Lee J, Kuk JL, Ardern CI. The relationship between changes in sitting time and mortality in post-menopausal US women. *J Public Health*. 2016;38(2):270–8.
34. Keadle SK, Arem H, Moore SC, Sampson JN, Matthews CE. Impact of changes in television viewing time and physical activity on longevity: a prospective cohort study. *Int J Behav Nutr Phys Act*. 2015;12:156.
35. Grunseit AC, Chau JY, Rangul V, Holmen TL, Bauman A. Patterns of sitting and mortality in the Nord-Trøndelag health study (HUNT). *Int J Behav Nutr Phys Act*. 2017;14(1):8.
36. Cabanas-Sanchez V, Guallar-Castillon P, Higueras-Fresnillo S, Rodriguez-Artalejo F, Martinez-Gomez D. Changes in sitting time and cardiovascular mortality in older adults. *Am J Prev Med*. 2018; 54(3):419–22.
37. Katzmarzyk PT, Pate RR. Physical activity and mortality: the potential impact of sitting. *Trans J ACSM*. 2017;2:32–3.
38. Fishman EI, Steeves JA, Zipunnikov V, et al. Association between objectively measured physical activity and mortality in NHANES. *Med Sci Sports Exerc*. 2016;48(7):1303–11.
39. Matthews CE, Keadle SK, Troiano RP, et al. Accelerometer-measured dose–response for physical activity, sedentary time, and mortality in US adults. *Am J Clin Nutr*. 2016;104(5):1424–32.
40. Matthews CE, Moore SC, Sampson J, et al. Mortality benefits for replacing sitting time with different physical activities. *Med Sci Sports Exerc*. 2015;47(9):1833–40.
41. Schmid D, Ricci C, Baumeister SE, Leitzmann MF. Replacing sedentary time with physical activity in relation to mortality. *Med Sci Sports Exerc*. 2016;48(7):1312–9.