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Sedentary behaviour and health in adults: an overview of systematic reviews¹

Travis J. Saunders, Travis McIsaac, Kevin Douillette, Nick Gaulton, Stephen Hunter, Ryan E. Rhodes, Stephanie A. Prince, Valerie Carson, Jean-Philippe Chaput, Sebastien Chastin, Lora Giangregorio, Ian Janssen, Peter T. Katzmarzyk, Michelle E. Kho, Veronica J. Poitras, Kenneth E. Powell, Robert Ross, Amanda Ross-White, Mark S. Tremblay, and Genevieve N. Healy

Abstract: The purpose of this overview of systematic reviews was to determine the relationship between different types and patterns of sedentary behaviour and selected health outcomes in adults and older adults. Five electronic databases were last searched in May, 2019, with a 10-year search limit. Included reviews met the a priori population (community-dwelling adults aged 18 years and older), intervention/exposure/comparator (various types and/or patterns of sedentary behaviour), and outcomes criteria. Eighteen systematic reviews were included in the evidence synthesis. High levels of sedentary behaviour are unfavourably associated with cognitive function, depression, function and disability, physical activity levels, and physical health-related quality of life in adults. Reducing or breaking up sedentary behaviour may benefit body composition and markers of cardiometabolic risk. Total sedentary behaviour and TV viewing were most consistently associated with unfavourable health outcomes, while computer and Internet use may be favourably associated with cognitive function for older adults. The quality of evidence within individual reviews (as assessed by review authors) varied from low to high, while the certainty of evidence was low to very low. These findings have important public health implications, suggesting that adults should avoid high levels of sedentary behaviour and break-up periods of prolonged sitting. (PROSPERO registration nos.: CRD42019123121 and CRD42019127157.)

Novelty

- High levels of sedentary behaviour are unfavourably associated with important health outcomes in adults.
- Reducing or breaking up sedentary behaviour may benefit body composition and markers of cardiometabolic risk.
- Computer and Internet use may be favourably associated with cognitive function in older adults.

Key words: sedentary behaviour, guidelines, public health, adults, sitting, screen time.

Résumé : Le but de ce survol des revues systématiques est de déterminer la relation entre les différents types et modèles de comportement sédentaire et certains résultats de santé chez les adultes et les personnes âgées. Cinq bases de données électroniques sont consultées pour la dernière fois en mai 2019, et ce, avec une limite de recherche de 10 ans. Les revues inclues traitent des critères *a priori* de la population (adultes vivant dans la communauté de 18 ans et plus), de l'intervention/exposition/comparateur (divers types ou modèles de comportement sédentaire) et des résultats. Dix-huit revues systématiques sont incluses dans la synthèse des données probantes. Des niveaux élevés de comportement sédentaire sont associés défavorablement à la fonction cognitive, à la dépression, à l'aptitude et à l'incapacité, aux niveaux d'activité physique et à la qualité de vie liée à la santé physique chez les adultes. Réduire ou rompre un comportement sédentaire peut être bénéfique pour la composition

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corporelle et les marqueurs de risque cardiométabolique. Le comportement sédentaire total et l'écoute de la télévision sont le plus souvent associés à des résultats de santé défavorables, tandis que l'utilisation de l'ordinateur et d'Internet peut être associée favorablement à la fonction cognitive chez les personnes âgées. La qualité des données probantes dans les revues individuelles (telle qu'évaluée par les auteurs de la revue) varie de faible à élevée, tandis que la certitude de ces données est faible à très faible. Ces résultats ont d'importantes implications pour la santé publique; ainsi, les adultes devraient éviter des niveaux élevés de comportement sédentaire et interrompre les périodes de position assise prolongée. (Numéros d'enregistrement PROSPERO: CRD42019123121 et CRD42019127157.) [Traduit par la Rédaction]

Les nouveautés

- Des niveaux élevés de comportement sédentaire sont associés défavorablement à d'importants résultats de santé chez les adultes.
- Réduire ou rompre un comportement sédentaire peut être bénéfique pour la composition corporelle et les marqueurs du risque cardiométabolique.
- L'utilisation de l'ordinateur et d'Internet peut être associée favorablement à la fonction cognitive chez les personnes âgées.

Mots-clés : comportement sédentaire, directives, santé publique, adultes, assis, temps d'écran.

Introduction

Sedentary behaviour refers to “any waking behavior characterized by an energy expenditure ≤ 1.5 metabolic equivalents (METs), while in a sitting, reclining or lying posture” (Tremblay et al. 2017). Canadian adults spend roughly 9–10 h/day engaging in sedentary behaviours (Prince et al. 2020b), with 5.5 h/day spent in bouts of sitting lasting 20 min or more (Carson et al. 2014). Given this level of exposure, a clear understanding of its relationship with health outcomes is necessary to inform public health recommendations for this behaviour.

Since the year 2000, the volume of research on sedentary behaviour has increased exponentially (LeBlanc et al. 2017), with studies examining the health impact of sitting per se (van Uffelen et al. 2010; van der Ploeg et al. 2012), as well as behaviours typically done while sitting (e.g., screen-based behaviours, reading, driving) (Jacobs et al. 2008; Grontved and Hu 2011; Basterra-Gortari et al. 2014). The United States Physical Activity Guidelines Advisory Committee (PAGAC) recently comprehensively reviewed the scientific evidence linking sedentary behaviour with specific physical health indicators in adults and older adults, including mortality, cardiovascular disease, type 2 diabetes, cancer, and obesity (2018 Physical Activity Guidelines Advisory Committee 2018; Katzmarzyk et al. 2019). After reviewing previous systematic reviews (SRs) and original research studies, the PAGAC Scientific Report concluded that individuals who accumulate high levels of sedentary behaviour are at increased risk of all-cause mortality, cardiovascular disease incidence and mortality, incident diabetes, and incidence of cancers of the colon, endometrium, and lung (2018 Physical Activity Guidelines Advisory Committee 2018). The PAGAC Scientific Report also identified strong evidence of a dose-response relationship between sedentary behaviour and both all-cause mortality and cardiovascular disease mortality (2018 Physical Activity Guidelines Advisory Committee 2018).

These findings highlight the wealth of evidence on the relationship between sedentary behaviour and key physical health outcomes. Although chronic disease morbidity and mortality are of great importance to public health, they do not represent the full scope of human health and wellness. In contrast to the health indicators identified above, to date there has been no attempt to comprehensively summarize the relationships between sedentary behaviour and other important health indicators, including brain and mental health, quality of life, function and disability, pain, productivity, and other 24-h movement behaviours (i.e., physical activity, sleep). These indicators have important implications for policymakers, clinicians, employers, and the general public, and are therefore relevant to consider when developing public health recommendations related to sedentary behaviour.

Another current knowledge gap is the relationship between different patterns of sedentary behaviour (e.g., bouts, breaks, frequency, duration, and timing) and health outcomes among

adults. The PAGAC Scientific Report examined the observational literature to determine whether bouts or breaks in sedentary behaviour influenced the relationship between sedentary behaviour and mortality, cardiovascular disease, type 2 diabetes, cancer, or obesity (2018 Physical Activity Guidelines Advisory Committee 2018). They found insufficient evidence to make a conclusion on this topic, with no studies identified for most of the above outcomes (2018 Physical Activity Guidelines Advisory Committee 2018). However, a growing number of intervention studies suggest that patterns of sedentary behaviour may influence markers of cardiometabolic risk (Chastin et al. 2015b, 2018; Saunders et al. 2018), which could adversely affect other important health outcomes. Thus, it is also important to understand the relationship between patterns of sedentary behaviour and additional health outcomes beyond those examined in the PAGAC Scientific Report, with a focus on intervention studies.

As part of the guideline development process for the Canadian 24-Hour Movement Guidelines for Adults aged 18–64 years and Adults aged 65 years or older (Ross et al. 2020), we undertook the current overview of SRs to examine the best available evidence for the relationship between sedentary behaviour and a range of health indicators in the adult population. An overview of SRs provides an ideal method to systematically summarize the best available evidence for a range of indicators in a single document to inform future policy and research related to sedentary behaviour (Becker and Oxman 2011; Hunt et al. 2018). Overviews can also minimize redundancy and maximize the use of limited resources; rather than creating additional SRs on topics that have already been comprehensively studied, overviews synthesize the results of previous SRs, while also identifying areas where de novo reviews may be needed. Given the research gaps identified above, the purpose of this overview of SRs is to address 2 specific research questions:

Research Question 1: What is the relationship between different types of sedentary behaviour and health outcomes in adults?

Research Question 2: What is the relationship between different patterns of sedentary behaviour and health outcomes in adults?

Materials and methods

Context

This overview of SRs was performed in concert with 3 other overviews (Chaput et al. 2020a; El-Kotob et al. 2020; McLaughlin et al. 2020) and 2 de novo SRs (Chaput et al. 2020b; Janssen et al. 2020) to inform the development of Canadian 24 Hour Movement Guidelines for Adults aged 18–64 years and Adults aged 65 years or older (Ross et al. 2020). Details of the methodology used to develop these overviews (Kho et al. 2020), and the guidelines themselves (Ross et al. 2020), are available elsewhere in this supplement. A

summary of the methodology specific to the current overview is presented below.

Protocol and registration

The present overview of SRs includes 2 specific research questions, both of which were registered a priori with the International Prospective Register of Systematic Reviews (PROSPERO; registration nos. CRD42019123121 and CRD42019127157 (available from <http://www.crd.york.ac.uk/prospéro>)), and conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher et al. 2009). Eligible participants, interventions, comparisons, outcomes, and study designs (PICOS) were identified a priori, and are outlined below.

Population

Eligible participants were apparently healthy, community-dwelling adults aged 18 years or older. Adults and older adults were defined as those aged 18–64 and ≥65 years of age, respectively. We considered adults with obesity, adults with metabolic syndrome, or adults who have had 1 or more falls in the previous year to be apparently healthy for the purposes of this overview. Studies that included adults with a chronic condition (e.g., heart disease, diabetes, cancer) among their participant pool were included, as were those with mixed populations (e.g., including individuals who did and did not meet the eligibility criteria) if ≥80% of the study population met the inclusion criteria, if the sample mean fell within the criteria, or if the results of the eligible participants were reported separately.

Ineligible participants included children and youth (<18 years), individuals who were pregnant, residents in long-term care, patients in acute care or a hospital setting, individuals who were unable to move under their own power, and elite athletes. Studies were also excluded if they targeted only a disease-specific population (e.g., prospective cohort studies including only individuals with heart disease).

Intervention/exposure

The interventions or exposures were sedentary behaviours, as defined by the Sedentary Behaviour Research Network (Tremblay et al. 2017). Sedentary behaviours could be device-measured (e.g., accelerometry or inclinometry) or self-reported, and included total, occupational, and leisure sitting time, as well as screen-based and nonscreen based sedentary behaviours. We also included studies that examined patterns of sedentary behaviour, which refers to sedentary bouts, breaks, frequency, duration, or timing. Studies that focused exclusively on exergaming were excluded from this overview, since these represent a form of physical activity (Siegel et al. 2009). Studies focusing on the impact of health-related content delivered via a mode of sedentary behaviour (e.g., text messages or websites encouraging people to adopt healthier lifestyles) were excluded as it was theorized that any positive or negative health impact could relate to the content being delivered, rather than the sedentary behaviour per se.

Comparison

When available, different types or patterns of sedentary behaviour were used for comparison. However, a comparator or control group was not required for inclusion.

Outcomes

Thirteen health indicators were identified based on expert input and consensus (Ross et al. 2020). All outcomes that were identified as vital (primary outcomes) for Research Questions 1 or 2 were considered as critical for this overview, and included

(i) health-related quality of life, (ii) brain health, (iii) cognitive function, (iv) depression, (v) musculoskeletal pain, (vi) accidents or injuries, (vii) biomarkers of cardiometabolic risk, and (viii) body composition. Five health outcomes were identified as *important* (secondary outcomes): (i) function and disability, (ii) fatigue, (iii) work productivity, (iv) sleep duration, and (v) physical activity duration. Although of great relevance to health, all-cause mortality, cardiovascular disease, type 2 diabetes, and cancer were not included as the relationship between sedentary behaviour and these indicators was recently comprehensively summarized by the US PAGAC Scientific Report (2018 Physical Activity Guidelines Advisory Committee 2018; Katzmarzyk et al. 2019).

Study designs

Published or in-press peer-reviewed SRs with or without meta-analyses were eligible for inclusion. SRs summarizing intervention studies were included for all outcomes. To minimize redundancy with the PAGAC Report, only SRs of intervention studies were included for biomarkers of cardiometabolic risk and obesity. For all other outcomes, SRs of all study designs were eligible for inclusion. Grey literature was ineligible for inclusion. SRs that did not receive a “yes” or “partial yes” for items 4 (adequacy of literature search) and 9 (risk of bias from individual studies being included in the review) on A MeaSurement Tool to Assess systematic Reviews (AMSTAR 2) assessments were excluded as these characteristics were considered critical flaws (Shea et al. 2017). For the purpose of this overview, SRs must have searched at least 2 relevant databases and provided a key word and/or search strategy. SRs were not required to justify restricting their search to studies published in specific languages, as long as the SR was published in English or French (Nussbaumer-Streit et al. 2020).

Information sources and search strategy

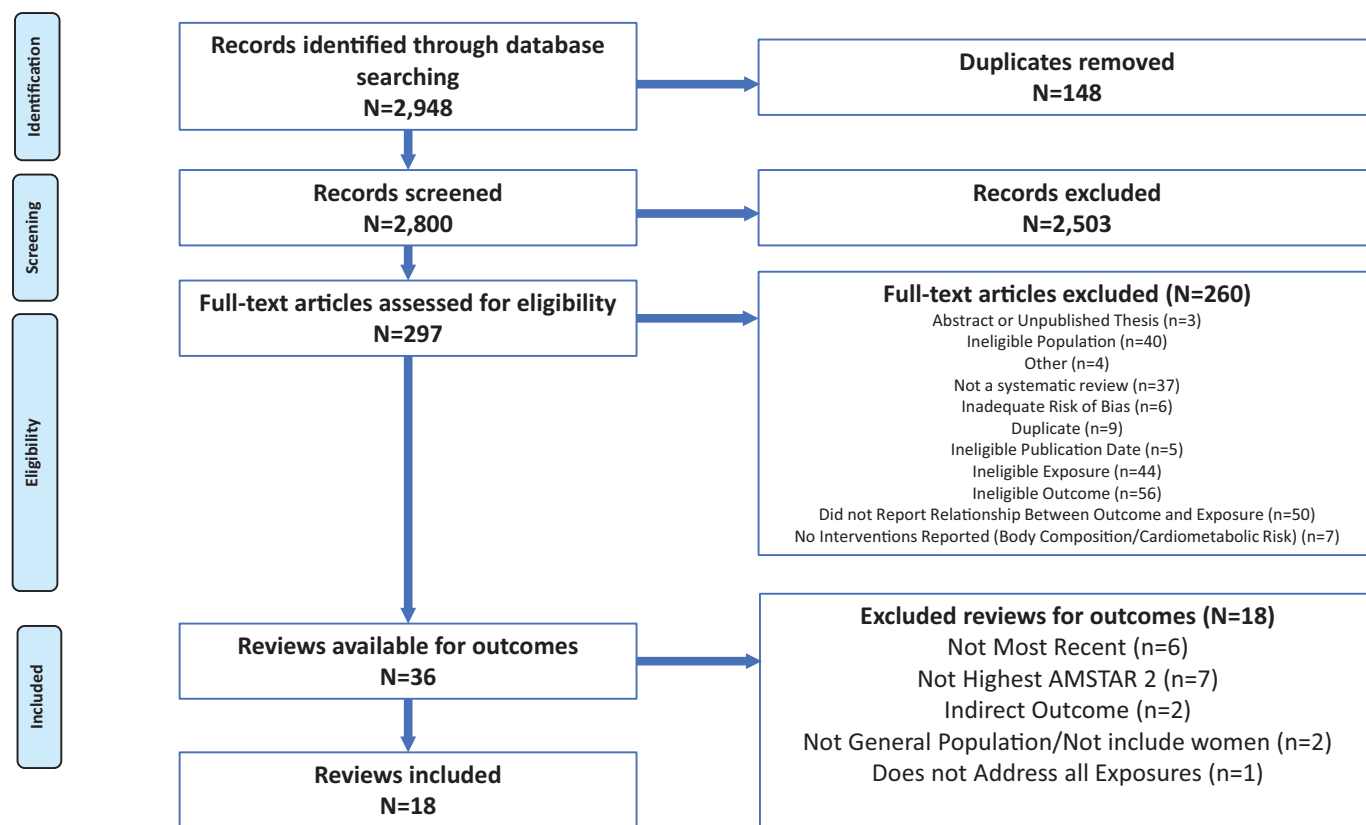
We searched the following databases using the Ovid platform: Medline, Embase, PsycInfo, and Cochrane. CINAHL was also searched, using the Ebsco platform. Searches were conducted the week of February 25, 2019, and an updated search carried out on May 13, 2019. After the results were reviewed at the title/abstract level, a third search was conducted the week of August 19, 2019. This took the articles that passed the title and abstract stage of screening and searched both for citing articles and cited articles, using Web of Science’s Core Collection (Clarivate Analytics) cited reference search. A detailed description of the searches with all keywords and subject headings is available via the following link: <https://qspace.library.queensu.ca/handle/1974/27648>. All searches included indexed works from January 1, 2009, until the date of the search. This 10-year search-limit was used to manage scope and with a goal to include the most recent body of evidence. However, there were no limits on the publication dates of primary studies within SRs.

Study selection

Bibliographic records were extracted and imported into Reference Manager Software (Thompson Reuters, San Francisco, Calif., USA) for removal of duplicate references. Titles and abstracts of potentially relevant articles were then imported into Covidence (Veritas Health Innovation, Melbourne, Australia) and screened by 2 independent reviewers. All articles included at this stage by 1 or both reviewers were obtained for full-text review. Full-text review was again completed by 2 independent reviewers. Any discrepancies at the full-text review stage were addressed via discussion among the reviewers, or by a third reviewer if needed. Reasons for exclusions at full-text screening stage were documented (Fig. 1 and Supplemental File S1²).

²Supplementary data are available with the article through the journal Web site at <http://nrcresearchpress.com/doi/suppl/10.1139/apnm-2020-0272>.

Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram for the identification, screening, eligibility, and inclusion of studies. AMSTAR 2, A MeaSurement Tool to Assess systematic Reviews.



This overview of reviews sought to identify 1 key SR for each outcome of interest. Studies that reported direct outcome measures were prioritized over studies that reported indirect markers. If multiple SRs reported an outcome, we prioritized those that examined the effect of age or exposure dose or dose-response profile, type, or pattern of sedentary behaviour on the estimate of effect. If multiple SRs remained eligible for selection, we then selected the review that was of highest quality based on full AMSTAR 2 assessment. If there were multiple SRs of a given quality, we then prioritized the most recent review. If a selected SR did not address the effect of age, exposure dose type, or pattern, we included additional reviews to address these factors.

If estimates of effect from more than 1 SR were included for a given outcome (i.e., to be able to evaluate the effect of age, exposure dose, or type), we assessed and reported on the degree of overlap in primary studies using the corrected covered area (CCA) (Pieper et al. 2014). The degree of primary study overlap among the SRs was interpreted as either slight (0%–5%), moderate (6%–10%), high (11%–15%), or very high (>15%) (Pieper et al. 2014). The degree of overlap was reported but was not applied as an exclusion criterion.

Data extraction

Google Sheets (Google, Mountain View, Calif., USA) were used for data extraction. Data extraction was completed by 1 reviewer and verified by another reviewer. Information related to frequency, volume, type, dose, and pattern of sedentary behaviour was extracted, where available. Appropriately conducted meta-analyses were identified using the criteria outlined in the AMSTAR 2 (Shea et al. 2017) and results from meta-analyses meeting these criteria were extracted; if there were no appropriately conducted meta-analyses only narrative results were extracted. Where multiple models were reported, results from the most fully

adjusted models were extracted. If this included adjustment for other movement behaviours (i.e., physical activity or sleep), results were also extracted from the most adjusted model that was not adjusted for other movement behaviours. When available, we also extracted differences in effect by age, sex, race/ethnicity, socioeconomic status, weight status, and/or chronic disease status. Reviewers were not blinded to the authors or journals when extracting data.

Quality assessment

Two reviewers independently assessed the methodological quality of each SR using the AMSTAR 2 rating scale (Shea et al. 2017). AMSTAR 2 contains 16 items to appraise the methodological aspects of SRs. All assessments were discussed and agreed upon based on discussion among the 2 reviewers (or in consultation with a third reviewer, if required).

The outputs of the quality assessment performed by the authors of the SRs was extracted and reported (i.e., risk of bias, quality or strength of evidence, or scores on various quality assessment scales). Certainty of evidence for each health outcome was determined using the GRADE approach (Balslem et al. 2011). Certainty of evidence ratings began as high for randomized controlled trials and low for all other study designs. Certainty of evidence was downgraded due to risk of bias, inconsistency (evidenced by high levels of heterogeneity in meta-analyses or mixed study findings), indirectness, or imprecision, and upgraded based on large effect sizes or dose-response evidence.

Synthesis of results

Results were summarized via narrative synthesis, grouped by outcome. Results and conclusions were described as reported by the systematic review authors, such as reporting available summary estimates and confidence intervals as well as the number of

primary studies and participants that contributed to each available estimate. Tables were used to ensure consistency of data presentation across studies.

Results

Description of studies

The initial search identified 2948 records, with 2800 remaining after duplicates were removed (Fig. 1). Following title and abstract screening, 297 were obtained for full review, with 36 papers meeting all inclusion criteria. Reasons for excluding individual studies at full-text review are available in Supplemental File S1.² Following the process outlined above, 18 of 36 eligible systematic reviews were included in the final overview. Reasons for final exclusions at this stage are available in Supplemental File S2.² The characteristics of SRs included for critical outcomes are listed in Table 1, while those for important outcomes are available in Supplemental File S3.² The 18 included SRs contained results from more than 510 000 participants in 32 countries. Summaries of key findings for critical and important outcomes are presented in Tables 2 and 3, respectively.

Critical outcomes

Health-related quality of life

We included 3 SRs for this indicator, representing 25 individual studies with more than 64 000 unique participants from 9 countries. Boberska et al. (2018) performed an SR ($N = 58\ 109$) and meta-analysis of 19 observational studies on the relationship between sedentary behaviour and quality of life across the lifespan. Thirteen observational studies were included in the meta-analysis, which found that lower levels of sedentary behaviour were associated with higher physical domain health-related quality of life ($r = -0.152$; 95% confidence interval (CI): -0.206 to -0.097), but there was no significant association with the mental, social, functional domains, or overall health-related quality of life. Quality scores of included studies ranged from 72%–100% using the QUALSYST tool (Kmet, Lee, and Cook, 2004), while the AMSTAR 2 rating for the SR was moderate.

To investigate whether the relationship between sedentary behaviour and quality of life varied by age, we included 1 SR of young adults (Castro et al. 2018) and 1 of older adults (Ramalho et al. 2018). Castro et al. (2018) identified a single cross-sectional study ($N = 881$) rated as low risk using the Cochrane risk of bias tool, and found this to be insufficient evidence to determine whether sedentary behaviour was associated with quality of life in university students. Ramalho et al. (2018) identified 5 observational studies in adults aged 60 years or older ($N = 5767$), with 2/5 reporting that higher levels of sedentary behaviour were associated with lower levels of quality of life. Based on these findings, the authors concluded this indicated a tendency toward no association between sedentary behaviour and quality of life in older adults. The evidence collected by Ramalho et al. (2018) ranged from “fair” to “good” using the RTI Item Bank (Viswanathan et al. 2013). Both SRs received AMSTAR 2 ratings of moderate. There was no overlap in included studies between the 3 SRs included for this outcome. The certainty of evidence began as low due to a reliance on observational studies, and further downgraded to very low due to inconsistency of findings.

Brain health

We included 1 SR examining the association between sedentary behaviour and brain health. Falck et al. (2017) identified 1 case-control study of 466 adults aged 60–90 years. They report that adults diagnosed with Alzheimer’s disease watched significantly more daily TV than controls, with the odds of Alzheimer’s increasing by 32% (odds ratio = 1.32, 95% CI: 1.08 to 1.62) for each 1-hour increase in daily TV viewing. The quality of the included study was low (18/22 on the STROBE checklist (von Elm et al. 2008)), and the

authors were unable to determine the attributable risk of sedentary behaviour to dementia. The AMSTAR 2 rating for the SR was moderate. The certainty of evidence for this outcome began as low because of the observational nature of the included study, and was further downgraded to very low because of high risk of bias.

Cognitive function

We included 4 SRs examining the associations of sedentary behaviour with cognitive function in adults and older adults. These reviews included 49 unique studies ($N = 16\ 512$) from 7 countries. Falck et al. (2017) report that 4/6 studies, including all 3 high-quality studies, observed significant associations between higher levels of total sedentary behaviour and decreased cognitive function in adults aged ≥ 40 years. The authors concluded that high levels of sedentary behaviour are associated with reduced cognitive performance (Falck et al. 2017). The quality of included studies ranged from low to high, while the AMSTAR 2 rating for the SR was moderate.

To investigate whether this relationship varied by age, we also included 1 SR of young adults (Castro et al. 2018) and 1 in older adults (Ramalho et al. 2018). Castro et al. (2018) ($N = 523$) found 1 study that reported an unfavourable association between accelerometer-derived sedentary time and executive function (e.g., higher sedentary behaviour associated with lower executive function), while another reported no relationship between sitting time, screen time, or passive transportation with working memory. A third study reported an adverse association between perceived cognitive ability and total sitting time, but no association with device-measured sedentary time. Although the 3 included studies were deemed to have low risk of bias, the authors concluded there was insufficient evidence to determine the relationship between sedentary behaviour and cognitive function in young adults. Ramalho et al. (2018) concluded that while TV viewing may be unfavourably associated with cognitive function in 4 studies of older adults ($n = 10\ 377$), a beneficial relationship may exist for computer and Internet use in this population. The 4 studies included in the review by Ramalho et al. (2018) had “fair” to “good” risk of bias assessed using the RTI item bank (Viswanathan et al. 2013).

To examine the impact of occupational sedentary behaviour, we included 1 SR of 38 intervention studies ($N = 2126$), all comparing the effects of replacing seated with nonseated workstations (including standing desks, cycling desks, and walking desks) on cognition (Sui et al. 2019). The included interventions ranged from 4 min to 12 months in length. They reported that 33/38 studies observed no significant difference in cognitive performance between seated and nonseated workstations, 14 reported that nonseated workstations were associated with improved cognitive performance, and 6 studies reported that nonseated workstations were associated with reduced cognitive performance (some studies reported multiple indicators of cognitive performance). Effect sizes ranged from no effect to large effect. The authors concluded that nonseated workstation interventions had an overall null association with cognitive outcomes, which was consistent for all types of workstations. The majority of included studies were found to have an unclear (63%) or high (34%) risk of bias assessed by the Cochrane risk of bias tool (Higgins et al. 2011), while the SR received an AMSTAR 2 rating of moderate.

There were 49 unique studies included for this indicator, 2 of which were reported in multiple reviews. This resulted in a CCA of 1.36%, indicating a slight degree of overlap. The certainty of evidence for this outcome is low because of the observational and nonrandomized nature of included studies. These studies did not show serious risk of bias, inconsistency, indirectness, or imprecision and were therefore not further downgraded.

Table 1. Overview of key systematic reviews that examined the relationship between sedentary behaviour (SB) and critical health outcomes in adults.

Reference	Study designs and no. of primary studies included	Population	Intervention/exposure and comparison	Outcome measurement	Main findings	Quality of evidence	AMSTAR 2 rating and rationale
Outcome: HRQOL Boberska et al. (2018)	Systematic review ($n = 19$) and meta-analysis ($n = 13$) of observational studies from 5 countries: USA ($n = 5$) Australia ($n = 7$) Canada ($n = 5$) UK ($n = 3$) Belgium ($n = 1$)	Total: $N = 58\ 109$ adults Meta-analysis: $N = 52\ 049$ adults	Device-measured sedentary time, or self-reported screen time, total sitting, and driving time	Self-reported HRQOL, most frequently assessed using SF-36	Higher levels of SB associated with lower physical HRQOL ($r = -0.152$; 95% CI: $-0.206, -0.097$; I^2 statistic = 78.8%) There were no significant associations observed for mental, social, or functional domains, or overall HRQOL among adults	All studies needed a minimum score of 65% using QUALSYST, with included studies ranging from 72%–100% Funnel plots showed likelihood of publication bias	<i>Moderate</i> More than 1 noncritical weakness (no justification for excluding individual studies, no justification for eligible study designs, and no information on funding of individual studies)
Castro et al. (2018)	Systematic review that included 1 cross-sectional study from Mexico	$N = 881$ undergraduate and postgraduate university students	Self-reported screen time (TV, computer, and video game time)	Self-reported quality of life	1/1 studies found that total screen time was negatively associated with social quality of life. There were no significant associations observed between SB and environmental, personal, or overall quality of life	Low risk of bias using the Cochrane tool for risk of bias	<i>Moderate</i> More than 1 noncritical weakness (no justification for excluding individual studies, no justification for eligible study designs, no information on funding of individual studies)
Ramalho et al. (2018)	Systematic review that included $n = 3$ cross-sectional and $n = 2$ longitudinal studies from 4 countries: USA ($n = 2$), Spain ($n = 1$), Thailand ($n = 1$), Brazil ($n = 2$)	$N = 5767$ adults aged ≥ 60 y, with an average of ≥ 65 y in all included studies	Self-reported or device-measured SB Device measures: ActiGraph GT1M, ActiGraph GT3X Self-reported measures: total sedentary time TV viewing, computer use, reading, hobbies, socializing, sitting, driving, office work, housework, lying down, playing cards, knitting, etc.	Self-reported quality of life	2/5 studies reported significant and negative associations between SB and quality of life	Risk of bias ranged from fair to good using the RTI item bank. The overall strength of evidence was rated as low	<i>Moderate</i> More than 1 noncritical weakness (no preregistration, no justification for excluding individual studies, no justification for eligible study designs, no information on funding of individual studies)
Outcome: Brain health Falck et al. (2017)	Systematic review that included $n = 1$ case-control study from the USA	$N = 466$ adults aged 60–90 y	Self-reported TV viewing	Diagnosed cases of Alzheimer's disease	1/1 studies: cases watched significantly more TV than controls, and odds of developing Alzheimer's increased 1.32 (95% CI: 1.08, 1.62) for each 1-h increase in daily TV viewing	The quality of evidence ranged was low (18/22) on the STROBE checklist	<i>Moderate</i> More than 1 noncritical weakness (no preregistration, no justification for excluding individual studies, no information on funding of individual studies)
Outcome: Cognitive function Falck et al. (2017)	Systematic review that included $n = 6$ observational studies from 3 countries: USA ($n = 3$), France ($n = 2$), England ($n = 1$)	$N = 11\ 958$ adults aged ≥ 40 y	Self-reported and device-measured screen time, TV time, total SB	Cognitive function as assessed by dementia diagnosis, as well as a variety of lab-based cognitive tests	4/6 studies: associations between increased SB and decreased cognitive function 2 studies: associations between increased SB and improved CF of lab-based cognitive tests All 3 of the high-quality studies found negative associations between SB and CF	The quality of evidence ranged from low to high on the STROBE checklist, with an average score of 20/22	<i>Moderate</i> More than 1 noncritical weakness (no preregistration, no justification for excluding individual studies, no information on funding of individual studies)

Table 1 (continued).

Reference	Study designs and no. of primary studies included	Population	Intervention/exposure and comparison	Outcome measurement	Main findings	Quality of evidence	AMSTAR 2 rating and rationale
Castro et al. (2018)	Systematic review that included 2 prospective cohort studies from the USA and 1 cross-sectional study from Spain	N = 523 undergraduate and postgraduate university students	Self-reported screen time (TV, computer, and video game time), passive transportation, and device-measured total sitting time	Working memory capacity, executive function, and perceived cognitive ability	1/1 studies on executive function reported a negative association with accelerometer-derived total sedentary time. 1/1 studies on working memory capacity reported no association with self-reported sitting, screen time, or passive transportation. 1/1 studies on perceived cognitive ability reported a negative association with total sitting time, but no association with device-measured sedentary time	Low risk of bias using the Cochrane tool for risk of bias	<i>Moderate</i> More than 1 noncritical weakness (no justification for excluding individual studies, no justification for eligible study designs, no information on funding of individual studies)
Ramalho et al. (2018)	Systematic review that included $n = 2$ cross-sectional and $n = 2$ longitudinal studies from 5 countries: England ($n = 2$), France ($n = 1$), Italy ($n = 1$), Switzerland ($n = 1$), Germany ($n = 1$)	N = 10 377 adults aged ≥ 60 y, with an average of ≥ 65 y in all included studies	Self-reported or device-measured TV viewing, computer use, and total SB	Lab-based tests of cognitive function	3/4 studies reported negative associations between TV viewing and measures of cognitive function 2/2 studies reported positive associations between Internet/computer use and cognitive function	Risk of bias ranged from fair to good using the RTI item bank. The overall strength of evidence was rated as low	<i>Moderate</i> More than 1 noncritical weakness (no preregistration, no justification for excluding individual studies, no justification for eligible study designs, no information on funding of individual studies)
Sui et al. (2019)	Systematic review that included $n = 38$ intervention studies	N = 2126 office workers and simulated office workers	Interventions: any environmental and/or behavioral, active and/or standing workstation intervention to reduce SB. Duration of interventions ranged from 4 min to 12 mo	Any variables assessing cognition that did not mimic work-related tasks (e.g., reading, memory)	1/1 studies reported no association between device-measured sitting and cognitive function 33/38 studies observed no difference between seated and nonseated workstations, 14 reported that nonseated workstations were associated with improved cognitive performance, and 6 studies reported that nonseated workstations were associated with reduced cognitive performance	Using the Cochrane Risk of Bias Tool, 24/38 studies were identified as unclear risk of bias, 1/38 was identified as low risk of bias, and 13 had high risk of bias	<i>Moderate</i> More than 1 noncritical weakness (no preregistration, no justification for excluding individual studies, data extraction not performed in duplicate, no information on funding of individual studies, conflicts of interest not reported)
Outcome: Depression							
Zhai et al. (2015)	Meta-analysis that included $n = 8$ longitudinal studies performed in 7 countries: Sweden ($n = 2$), Finland ($n = 1$), Netherlands ($n = 1$), Spain ($n = 1$), USA ($n = 1$) UK ($n = 1$), Australia ($n = 1$)	N = 82 406 adult participants aged 18–85 y	Self-reported or device-measured SB	Depression, defined as reporting a doctor's diagnosis, regular use of antidepressant medication, via interview, or depression rating scales	Compared with those reporting no or occasional SB, those with the highest SB had a 1.14 (95% CI: 1.06–1.21) relative risk of depression	The studies were rated as good quality, ranging from 7–9 on the Newcastle–Ottawa scale, with an average of 7.9	<i>Moderate</i> More than 1 noncritical weakness (no preregistration, no justification for excluding individual studies, sources of funding for individual studies not identified)

Table 1 (continued).

Reference	Study designs and no. of primary studies included	Population	Intervention/exposure and comparison	Outcome measurement	Main findings	Quality of evidence	AMSTAR 2 rating and rationale
Teychenne et al. (2010)	Systematic review that included $n = 4$ intervention, $n = 2$ longitudinal, and $n = 5$ cross sectional studies performed in 3 countries: USA ($n = 9$), Spain ($n = 1$), Sweden ($n = 1$)	$N = 18$ 185 healthy adults aged 18–60 y	Self-reported or device-measured SB	Self-reported depression scales	7/7 observational studies and 1/4 intervention studies found positive associations between SB and depression or depressive symptoms. 2/4 intervention studies and 1/7 studies observed inverse associations between SB and depression, while 1/4 interventions reported no association. Total sedentary time and TV viewing were generally positively associated with depression or depressive symptoms, while Internet and computer use often demonstrated beneficial associations with depression or depressive symptoms	The quality score of studies included in the review ranged from 23%–91% using the STROBE and CONSORT checklists (mean score: 63%)	<i>Moderate</i> More than 1 noncritical weakness (no preregistration, no justification for included study designs, study selection and data extraction not performed in duplicate, no justification for excluding individual studies, sources of funding for individual studies not identified)
Ramalho et al. (2018)	Systematic review that included $n = 3$ cross-sectional and $n = 3$ longitudinal studies from 5 countries: England ($n = 4$), Italy ($n = 1$), Switzerland ($n = 1$), Germany ($n = 1$), USA ($n = 1$)	$N = 19$ 159 adults aged ≥ 60 y, with an average of ≥ 65 y in all included studies	Self-reported or device-measured TV viewing, computer use, and total SB	Self-reported depression and depression symptoms	4/6 studies observed null associations between SB and depressive symptoms, 3/6 studies observed positive associations between SB and depressive symptoms, and 2/6 studies reported negative associations	Risk of bias ranged from fair to good using the RTI item bank. The overall strength of evidence was rated as low	<i>Moderate</i> More than 1 noncritical weakness (no preregistration, no justification for excluding individual studies, no justification for eligible study designs, no information on funding of individual studies)
Outcome: Musculoskeletal pain							
Castro et al. (2018)	Systematic review that included $n = 17$ cross-sectional and $n = 3$ prospective cohort studies from 17 countries: USA ($n = 5$), Colombia ($n = 1$), Malaysia ($n = 1$), India ($n = 1$), Ireland ($n = 1$), Turkey ($n = 1$), Thailand ($n = 1$), Pakistan ($n = 1$), Japan ($n = 1$), South Africa ($n = 1$), Bahrain ($n = 1$), Belgium ($n = 1$), Canada ($n = 1$), China ($n = 1$), Israel ($n = 1$), Saudi Arabia ($n = 1$), Romania ($n = 1$)	$N = 7093$ undergraduate and postgraduate university students	Self-reported screen time (TV, computer, and video game time), total sitting time, and studying time	Musculoskeletal symptoms	Positive associations were observed between musculoskeletal symptoms and total sitting time (3/3 studies), computer use (8/10 studies), video games (1/3 studies), and mobile phones (2/6 studies). No associations were observed between musculoskeletal symptoms and TV viewing (1/1 studies), total screen time (1/1 studies), or studying (3/3 studies)	High risk of bias using the Cochrane Risk of Bias tool	<i>Moderate</i> More than 1 noncritical weakness (No justification for excluding individual studies, no justification for eligible study designs, no information on funding of individual studies)

Table 1 (continued).

Reference	Study designs and no. of primary studies included	Population	Intervention/exposure and comparison	Outcome measurement	Main findings	Quality of evidence	AMSTAR 2 rating and rationale
Shrestha et al. (2018)	Systematic review that included $n = 7$ intervention studies from 5 countries: Australia ($n = 3$), Finland ($n = 1$), UK ($n = 1$), Denmark ($n = 1$), USA ($n = 1$)	$N = 569$ adults aged ≥ 18 y	Interventions to reduce workplace SB, including physical design of workplace environment; workplace policy changes; provision of information and counselling; and multi-component interventions with no intervention or with other interventions, and were categorized as short (<3 mo) or medium term (3–12 mo)	Self-reported musculo-skeletal symptoms and body pain	3/5 interventions reported a lower prevalence of musculoskeletal symptoms in participants using sit-stand desks when compared with sit-desks. 1/5 studies reported an increased prevalence of musculoskeletal symptoms in the sit-stand desk group, and 1/5 studies reported no difference 1/1 multi-component intervention and 1/1 active workstation intervention reported no changes in musculoskeletal symptoms when compared with baseline	The risk of bias was rated as low for 2 studies and high for all others using the Cochrane tool for risk of bias	High No critical weakness and 1 noncritical weakness (no justification for eligible study designs)
Josaphat et al. (2019)	Systematic review that included $n = 1$ intervention study from Australia	$N = 23$ adult office workers with overweight or obesity with mean age of 48.2 y	Randomized controlled trial comparing 8 h of seated work to alternating between sitting and standing every 30 min	Self-reported musculoskeletal discomfort	1/1 studies reported reduced discomfort when alternating sitting and standing when compared with sitting for 8 h	Using the Cochrane tool, the risk of bias due to allocation sequence, concealment, attrition, and reporting were low, risk of performance bias was high, and the risk of detection and other bias was unclear	Low 1 Critical weakness (no consideration of bias when interpreting results) and more than 1 noncritical weakness (no preregistration, no justification for excluding individual studies, no justification for included study designs, study selection and data extraction not performed in duplicate, funding of individual studies not reported)
Outcome: Accidents and injuries O'Donoghue et al. (2016)	Systematic review that included $n = 4$ cross-sectional and $n = 1$ prospective observational studies	$N = 60\ 049$ adults aged 18–65 y	Self-reported transport sitting time, total sitting time, and device-measured sedentary time	Disability, illness, and injury	4/4 studies reported no association between self-reported sitting time ($n = 4$) or device-measured sedentary time ($n = 1$) and disability, illness, or injury. 1/1 studies reported a positive association between transport sitting time and disability, illness or injury	Quality scores ranged from 80%–91% using the QUALSYST tool, with an average of 87%	Low 1 Critical weakness (impact of risk of bias not discussed) and more than 1 noncritical weakness (no justification for excluding individual studies, no explanation for selection of study designs, data extraction not performed in duplicate, no details on the funding of individual studies)
Rezende et al. (2014)	Systematic review (no eligible studies identified)	$N = 0$ adults aged ≥ 60 y	Self-reported or device-measured SB	Accidental falls	NA	NA	Moderate More than 1 noncritical weakness (protocol not pre-registered, no justification for included study designs, no information on funding of individual studies)

Table 1 (continued).

Reference	Study designs and no. of primary studies included	Population	Intervention/exposure and comparison	Outcome measurement	Main findings	Quality of evidence	AMSTAR 2 rating and rationale
Shrestha et al. (2018)	Systematic review that included $n = 7$ intervention studies from 5 countries: Australia ($n = 3$), Finland ($n = 1$), UK ($n = 1$), Denmark ($n = 1$), USA ($n = 1$)	$N = 569$ adults	Interventions to reduce workplace SB, including physical design of workplace environment; workplace policy changes; provision of information and counselling; and multi-component interventions Interventions were compared with no intervention or with other interventions, and were categorized as short (<3 mo) or medium term (3–12 mo)	Adverse events	Excluding the musculoskeletal pain described previously, no adverse events were reported	The risk of bias was rated as high for all included studies using the Cochrane tool for risk of bias	High No critical weakness and 1 noncritical weakness (no justification for eligible study designs)
Outcome: Biomarkers of cardiometabolic risk							
Torbeyns et al. (2014)	Systematic review that included $n = 3$ nonrandomized intervention studies	$N = 54$ adult participants	Replacing seated workstations with standing or treadmill workstations. Interventions ranged in duration from 3 h to 9 mo	Markers of cardiometabolic risk	1/1 standing desk intervention reported an increase in HDL-cholesterol, while 1/1 reported a decrease in postprandial glucose, when compared with a seated workstation. 1/1 treadmill desk intervention reported a significant reduction in total and LDL-cholesterol	Quality scores ranged from weak to moderate using the Scottish Intercollegiate Guidelines Network checklist	Moderate More than 1 noncritical weakness (no pre-registration, no justification for excluding individual studies, no explanation of included study designs, study selection and data extraction not performed in duplicate, sources of funding for individual studies not listed)
Wirth et al. (2017)	Systematic review that included $n = 1$ randomized controlled trial performed in Denmark	$N = 66$ older adults (mean age: 63 y)	Reduced daily TV viewing, replacing sitting with standing, and breaking up long sitting for a period of 6 mo	Markers of cardiometabolic risk (fasting insulin and glucose, cholesterol, triglycerides, and HbA1c)	1/1 intervention studies targeting reduced SB in older adults observed a significant reduction in fasting insulin levels in favour of the intervention group, with no changes observed for total, HDL- or LDL-cholesterol, or fasting glucose	Quality score of 5/6 using the CASP tool	Moderate More than 1 noncritical weakness (no justification for excluding individual studies, no explanation of included study designs, study selection not performed in duplicate, sources of funding for individual studies not reported, conflicts of interest not reported)

Table 1 (continued).

Reference	Study designs and no. of primary studies included	Population	Intervention/exposure and comparison	Outcome measurement	Main findings	Quality of evidence	AMSTAR 2 rating and rationale
Josaphat et al. (2019)	Systematic review that included $n = 5$ randomized and $n = 5$ nonrandomized intervention studies	$N = 324$ adult office workers with overweight or obesity	Replacing seated workstations with standing or treadmill workstations for periods ranging from 8 h to 12 mo	Markers of cardiometabolic risk (glycemic control, blood pressure, cholesterol, triglycerides, HbA1c)	3/4 randomized trials reported that standing workstations resulted in improved measures of glycemic control, when compared with seated workstations. 2/3 nonrandomized interventions reported that treadmill workstations resulted in lower HbA1c levels; 1/3 reported improved total and LDL-cholesterol levels, 1/3 reported improvements in HDL-cholesterol, and 1/3 reported no changes in cholesterol levels. 3/3 nonrandomized studies reported no changes in fasting insulin, glucose, or triglycerides in response to treadmill desk use	Using the Cochrane tool, all but 1 included study were rated as high risk of bias for at least one indicator	Low 1 Critical weakness (no consideration of bias when interpreting results) and more than 1 noncritical weakness (no preregistration, no justification for excluding individual studies, no justification for included study designs, study selection and data extraction not performed in duplicate, funding of individual studies not reported)
					2/2 nonrandomized studies reported that standing desks reduced blood pressure, while 2/2 randomized studies reported no effects		
					2/3 nonrandomized studies reported a significant reduction in blood pressure following the use of a treadmill desk		
					1/1 randomized study reported that intermittent cycling throughout a 4-h workday did not result in acute changes in blood pressure. 1/1 nonrandomized study reported that using a cycling desk during an 8-h workday decreased systolic blood pressure when compared with sitting		

Table 1 (continued).

Reference	Study designs and no. of primary studies included	Population	Intervention/exposure and comparison	Outcome measurement	Main findings	Quality of evidence	AMSTAR 2 rating and rationale
Saunders et al. (2018)	Systematic review ($n = 44$) and meta-analysis ($n = 20$) of intervention studies	Total: $N = 702$ Meta-analysis: $n = 384$ across the lifespan (mean age ≥ 18 y for all meta-analyses)	Interventions lasting <24 hours breaking up sedentary time, compared with uninterrupted sedentary time	Markers of cardiometabolic risk (postprandial glucose, insulin and triglycerides)	Compared with uninterrupted sitting, breaking up sitting time was associated with benefits in postprandial glucose: SMD: -0.36 (95% CI: -0.50 to -0.21); I^2 : 15.9% and insulin: SMD: -0.37 (95% CI: -0.53 to -0.20); I^2 : 0.0% These effects were not modified by meal timing Although there was no overall effect observed for postprandial triglycerides (SMD: 0.06 (95% CI: -0.15 to 0.26; I^2 : 10.3%), a significant effect was observed when the test meal was performed the day following the intervention (SMD: -0.57 95%CI: -1.05 to -0.09 ; I^2 : 25.1%) These results were not influenced by the age or weight status of participants or by the intensity of the activity breaks Two randomized and 1 nonrandomized intervention reported that breaking up sitting resulted in reduced blood pressure, while 2 other randomized interventions reported no effect. These outcomes were not assessed via meta-analysis	The quality of included studies ranged from 20–30 out of 32 on the Downs and Black Checklist	Moderate more than 1 noncritical weakness (no justification for excluding individual studies, no explanation of included study designs, data extraction not done in duplicate, insufficient detail on included studies, sources of funding for individual studies not reported, impact of risk of bias of individual studies on meta-analysis not reported)
Outcome: Body composition Neuhaeus et al. (2014)	Systematic review that included of $n = 2$ randomized and $n = 4$ nonrandomized intervention studies	$N = 197$ adults aged ≥ 18 y	Seated workstations, in comparison to activity permissive workstations (e.g. height-adjustable workstations, treadmill and pedal desks). Interventions ranged in duration from 4 wk to 12 mo	BMI, waist circumference	3/3 studies (1 randomized) using a treadmill or pedal desk reported a significant improvement in waist circumference, while 2/2 nonrandomized studies using sit-stand desks reported no change. 1 Randomized study reported a significant improvement in BMI following the introduction of an activity permissive workstation, while 1 randomized and 2 nonrandomized interventions reported no change	Across all studies included in the review, QALSYST scores ranged from 56%–100%	Moderate More than 1 noncritical weakness (no preregistration, no justification for excluding individual studies, no explanation for included designs)

Table 1 (continued).

Reference	Study designs and no. of primary studies included	Population	Intervention/exposure and comparison	Outcome measurement	Main findings	Quality of evidence	AMSTAR 2 rating and rationale
Josaphat et al. (2019)	Systematic review that included $n = 4$ randomized and $n = 3$ nonrandomized intervention studies	$N = 198$ adult office workers with overweight or obesity	Replacing seated workstations with standing or treadmill workstations. Interventions ranged from 5 d to 12 mo	BMI, body weight, body fat %	3/3 nonrandomized studies using a treadmill desk reported a significant improvement in at least 1 measure of body composition, while 2/2 randomized studies failed to detect any changes in body composition. 2/2 randomized studies using a sit-stand desk reported no change in body composition	Using the Cochrane tool, 5/7 studies were rated as high risk of bias for at least 1 indicator	Low 1 Critical weakness (no consideration of bias when interpreting results) and more than 1 noncritical weakness (no preregistration, no justification for excluding individual studies, no justification for included study designs, study selection and data extraction not performed in duplicate, funding of individual studies not reported)
Wirth et al. (2017)	Systematic review that included $n = 1$ randomized controlled trial performed in Denmark	$N = 66$ older adults (mean age: 63 y)	Reduced daily TV viewing, replacing sitting with standing, and breaking up long sitting	Waist circumference	1/1 intervention studies targeting reduced SB in older adults observed no change in waist circumference following the intervention	Quality score of 5/6 using the CASP tool	Moderate More than 1 noncritical weakness (no justification for excluding individual studies, no explanation of included study designs, study selection not performed in duplicate, sources of funding for individual studies not reported, conflicts of interest not reported)

Note: Numerical data were included when results were pooled in meta-analyses; narrative descriptions of study findings were provided in all other instances. Countries of included studies are reported when provided in systematic reviews. BMI, body mass index; CASP, Critical Appraisal Skills Programme; CI, confidence interval; HbA1c, glycated hemoglobin; HDL, high density lipoprotein; HRQOL, health-related quality of life; LDL, low density lipoprotein; SMD, standardized mean difference.

Table 2. Summary of key findings for critical outcomes.

Outcome	Key findings	Certainty of evidence
Health-related quality of life	Lower levels of sedentary behaviour are associated with higher physical health-related quality of life	Very low because of reliance on observational studies and inconsistency of findings
Brain health	Higher levels of TV viewing may be associated with higher likelihood of dementia	Very low because of reliance on observational studies and high risk of bias
Cognitive function	Higher levels of sedentary behaviour are associated with reduced cognitive performance. Among older adults, TV viewing may be unfavourably associated with cognitive function, while a beneficial association may be seen for computer and Internet use Replacing seated with nonseated workstations does not impact cognitive function	Low because of reliance on observational and nonrandomized studies
Depression	Higher levels of sedentary behaviour were associated with a greater risk of depression Higher total sedentary time and TV viewing are generally unfavourably associated with depression and depressive symptoms, while Internet and computer use often demonstrated beneficial associations with depression and depressive symptoms	Very low because of a reliance on observational research and inconsistency of findings
Musculoskeletal pain	The relationship between sedentary behaviour and musculoskeletal pain is unclear. The impact of replacing seated with nonseated workstations on musculoskeletal pain is also unclear	Very low because of reliance on observational and nonrandomized studies, high risk of bias, and inconsistency of findings
Accidents and injuries	Sedentary behaviour is not associated with accidents or injuries in adults aged 18–65 y, while there is insufficient evidence among older adults. The impact of replacing seated with nonseated workstations on accidents and injuries is also unclear	Very low because of reliance on observational and nonrandomized studies and inconsistency of findings
Biomarkers of cardiometabolic risk	Reducing or breaking up periods of prolonged sitting may have beneficial effects on markers of cardiometabolic risk	Low because of inclusion of nonrandomized intervention studies
Body composition	Replacing seated workstations with treadmill or pedal workstations may have beneficial effects on body composition	Very low because of inclusion of nonrandomized intervention studies and inconsistency of findings

Table 3. Summary of key findings for important outcomes.

Outcome	Key findings	Certainty of evidence
Function and disability	Higher levels of sedentary behaviour are associated with increased prevalence of frailty and reduced function	Low because of reliance on observational studies
Fatigue	The relationship between sedentary behaviour and fatigue is unclear	Very low because of reliance on observational and nonrandomized intervention studies, as well as inconsistency of findings
Work productivity	Replacing seated desks with sit–stand desks does not impact work performance	Very low because of inclusion of nonrandomized intervention studies and high risk of bias
Sleep duration	The relationship between sedentary behaviour and sleep is unclear	Very low because of reliance on observational studies and high risk of bias
Physical activity duration	Higher levels of sedentary behaviour are associated with lower levels of physical activity Replacing seated with nonseated workstations is associated with increased physical activity levels	Low because of inclusion of observational and nonrandomized intervention studies

Depression

We included 3 SRs ($N = 103\,278$), representing 22 individual studies from 10 countries that examined the relationship between sedentary behaviour and depression. [Zhai et al. \(2015\)](#) performed an SR and meta-analysis of 8 longitudinal studies ($N = 82\,406$) examining the relationship between sedentary behaviour and depression across the adult lifespan. Individuals with the highest levels of sedentary behaviour had a relative risk of depression of 1.14 (95% CI: 1.06–1.21), when compared with those reporting no or occasional sedentary behaviour. The included studies were rated as good quality using the Newcastle–Ottawa scale ([Wells et al. n.d.](#)), while the SR received an AMSTAR 2 rating of moderate.

To examine whether these associations varied by age, we also included SRs in younger and older adults. [Teychenne et al. \(2010\)](#) identified 11 studies (7 observational and 4 intervention) among healthy adults aged 18–60 years of age ($N = 18\,185$). The most frequently reported outcome was depressive symptoms measured via the Center for Epidemiological Studies Depression Scale ([Radloff 1977](#)). They reported that 7/7 observational studies and 1/4 intervention studies identified unfavourable associations between sedentary behaviour and depression or depressive symptoms. Two intervention studies and 1 observational study observed favourable associations between sedentary behaviour and depression or depression symptoms, while 1 intervention study reported

no association (some studies reported multiple associations). The authors noted that total sedentary time and TV viewing were generally deleteriously associated with depression or depressive symptoms, while Internet and computer use often demonstrated beneficial associations. The quality score of studies included in the review ranged from 23%–91% using the STROBE (von Elm et al. 2008) and CONSORT (Moher et al. 2001) checklists, while the SR had an AMSTAR 2 rating of moderate.

Ramalho et al. (2018) identified 3 cross-sectional and 3 longitudinal studies reporting on the relationship between sedentary behaviour and depressive symptoms in adults aged 60 years or older ($N = 19\ 159$). They reported that 4/6 studies observed null associations between sedentary behaviour and depressive symptoms, 3/6 studies observed positive associations between sedentary behaviour and depressive symptoms, and 2/6 studies reported negative associations (some studies reported multiple associations). The authors concluded that mentally passive sedentary behaviours such as TV viewing may be unfavourably associated with depressive symptoms, although these results were not consistent. Using the RTI item bank the authors characterized the strength of the evidence as low (Viswanathan et al. 2013), while the SR had a moderate AMSTAR 2 rating.

Of the 22 individual studies included for this indicator, 3 were reported in multiple SRs.

The CCA for included studies for this outcome was 6.8%, representing a moderate degree of overlap. The certainty of evidence for this outcome began as low because of a reliance on observational data and was further downgraded to very low because of inconsistency of results.

Musculoskeletal pain

We included 3 SRs examining the relationship between sedentary behaviour and musculoskeletal pain, representing data from 28 unique studies ($N = 7685$) from 21 countries. Castro et al. (2018) examined the relationship between sedentary behaviour and musculoskeletal symptoms in university students. Their review included 20 studies examining this relationship, and report that musculoskeletal symptoms were positively associated with total sitting time (3/3 studies), computer use (8/10 studies), video games (1/3 studies), and mobile phones (2/6 studies). However, they report that the risk of bias of the available research assessed by the Cochrane risk of bias tool (Higgins et al. 2011) was too high to conclude that there is an association between sedentary behaviour and symptoms in this age group. The AMSTAR 2 rating of this review was moderate. We did not identify any SRs examining the relationship between sedentary behaviour and pain in older adults.

To examine the impact of occupational sitting in adults aged 18 years or older, we included the systematic review Shrestha et al. (2018) ($N = 569$). They identified 5 interventions (2 randomized, 3 nonrandomized) comparing sit-stand desks with seated desks over the short (<3 months) or medium (3–12 months) term. Three of the 5 studies (1 randomized, 2 nonrandomized) reported a lower prevalence of musculoskeletal symptoms while using a sit-stand desk, 1 nonrandomized study reported an increased prevalence of symptoms in the sit-stand desk group, while 1 randomized study observed no significant changes. The authors concluded that the impact of sit-stand desks on musculoskeletal pain is currently unclear. They also identified 1 multi-component intervention and 1 active workstation intervention. Both were randomized, and neither reported significant changes in musculoskeletal symptoms as a result of the intervention. In this review only 2 studies were judged to have low risk of bias using the Cochrane risk of bias tool (Higgins et al. 2011); neither of these studies identified a significant change in musculoskeletal pain following the intervention. This review received an AMSTAR 2 rating of high. To examine the impact of weight status, we included Josaphat et al. (2019), who performed a similar SR of occupational sitting inter-

ventions among individuals with overweight and obesity. They reported that 1 study ($N = 23$) with high risk of performance bias indicated that decreasing sitting time resulted in reduced lower back pain and discomfort. This review received an AMSTAR 2 rating of low.

There was no overlap across the SRs used to inform this outcome. The certainty of evidence for this outcome began as low due to a reliance on observational studies and non-randomized trials, and was further downgraded to very low due to high risk of bias and inconsistency of findings.

Accidents and injuries

We included 3 SRs on the relationship between sedentary behaviour and accidents or injuries, representing 12 unique studies ($N = 60\ 618$). O'Donoghue et al. (2016) identified 5 studies examining the relationship between sedentary behaviour and disability, illness, and injury in adults aged 18–65 years ($N = 60\ 049$). They report that 1/1 studies observed a positive association between transport sitting time and injury, illness, or disability, while 4/4 studies reported no association between accidents and injuries with self-reported or device-measured sitting time. The authors concluded that there is no significant relationship between sedentary behaviour and these outcomes. The included studies received QUALSYST scores ranging from 80%–91% (Kmet et al. 2004), while the SR received an AMSTAR 2 rating of low. Although de Rezende et al. (2014) included accidental falls as an outcome in their SR of sedentary behaviour and health outcomes among adults aged 60 years and older, no relevant studies were identified. The SR described above by Shrestha et al. (2018) examined adverse events in response to workplace sedentary behaviour interventions. They reported no adverse events beyond the musculoskeletal symptoms reported in the previous section. There was no overlap across the SRs used to inform this outcome. The certainty of evidence for this outcome began as low because of a reliance on observational and nonrandomized trials, and was further downgraded to very low because of risk of bias and inconsistency of findings.

Biomarkers of cardiometabolic risk

We included 4 SRs for this outcome, representing 55 individual studies ($N = 1102$). Torbeyns et al. (2014) ($N = 54$) identified 3 non-randomized interventions, ranging from 3 h to 9 months in duration. Two interventions replaced seated workstations with standing workstations, while 1 replaced seated workstations with treadmill workstations. They reported that replacing sitting with standing for 3 h acutely reduced postprandial glucose excursions by 43% in 1 study, while a 3-month standing desk intervention increased high-density lipoprotein (HDL)-cholesterol in another study (there were no significant changes reported for other biomarkers). One study reported that replacing seated workstations with treadmill workstations resulted in reduced low-density lipoprotein (LDL) and total cholesterol in overweight and obese office workers. Quality scores for these interventions ranged from weak-to-moderate using the Scottish Intercollegiate Guidelines Network checklist (SIGN n.d.), while the review was given an AMSTAR 2 rating of moderate. To examine the relationship between sedentary behaviour and cardiometabolic risk in older adults we included the review by Wirth et al. (2017). They reported that 1/1 randomized controlled trial ($N = 66$) reducing sedentary behaviour in adults with a mean age of 63 years resulted in a significant reduction in fasting insulin levels in favour of the intervention group, with no changes observed for total, HDL, or LDL-cholesterol, or fasting glucose. The trial received a quality score of 5/6 using the Critical Appraisal Skills Programme tool (CASP n.d.), and the SR received an AMSTAR 2 rating of moderate.

To examine whether these associations varied by weight status we included the SR by Josaphat et al. (2019), who reviewed 5 randomized and 5 nonrandomized intervention studies replacing

seated workstations with standing, treadmill, or cycling workstations in overweight and obese office workers ($N = 324$). The interventions ranged in duration from 8 h to 12 months. They reported that 3/4 randomized trials found that standing workstations resulted in improved measures of glycemic control, when compared with seated workstations. Both (2/2) nonrandomized studies reported that standing desks reduced blood pressure, while both (2/2) randomized studies reported no effects. Based on these findings, the authors concluded that standing desks improve glycemic control, but not blood pressure. [Josaphat et al. \(2019\)](#) found conflicting results related to treadmill desks and biomarkers of cardiometabolic risk; 2/3 nonrandomized interventions reported that treadmill workstations resulted in lower HbA1c levels, 1/3 reported improved total and LDL-cholesterol levels, 1/3 reported improvements in HDL-cholesterol, and 1/3 reported no changes in cholesterol levels. All (3/3) nonrandomized studies reported no changes in fasting insulin, glucose, or triglycerides in response to treadmill desk use. They also reported that 2/3 nonrandomized studies reported a significant reduction in blood pressure following the use of a treadmill desk.

Finally, [Josaphat et al. \(2019\)](#) examined the impact of cycling desks on biomarkers of cardiometabolic risk, and reported that 1/1 randomized study found that intermittent cycling throughout a 4-h workday did not result in acute changes in blood pressure. In contrast, 1/1 nonrandomized study reported that using a cycling desk during an 8-h workday decreased systolic blood pressure when compared with sitting. Using the Cochrane risk of bias tool ([Higgins et al. 2011](#)), all but 1 included study were rated as high risk of bias for at least 1 indicator, while the review itself received an AMSTAR 2 rating of low.

To examine the acute impact of breaking up sedentary time, we included an SR and meta-analysis by [Saunders et al. \(2018\)](#) ($N = 702$) examining the impact of <24 h of prolonged sitting. They reported that in comparison to uninterrupted sitting, breaking up sitting was associated with acute reductions in postprandial glucose (standardized mean difference (SMD): -0.36 ; 95% CI: -0.50 to -0.21) and insulin (SMD: -0.37 ; 95% CI: -0.53 to -0.20). Although there was no overall effect seen for postprandial triglycerides (SMD: 0.06 ; 95% CI: -0.15 to 0.26), a significant effect was observed when the test meal was performed the day following the intervention (SMD: -0.57 ; 95% CI: -1.05 to -0.09). These results were not influenced by age or weight status of the participants, or the intensity of the activity breaks. The authors also identified 5 interventions examining the impact of breaks in sedentary time on blood pressure. They observed that 2 randomized and 1 nonrandomized intervention reported that breaking up sitting resulted in reduced blood pressure, while 2 other randomized interventions reported no effect. Based on these findings the authors concluded there was insufficient evidence to determine the association between breaks in sedentary time and blood pressure. The quality of the included studies ranged from 20–30 out of 32 on the Downs and Black Checklist ([Downs and Black 1998](#)), and the review itself received an AMSTAR 2 rating of moderate.

Of 55 individual unique studies included for this indicator, 3 were included in multiple reviews. This resulted in a CCA of 1.8%, representing a slight degree of overlap. The certainty of evidence for this outcome was rated as low because of the inclusion of nonrandomized interventions within the cohort of included studies. The reviews did not show serious risk of bias, inconsistency, indirectness, or imprecision and were therefore not downgraded further.

Body composition

We included 3 SRs representing 12 individual studies ($N = 413$) examining the association of sedentary behaviour and body composition. [Neuhaas et al. \(2014\)](#) included 2 randomized and 4 nonrandomized intervention studies examining the impact of replacing sedentary behaviour with physical activity through the use of

activity permissive workstations (e.g., treadmill desks, pedal desks, standing desks, etc.) on waist circumference and/or body mass index ($N = 197$). These interventions ranged in duration from 4 weeks to 12 months. They reported that 3/3 studies (1 randomized) using a treadmill or pedal desk reported a significant improvement in waist circumference, while 2/2 nonrandomized studies using sit-stand desks reported no change. One randomized study reported a significant improvement in body mass index following the introduction of an activity permissive workstation, while 1 randomized and 2 nonrandomized interventions reported no change. The authors suggested that the findings were predominantly positive for waist circumference, but not body mass index. The QUALSYST scores of included studies ranged from 56%–100%, while the review itself received an AMSTAR 2 rating of moderate ([Kmet et al. 2004](#)).

To examine the impact of body composition on these findings we included [Josaphat et al. \(2019\)](#), which only included studies of individuals with overweight or obesity ($N = 198$). The included interventions ranged in duration from 5 days to 12 months. They report that 3/3 nonrandomized studies using a treadmill desk reported a significant improvement in at least 1 measure of body composition, while 2/2 randomized studies failed to detect any changes in body composition. Both (2/2) randomized studies using a sit-stand desk reported no change in body composition. The authors suggested that treadmill desks, but not sit-stand desks, may be beneficial for measures of body composition.

To examine the impact in older adults, we also included the SR done by [Wirth et al. \(2017\)](#). They reported that 1/1 randomized controlled trial ($N = 66$) targeting reduced sedentary behaviour in older adults did not result in any significant changes in body composition.

Of 12 individual studies identified for this indicator, 2 were reported in multiple SRs. This resulted in a CCA of 8.33%, indicating a moderate degree of overlap. The certainty of evidence for this outcome was rated as low because of the inclusion of nonrandomized interventions within the cohort of included studies. The certainty of evidence was further downgraded to very low because of inconsistency of findings.

Important outcomes

Function and disability

Three SRs were included which examined the relationship between sedentary behaviour and physical function and disability ($N = 131\ 873$) in 26 unique studies performed in 11 countries. [Kehler et al. \(2018\)](#) examined the relationship between sedentary behaviour and frailty (most frequently assessed using the Fried criteria ([Fried et al. 2001](#))) among adults aged 30–86 years ($N = 20\ 505$). They identified 16 studies, of which 13 reported that high levels of sedentary behaviour were associated with increased prevalence of frailty or frailty levels. These associations were observed in 6/6 longitudinal studies and in 6/7 studies adjusting for physical activity. The authors concluded that higher levels of sedentary behaviour are associated with higher prevalence of frailty. The studies included in this review ranged from low to moderate risk of bias as assessed using the Newcastle–Ottawa scale ([Wells et al. n.d.](#)) and the AMSTAR 2 rating for the review was moderate.

To examine the association among older adults, we included the SR of adults aged ≥ 65 years by [Chastin et al. 2015a](#). They found that 3/5 studies reported that high levels of sedentary behaviour were associated with reduced function. Unfavourable associations were seen between sedentary behaviour and functional limitations (2/2 studies), muscle strength (1/1 study) and lower limb function (1/2 studies). No (0/1) studies reported associations between sedentary behaviour and flexibility or mobility issues. As noted above, [O'Donoghue et al. \(2016\)](#) examined the association between sedentary behaviour injury, illness, or disability in adults aged 18–65 years ($N = 60\ 049$), and concluded that there was no

significant relationship in this age group. The QALSYST scores for studies included in these 2 age-specific reviews ranged from 46%–91%, with AMSTAR 2 ratings of low (O'Donoghue et al. 2016) and moderate (Chastin et al. 2015a) for the reviews themselves. There was no overlap in the included studies across the 3 SRs used to inform this outcome. The certainty of evidence for this outcome was rated as low because of the observational nature of included studies. These studies did not show serious risk of bias, inconsistency, indirectness, or imprecision and were therefore not further downgraded.

Fatigue

We included 3 SRs for this indicator, representing 1620 participants from 4 countries. O'Donoghue et al. (2016) reported that 1/1 study with a quality score of 80% found that sedentary behaviour was positively associated with tiredness in adults aged 18–65 years ($N = 1332$). The AMSTAR 2 rating for this review was low. We did not identify any SRs examining sedentary behaviour and fatigue in older adult populations.

Neuhaus et al. (2014) examined the impact of occupational sitting on fatigue in 1 randomized and 10 nonrandomized intervention studies ($N = 265$), ranging in duration from 1 day to 3 months. In comparison with using a seated workstation, 5/11 studies (1 randomized) reported a decrease in fatigue when using an “activity permission workstation” (i.e., height-adjustable desks, as well as treadmill and pedal desks), 2/11 reported an increase in fatigue, while 5/11 reported no change (1 study reported multiple measures of fatigue). The authors suggested that these findings provided inconclusive results on the relationship between sedentary behaviour and fatigue. The quality of included studies was rated as 31%–100% using the QALSYST tool (Kmet et al. 2004), while the AMSTAR 2 rating of the review as moderate.

Josaphat et al. (2019) was included to examine the impact of weight status on these relationships. In their SR of seated and nonseated workstations in individuals with overweight and obesity, 1/1 randomized crossover study lasting 5 days reported lower fatigue with reduced occupational sitting time ($N = 23$). The AMSTAR 2 rating for this review was low. There was no overlap in the included studies across the 3 SRs used to inform this outcome. The certainty of evidence for this outcome began as low because of the inclusion of observational and nonrandomized intervention studies. The certainty of evidence was further downgraded to very low because of inconsistency in results.

Work productivity

We included 2 SRs that examined the relationship between occupational sitting and work productivity ($N = 129$). Shrestha et al. (2018) identified 3 nonrandomized intervention studies lasting 3 months in length, examining the impact of replacing seated desks with sit–stand desks ($N = 106$). Although all 3 studies suffered from a high risk of bias, the authors concluded that replacing occupational sitting with standing did not impact work performance. The AMSTAR 2 rating for the review was high. To examine the impact of weight status we included the SR by Josaphat et al. (2019), which identified 1 RCT of office workers ($N = 23$) lasting 5 days, indicating no significant change in productivity for overweight and obesity office workers when using a sit–stand desk, in comparison to a traditional seated desk. This study had a low risk of bias using the Cochrane risk of bias tool (Higgins et al. 2011), and the AMSTAR 2 rating for the review was low. There was no overlap across the SRs used to inform this outcome. The certainty of evidence for this outcome began as low because of the inclusion of nonrandomized intervention studies. The certainty of evidence was further downgraded to very low because of high risk of bias.

Sleep duration

We identified 1 eligible SR that examined the relationship between sedentary behaviour and sleep duration in university students. Castro et al. (2018) identified a single cross-sectional study in the United States ($N = 162$) reporting an unfavourable association between time spent playing video games and sleep duration, with no association observed between TV viewing and sleep duration. The study was rated as high risk of bias using the Cochrane risk of bias tool (Higgins et al. 2011), while the AMSTAR 2 rating for this review was moderate. We did not identify any eligible SRs for sleep duration in older adults. The certainty of evidence for this outcome began as low because of inclusion of observational studies, and further downgraded to very low because of high risk of bias.

Physical activity duration

We included 5 SRs for this indicator, representing 56 unique studies ($N = 287\,410$). Mansoubi et al. (2016) examined the relationship between sedentary behaviour and physical activity in 26 studies (6 prospective, 20 cross-sectional) enrolling more than 220 000 adults aged 18–60 years from 9 countries. They reported that TV viewing, daily sedentary time, sitting time, general screen time, and occupational sitting time were all negatively associated with physical activity levels in the majority of studies. These associations were typically weak or moderate strength, with larger associations observed for light-intensity physical activity. Study quality ranged from 3/9 to 8/9 using a 13-item checklist (Craggs et al. 2011), with 15 of 26 identified studies classified as high quality ($\geq 7/9$). To examine the impact of age, we included SRs in both younger (Castro et al. 2018) and older adults (Chastin et al. 2015). Castro et al. (2018) reported that of 5 studies with low risk of bias (1 prospective cohort and 4 cross-sectional; $N = 10\,802$) reported a negative association between sitting time and physical activity in university students from 4 different countries. Chastin et al. (2015) reported similar findings in 3/4 cross-sectional studies of 53 794 adults aged ≥ 65 years from 4 countries. All of the above reviews received AMSTAR 2 ratings of moderate.

To examine the impact of occupational sitting, we included an SR and meta-analysis of 5 randomized and 5 nonrandomized interventions by Shrestha et al. (2018) ($N = 966$). They found that sit–stand desks reduce occupational sitting time by 100 min/day (95% CI: -116 to -84 , I^2 statistic = 37%), and increase occupational standing by 89 min/day (95% CI: 76 to 102, $I^2 = 58%$) over the short term (≤ 3 months), and by 53 min/day over the medium term (3–12 months) (95% CI: 17 to 90, $I^2 = 0%$). However, they reported no significant difference in time spent stepping at work. Both (2/2) randomized multi-component interventions reported increases in standing time, although the results were not pooled because of high heterogeneity. All but 1 of the above studies were judged to have a high risk of bias using the Cochrane risk of bias tool (Higgins et al. 2011), and the review received an AMSTAR 2 rating of high. To examine the impact of weight status on these relationships we included a review of 11 intervention studies of office workers with overweight and obesity ($N = 396$) by Josaphat et al. (2019). Durations ranged from 8 h to 12 months. They report similar findings with 6/6 sit–stand desk interventions (4 randomized) reporting reduced sitting and/or increased occupational standing time. Further, they also reported that 6/7 treadmill (1 randomized) workstation interventions increased physical activity levels. Nine of 11 studies were rated as high risk of at least 1 form of bias using the Cochrane risk of bias tool. The review by Josaphat et al. (2019) received an AMSTAR 2 rating of low.

Across 56 unique studies included for this indicator, 1 was reported in multiple reviews. This resulted in a CCA of 0.89%, indicating a slight degree of overlap. The certainty of evidence for this outcome began as low because of the inclusion of observational and nonrandomized intervention studies. These studies did not

show evidence of serious risk of bias, inconsistency, indirectness or imprecision, and were therefore not further downgraded.

Discussion

The purpose of this overview of reviews was to summarize the relationship between different types and patterns of sedentary behaviour with a variety of health outcomes in adults. Our findings suggest that in general, high levels of sedentary behaviour are unfavourably associated with cognitive function, depression, function and disability, physical activity levels, and physical health-related quality of life. We also found that reducing or breaking up sedentary time may result in beneficial changes in body composition and acute improvements in markers of cardio-metabolic risk. In contrast, we found little evidence that sedentary behaviour is associated with musculoskeletal pain, accidents or injuries, fatigue, sleep, or work productivity. Our results suggest that total sedentary behaviour and TV viewing are most consistently associated with negative health outcomes, while the impact of computer and Internet use may differ by age group and outcome of interest. This work supports the development of the sedentary behaviour recommendations of the Canadian 24-Hour Movement Guidelines for Adults aged 18–64 years and Adults aged 65 years or older by extending the evidence generated by the US PAGAC Scientific Report to examine indicators of health (i.e., brain health and cognitive function, health related quality of life, depression, function and disability, musculoskeletal pain, accidents/injuries, cardiometabolic risk, body composition fatigue, work productivity, sleep, and physical activity) alongside both total and pattern-specific sedentary behaviour among adults.

One purpose of this overview of reviews was to inform public health guidelines; we therefore sought to identify the optimal daily dose of sedentary behaviour for each health outcome of interest. However, we did not identify any SRs reporting on the dose–response relationships in the current overview. Similarly, although a number of SRs have investigated the impact of interventions designed to reduce occupational sedentary behaviour, there has been little research on interventions targeting other forms of sedentary behaviour in any adult age group. Further, we did not identify any reviews examining the impact of breaking up sedentary time on any outcome aside from markers of cardiometabolic health (Chastin et al. 2015b, 2018; Saunders et al. 2018). These knowledge gaps have important implications for public health recommendations, and therefore future research is needed investigate the relationship between sedentary behaviour dose and patterns with a wider range of health outcomes.

Although we sought to identify whether the above relationships varied as a function of age, sex, race/ethnicity, socioeconomic status, weight status, or chronic disease status, only 2 SRs took any of these factors into consideration (Boberska et al. 2018; Kehler et al. 2018). Age was the most assessed covariate with reviews often targeting specific groups (e.g., university students, workers, older adults). As a result, we included multiple SRs for most outcomes in an attempt to determine whether the findings were generally consistent across the adult lifespan. Despite this, we did not find evidence of variation for most outcomes, although there was evidence that internet and computer use may be positively associated with cognitive function in older adults. While three-fourths of the studies identified by Ramalho et al. (2018) reported negative associations between TV viewing and cognitive function in adults aged 60 years and older, the opposite was true for Internet and computer use. Investigations of specific types of computer use, such as computerized cognitive training, have also suggested potential benefits for cognitive function in this age group (Lampit et al. 2014). This supports the recent suggestion by Hallgren, Dunstan, and Owen that the health impacts of mentally “passive” forms of sedentary behaviour (e.g., watching TV) may differ from those of mentally “active” forms (e.g., computer use,

reading) (Hallgren et al. 2020). Unfortunately, the SR focusing on cognitive function in younger adults only identified 3 original studies that did not specifically report on active versus passive forms of sedentary behaviour (Castro et al. 2018). Further, we did not identify any SRs that reported on the relationship between reading and any outcome of interest. Future research is needed to better understand whether mentally active and passive forms of sedentary behaviour have opposing relationships with health outcomes, and whether these relationships are consistent across the adult lifespan. Although 2 SRs did examine whether associations differed according to chronic disease status (Boberska et al. 2018; Kehler et al. 2018), no reviews reported on differences related to sex, race/ethnicity, or socioeconomic status, which is another key area that deserves future study. This is important as studies have identified that duration and type of sedentary behaviour differ by sex, race, and socioeconomic status (Chastin et al. 2015a; O’Donoghue et al. 2016; Prince et al. 2017).

One notable finding of our overview is that we did not identify any eligible systematic reviews of observational studies focusing on occupational sedentary time. This is surprising, given the increasingly sedentary nature of work in developed nations (Church et al. 2011). However, we did identify several SRs and meta-analyses reporting on the impact of interventions aimed at reducing occupational sedentary behaviour, typically through the introduction of sit–stand, pedal, or treadmill desks. Replacing seated desks with sit–stand or treadmill desks are likely to result in increased standing and walking, respectively (Josaphat et al. 2019). There is an unclear relationship between these workstations and musculoskeletal symptoms, while there appear to be little or no change in other outcomes including cognition, productivity, fatigue, or more vigorous forms of physical activity, though the evidence on these outcomes is largely based on a small number of primary studies. Future research is needed to better understand the relationship between occupational sedentary behaviour and a wide range of outcomes.

We did not identify any eligible reviews examining the health impact of smartphones, social media, or other forms of new media. All forms of recreational screen time can potentially contribute to sedentary behaviour. Understanding the health implications of social media and electronic device use is crucial given their prevalent use, and their purported links to reduced mental health (Thomé et al. 2011), impaired sleep (Sampasa-Kanyinga et al. 2018), musculoskeletal symptoms (Lee et al. 2015), and risk of motor vehicle accidents (Rumschlag et al. 2015). It is especially important with respect to public health recommendations, as the available evidence focuses on modalities (e.g., TV and computer use) that may no longer reflect the most common recreational sedentary behaviours of adults in developed nations (Prince et al. 2020b).

Potential mechanisms

A number of mechanisms have been suggested that may underlie the relationships between sedentary behaviour and health outcomes identified in the current overview. One of the most likely mechanisms through which sedentary behaviour is thought to influence health is via the displacement of other important behaviours, in particular physical activity and sleep. As noted above, sedentary behaviour is consistently associated with reduced physical activity across the adult lifespan (Chastin et al. 2015a; Mansoubi et al. 2016; Castro et al. 2018). Physical activity shows beneficial relationships with a wide range of health outcomes (2018 Physical Activity Guidelines Advisory Committee 2018; El-Kotob et al. 2020; McLaughlin et al. 2020), and therefore any behaviour that displaces physical activity could indirectly influence these health outcomes as well. Much less research exists on the relationship between sedentary behaviour and sleep; we identified only 1 eligible SR reporting on this relationship, while the review itself identified just 1 study in university students. How-

ever, several original studies have suggested that screen time may be associated with reduced sleep (Vallance et al. 2015; Lakerveld et al. 2016; Sampasa-Kanyinga et al. 2018). As with physical activity, anything that reduces sleep duration or quality could therefore indirectly affect several important health outcomes (Chaput et al. 2020a). Beyond displacing physical activity and sleep, high levels of sedentary behaviour may also reduce opportunities for social interaction, which could also negatively impact brain and mental health (Zhai et al. 2015). Finally, as reported above, prolonged sedentary behaviour may also lead to dysregulated glucose metabolism, while some original research has suggested that it may lead to impaired vascular function as well (Thosar et al. 2014). As suggested by Hallgren et al. (2020), both of these mechanisms could also negatively impact brain and mental health. There is a large amount and consistent body of research linking breaks in sedentary time with acute improvements in glycemic control (Saunders et al. 2018); future research is needed to investigate other risk factors such as blood pressure and to determine whether any acute changes have an impact on chronic disease morbidity or mortality over the longer term.

Strengths and weaknesses

The present overview of reviews has several strengths and limitations. Strengths include a rigorous and systematic methodology that was prospectively registered, the examination of more proximal (e.g., behaviours, fatigue, cognition) and novel outcomes not previously assessed by the US PAGAC Scientific Report, the assessment of review quality using the AMSTAR 2 tool, and adherence to the PRISMA guidelines (Moher et al. 2009). One of the limitations of the review includes the omission of grey literature or studies published in languages other than English or French, although other studies suggest that language restrictions are unlikely to impact these conclusions (Nussbaumer-Streit et al. 2020). Further, although we attempted to minimize the number of SRs reported for each outcome, the conclusions were generally consistent across all the eligible reviews for each health outcome. We were also limited to the information reported in the original SRs, which employed a variety of methodologies for data synthesis, presentation, and quality assessment. Although not a limitation of this overview per se, the majority of the current evidence is based on self-reported data, which has increased potential for bias when compared with device-based measures (Prince et al. 2020a). Much of the current evidence is based on cross-sectional studies, which limit the quality of the evidence when compared with prospective or intervention studies. As a result, the certainty of evidence was low or very low for all outcomes. This overview examined the relationship between sedentary behaviour and sleep duration; future research should also examine the relationship between sedentary behaviour and sleep quality. Finally, this overview was restricted to apparently healthy adults, and thereby excluded studies focusing on clinical populations. Future work should examine whether similar findings are observed in these populations.

Conclusions

Our findings suggest that high levels of sedentary behaviour are unfavourably associated with cognitive function, depression, function and disability, physical activity levels, and physical health-related quality of life in adults. Our results also suggest that reducing or breaking up periods of prolonged sitting may have beneficial effects on markers of cardiometabolic risk and body composition. Although sedentary behaviour was generally associated with negative health outcomes, there may be favourable associations between computer and Internet use and cognitive function in older adults. Our findings have important public health implications and suggest that adults should avoid accumulating high levels of sedentary behaviour. Future work is needed to identify whether a dose–response relationship exists between

sedentary behaviour and these health outcomes, and whether these relationships are consistent across sex, race/ethnicity, and socioeconomic status.

Conflict of interest statement

V.J.P. is a Canadian Agency for Drugs and Technologies in Health (CADTH) employee; the current work was unrelated to her employment, and CADTH had no role in the funding, design, or oversight of the work reported. V.J.P. and M.E.K. report personal fees and other support from the Canadian Society for Exercise Physiology during the conduct of the submitted work. T.J.S. has received personal fees for leading a report on the measurement of sedentary behaviour for the Public Health Agency of Canada (PHAC), honoraria for presenting on the health impact of physical activity and sedentary behaviour to school groups, and conference funding from Ergotron. S.A.P. is a research scientist at the PHAC; the current work was conducted during her fellowship at the University of Ottawa Heart Institute and was unrelated to her employment at PHAC. A.R.-W. reports personal fees from ProQuest LLC outside of the submitted work. The remaining authors declare that they have no conflicts of interest.

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