REVIEW / SYNTHÈSE

Physiological and health implications of a sedentary lifestyle

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Abstract: Sedentary behaviour is associated with deleterious health outcomes, which differ from those that can be attributed to a lack of moderate to vigorous physical activity. This has led to the field of "sedentary physiology", which may be considered as separate and distinct from exercise physiology. This paper gives an overview of this emerging area of research and highlights the ways that it differs from traditional exercise physiology. Definitions of key terms associated with the field of sedentary physiology and a review of the self-report and objective methods for assessing sedentary behaviour are provided. Proposed mechanisms of sedentary physiology are examined, and how they differ from those linking physical activity and health are highlighted. Evidence relating to associations of sedentary behaviours with major health outcomes and the population prevalence and correlates of sedentary behaviours are reviewed. Recommendations for future research are proposed.

Key words: sedentary behaviour, inactivity, sitting, TV viewing, screen time, obesity, metabolic risk.

Résumé : On associe comportements sédentaires et répercussions nuisibles sur la santé; toutefois ces répercussions sont différentes de celles associées à un manque d'activité physique d'intensité modérée à élevée. Ce constat est à l'origine de la physiologie de la sédentarité qui se distingue clairement de la physiologie de l'activité physique. Cet article présente un aperçu de ce domaine de recherche en émergence et souligne les caractéristiques qui le distinguent de la physiologie de l'activité physique classique. On définit les mots clés de la physiologie de la sédentarité et on présente les méthodes d'auto-évaluation et les méthodes objectives pour évaluer la sédentarité. Les mécanismes de la physiologie de la sédentarité sont analysés ainsi que les modalités qui les distinguent des mécanismes associant l'activité physique à la santé. On présente aussi la synthèse des données probantes concernant la relation entre les comportements sédentaires et les principales répercussions sur la santé et entre la prévalence des troubles dans la population et les comportements sédentaires. On suggère aussi des pistes de recherche.

Mots-clés : comportement sédentaire, inactivité, position assise, écoute de la télévision, temps d'écran, obésité, risque métabolique.

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Introduction

A relationship between sedentary behaviour and deleterious health consequences was noted as early as the 17th century by occupational physician Bernadino Ramazzini (Franco and Fusetti 2004). Though often conceptualized as reflecting the low end of the physical activity continuum, emerging evidence suggests that sedentary behaviour, as distinct from a lack of moderate to vigorous physical activity (MVPA), has independent and qualitatively different effects on human metabolism, physical function, and health outcomes and thus should be treated as a separate and unique construct (Owen et al. 2000; Hamilton et al. 2004, 2007, 2009; Healy et al. 2008*c*; Katzmarzyk et al. 2008; Pate et al. 2008; Rosenberg et al. 2008; Owen et al. 2010). In 2004, Hamilton et al. introduced evidence of qualitative differences in the biological processes regulating lipoprotein lipase activity depending on whether physical activity or

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inactivity was imposed. They proposed the term "inactivity physiology" to describe this new, important, and distinct area of study and defined it as

> the study of the biological responses to physical inactivity [that are] critical for elucidating the mechanisms operating at the lower end of this continuum where most of the change in disease occurs.

This review aims to advance and extend the discussion first forwarded by Hamilton et al. (2004). However, we introduce the term "sedentary physiology", as opposed to inactivity physiology, as a legitimate field of study that is complementary to, but distinct from, exercise physiology.

This review illustrates the importance of the entire movement continuum, presents relevant definitions, descriptions, and measurement procedures, reviews the current state of the science on sedentary physiology, explores the relationships of sedentary lifestyles with major health outcomes, provides an overview of the population prevalence of sedentary behaviour, and concludes with a listing of current research issues, opportunities, and future directions.

In this paper, unless otherwise stated, physical activity refers to activities of at least moderate intensity (≥3 metabolic equivalent tasks (METs)); light activity includes all movements <3 METs and >1.5 METs (e.g., incidental movements, lifestyle-embedded activities); and sedentary behaviours are considered those requiring ≤1.5 METs.

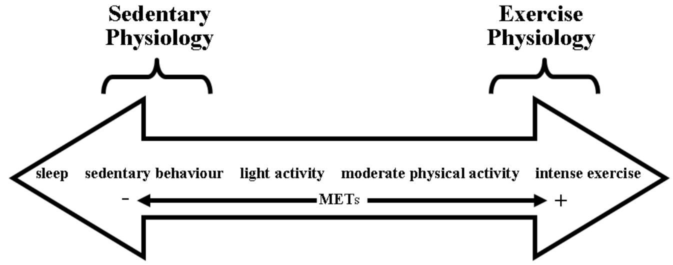
Conceptualizing sedentary physiology: the movement continuum

Figure 1 illustrates the movement continuum (definitions provided in Table 1). As behaviours move along the continuum they may provoke different physiological responses. The responses may

- change in a linear fashion as one moves up or down the continuum;
- change in a nonlinear fashion as one moves up or down the continuum;
- emerge only after a certain movement threshold is crossed — this may be the case moving up or down the continuum; and
- show no change or response.

Conceptualizing sedentary behaviour as distinct from a lack of physical activity is important for three main reasons: (*i*) the unique nature of sedentary behaviour, (*ii*) the physiological responses of sedentary behaviour, and (*iii*) the measurement of sedentary behaviour. First, approaches to reducing sedentary behaviour may be different than those designed to increase physical activity. For example, Tremblay et al. (2007*a*) illustrated how reductions in sedentary behaviour may be achieved through almost limitless microintervention opportunities designed to promote energy expenditure, whereas physical activity or exercise interventions have more constraints (e.g., time, location, equipment, logistics). For those who have not embraced an organized or structured program of physical activity, reducing sedentary behaviour may be a more achievable and viable approach as a proximal goal for increasing movement and energy expenditure. Furthermore, for those with limited financial resources or available time, a reduction in sedentary behaviour can be achieved with minimal financial or time requirements (e.g., registration fees, transportation, equipment, prolonged interruptions of work or domestic tasks). Finally, individuals can achieve high levels of moderate to vigorous physical activity and still exhibit high levels of sedentary behaviour — 1 behaviour does not necessarily displace the other. For example, an "active" individual might engage in 30 min each day of brisk walking or jogging (and in doing so meet or exceed current public health guidelines on physical activity); however, this leaves some 15.5 waking hours within which the proportions of time allocated to sitting vs. standing and light-intensity ambulatory activities can vary widely (Healy et al. 2007; Hamilton et al. 2008). This is illustrated in Fig. 2, which highlights the ubiquitous nature of sedentary time and the major contexts (domestic, recreational, transport, and occupational) where sedentary behaviours take place.

Fig. 1. The movement continuum, illustrating the different focus of sedentary physiology and exercise physiology. METs, metabolic equivalent tasks.



Second, the physiological responses and adaptations to sedentary behaviours are not necessarily the opposite of exercise and may differ within and between physiological systems (e.g., cardiovascular vs. musculoskeletal). The basic principles of exercise physiology (e.g., overload, progression, specificity, individuality) surely apply to the complete movement continuum to varying degrees. Consequently, movement and nonmovement behaviours throughout the day are important to understand because of their direct impact on biological processes and because they may mediate or moderate physiological responses and adaptations to exercise.

Third, methodologies for the assessment and surveillance of sedentary behaviour may require different metrics and indicators than those required for physical activity and exercise (Owen et al. 2000, 2010; Tremblay 2007a). A listing of research approaches to study the science of sedentary behaviour is provided in Table 2.

Describing and measuring sedentary behaviour

Physical activity and exercise are typically characterized by the FITT formula, with the acronym describing the frequency, intensity, time (duration), and type of activity. Sedentary behaviours can and should be described with similar details. However, because sedentary behaviours have virtually no variation in intensity, the SITT formula is proposed, with the acronym corresponding to the following:

- Sedentary behaviour frequency (number of bouts of a certain duration);

Table 1. Important terms used to describe the movement continuum.

Term	Definition
Sedentary	A distinct class of behaviours (e.g., sitting, watching TV, driving) characterized by little physical movement and low energy expenditure (≤1.5 METs)
Sedentarism	Extended engagement in behaviours characterized by minimal movement, low energy expenditure, and rest
Physically active	Meeting established guidelines for physical activity (usually reflected in achieving a threshold number of minutes of moderate to vigorous physical activity per day)
Physical inactivity	The absence of physical activity; usually reflected as the amount or proportion of time not engaged in physical activity of some predetermined intensity

Note: METs, metabolic equivalent tasks.

Fig. 2. Major contexts for sedentary behaviour and their distribution over a typical adult's waking hours. (From Dunstan et al. 2010*a*, reproduced with permission of Touch Briefings, European Endocrinology, Vol. 6, p. 20, © 2010.)

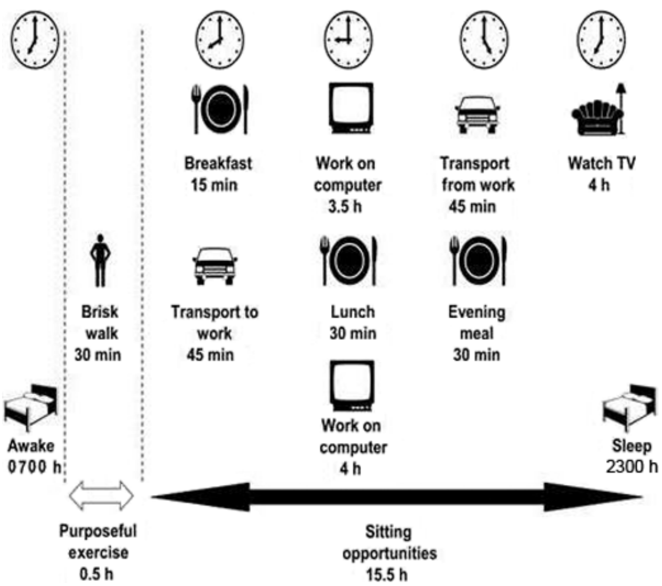


Table 2. Potential research methodologies for studying the science of sedentary behaviour.

Animal models	Human models	Population approaches
Denervation	Bed rest	Car time
Detraining	Casting	Chair or sitting time
Hind-limb unloading	Detraining	Indoor time
Microgravity	Imposed sitting	Screen time
Space flight	Microgravity	
Spinal cord injury	Space flight	
	Spinal cord injury	

- Interruptions (e.g., getting up from the couch while watching TV; Healy et al. 2008*a*);
- Time (the duration of sitting); and
- Type (mode of sedentary behaviour, such as TV viewing, driving a car, or using a computer).

Sedentary behaviour (from the Latin *sedere*, "to sit") is the term now used to characterize those behaviours for which energy expenditure is low, including prolonged sitting or lounging time in transit, at work, at home, and in leisure time. In this context, MET is used to quantify the energy expenditure of activities, with 1 MET corresponding to resting metabolic rate. Running has a value of at least 8 METs, moderate-pace walking has a value of 3 to 4 METs, and sedentary behaviours are generally defined as ≤1.5 METs (Owen et al. 2000; Pate et al. 2008).

The definition of sedentary behaviour is at present inconsistent in the research literature, and comparable definitions and measures are rare. Some research presents participants as sedentary because they are not physically active, while others classify participants as sedentary when they are engaging in particular activities characterized by low energy expenditure. Even the Merriam–Webster dictionary creates confusion by defining sedentary as "doing or requiring much sitting" and also being "not physically active".

These contrasting definitions — actively engaging in sedentary activities vs. the absence of moderately intense physical activity — continue to create confusion, given that emerging evidence demonstrates that the 2 entities do not relate to health in the same way. Pate et al. (2008) and Owen et al. (2010) emphasize the important and necessary distinction between sedentary behaviour and the absence of MVPA. Pate et al. (2008) highlight the fact that many of the studies making claims about the health dangers associated with sedentary behaviour have not actually measured it.

Construing "sedentary" as a lack of MVPA has occurred naturally in the exercise science field, which historically has focused on physical activities performed at a moderate intensity or higher. For example, the Harvard Alumni Study classified men who expended less than 2000 kcal·week^{-1} (1 kcal = 4.186 kJ) through walking, climbing stairs, and playing sports as sedentary, and went on to conclude that sedentary men had a 31% higher risk of death than more active men (Paffenbarger et al. 1986). Similarly, the 1999 Youth Risk Behaviour Survey classified participants as having a sedentary lifestyle if they did not report participating in sufficient MVPA (Lowry et al. 2002).

Self-report measures of sedentary behaviour

A further reason for a reliance on defining sedentary as the absence of MVPA is the simple fact that structured activities like running or cycling are far easier to control and measure under laboratory or research conditions than sedentary or light-intensity activities. Researchers have relied on self-report tools to collect information about health behaviours, an approach that is far better suited to the reporting of volitional physical activities that people can remember and describe (e.g., soccer game, aerobics class, bicycle ride) than to the reporting of a sporadic and varied set of activities that fall under the sedentary category (e.g., watching TV, attending a meeting, talking on the phone, playing a board game, reading, driving to work, lying on the couch, etc.). Furthermore, the direct measurement of free-living movement is an evolving field and has yet to reach a consensus on a methodology that can reliably quantify sedentary activity.

The issue of measuring sedentary behaviour is complicated by the simple fact that sedentary pursuits occur in a varied and sporadic manner throughout the day. To avoid having to create an exhaustive list of potential sedentary pursuits, researchers generally rely on a series of global or proxy measures with the hope that they will capture the majority of what is considered sedentary. Population approaches to measuring or quantifying sedentary behaviour include car time, chair time or sitting time, indoor time, and screen time. It is important to consider that while informative in different ways, none of these individual behaviours are representative of all sedentary activities that have occurred throughout the day (Sugiyama et al. 2008*a*). Currently, there is reasonably strong evidence on the reliability (and more modest evidence of validity) of measures of TV viewing time, but little is known about the measurement properties of other sedentary behaviours (Clark et al. 2009). A list of methodologies for measuring sedentary behaviours, in contrast to physical activity, is provided in Table 3.

Conclusions regarding the influence of sedentary behaviour should be drawn only if sedentary behaviour is actually measured and used analytically. Similarly, studies reporting the health effects of physical activity should specify clearly what intensity of activity is being discussed. If surrogate or proxy measures of sedentary behaviour are being used (e.g., TV viewing time, sitting time), then the conclusions drawn should be stated in terms that are limited to those behaviours (Pate et al. 2008).

Capturing sedentary time objectively

Though many objective techniques have been used to measure physical activity (movement sensors, heart rate monitors, doubly labelled water, etc.), few have been used extensively to measure sedentary behaviours (Tremblay 2010) — the notable exception being accelerometers. Accelerometry has provided sedentary behaviour researchers and other exercise scientists with an important research tool to more accurately measure the entire range of activity, from sedentary to very vigorous, in free-living subjects over a number of days. The incorporation of accelerometers into population-based public health research has been instrumental in advancing the field of sedentary physiology. Although accelerometers have recognized limitations, they allow for more robust assessments of movement behaviours than self-report methods. Examples of detailed physical activity and physical inactivity profiles derived from accelerometer measures have been published elsewhere (Esliger and Tremblay 2007).

Accelerometers are small electronic devices that are generally worn on the hip and which allow detailed data on the volume and intensity of most movement to be downloaded to a computer for later analysis (Troiano et al. 2008). As illustrated below, accelerometers can be used to describe not only the amount of movement that an individual has undertaken, but also the intensity, duration, frequency, and patterns of this movement.

Accelerometers have already demonstrated their scientific credentials for capturing (and for characterizing quantita-

Table 3. Examples of potential assessment procedures and indicators of physical activity and sedentarism. (From Tremblay 2010, reproduced with permission of Human Kinetics Publishers Inc., Physical activity and obesity, 2nd ed., p. 15, © 2010 Human Kinetics Publishers Inc.)

	PA measure		SB measure	
Assessment methods	Assessment procedure	Example indicators	Assessment procedure	Example indicators
Direct (objective)	Direct observation	Minutes of PA, types of PA	Direct observation	Minutes of SB, types of SB
	Portable indirect calorimetry	Energy expenditure, $\dot{V}O_2$	Portable indirect calorimetry	Minutes at resting metabolic rate
	Doubly labelled water	Energy expenditure	Doubly labelled water	Energy expenditure
	Accelerometry	Minutes above thresholds	Accelerometry	Minutes below thresholds
	Pedometry	Steps per day	Pedometry	Steps per day
	Heart rate monitoring	Minutes above thresholds	Heart rate monitoring	Minutes below thresholds or at rest
	Respiration rate	Minutes above thresholds	Respiration rate	Minutes below thresholds or at rest
Reported (subjective)	PA questionnaire or interview	Energy expenditure, minutes of PA	SB questionnaire or interview	Minutes of SB, chair time, screen time
	PA activity diary	Energy expenditure, minutes of PA	SB activity diary	Minutes of SB, chair time, screen time
	PA log	Frequency of PA, types of PA	SB log	Frequency of SB, types of SB
	Exercise equipment usage recall	Frequency, duration, intensity	Labour-saving device usage recall	Frequency, duration
	Active transportation recall	Type, frequency, duration, distance	Automobile usage recall	Frequency, duration, distance, car time
	Stairs climbed recall	Floors per day	Elevator and escalator recall	Floors per day, frequency of use
Global	MET value, energy expenditure	Occupational classification	Chair time, screen time, car time	
	Rating (e.g. higher, same, lower)	SB comparisons to peers	Rating (e.g. higher, same, lower)	
	Outdoor time	Household cocooning	Indoor time, screen time	

Note: PA, physical activity; SB, sedentary behaviour; $\dot{V}O_2$, oxygen consumption; MET, metabolic equivalent task.

tively) the amount of time that an individual spends below a given intensity threshold or cut-point (Healy et al. 2007, 2008*c*; Matthews et al. 2008). Using this objectively derived measure, researchers are able to examine the health consequences, determinants, and intervention outcomes relating to sedentary time, overcoming the limitations of self-report methods. Furthermore, collection of accelerometer data in the population-based United States National Health and Nutrition Examination Survey (NHANES) has highlighted the high prevalence of sedentary time in modern society (Matthews et al. 2008) and the remarkably low levels of MVPA time (Troiano et al. 2008), the more typical focus of exercise physiology and physical activity health promotion efforts.

Figure 3 illustrates how accelerometer data allow the portrayal of variations between individuals in the balance of their physical activity and sedentary time. For example, the typical behaviour pattern of the individual portrayed by the unfilled circles illustrates a high volume of sedentary time, with a midday spike in physical activity; for example, an after-lunch walk. This person could be characterized as a "physically active couch potato". This is in contrast to the "active non-couch potato", who spends a high proportion of the day in light-intensity activity (>1.5 to <3.0 METs). Both these individuals participate in equivalent amounts of MVPA (≥3 METs), and both would be classified as physically active according to current public health guidelines, yet the total energy expenditure and physiological overload clearly differs.

Accelerometers also have the ability to characterize patterns of sedentary time, not just total sedentary time (Healy et al. 2008*c*). Figure 4 illustrates how the same volume of total sedentary time may reflect quite different behavioural patterns. In Fig. 4, the "prolonger" (persistent sedentarism) is a person who would typically remain seated for long periods of time; the "breaker" (interrupted sedentarism) is a person who typically would stand up if only to move about briefly during seated activities. There is some evidence to suggest that the extent to which sedentary time is broken up is significantly associated with biomarkers of cardiometabolic health, independent of total sedentary time (Healy et al. 2008*a*).

Accelerometers do have their limitations — in particular, their inability to capture contextual information on the type of sedentary behaviour. This contextual information is useful for the development of intervention targets and public health messaging on how to reduce sedentary time (Owen et al. 2008). Furthermore, accelerometers cannot currently distinguish between sitting, lying, or standing still, which are behaviours with distinct cardiometabolic and public health implications. The emerging research interest in sedentary behaviour coupled with rapid advances in measurement technology (e.g., inclinometers that can distinguish between sitting and standing) create demand for new analytical techniques to more accurately quantify and classify free-living sedentary time.

Fig. 3. Illustration of accelerometer data portraying an active couch potato (moderate to vigorous intensity physical activity meeting guidelines considered "physically active" but also a high level of sedentary behaviour) versus an active non-couch potato (similar level of moderate to vigorous intensity physical activity but low level of sedentary behaviour). (From Dunstan et al. 2010*a*, reproduced with permission of Touch Briefings, European Endocrinology, Vol. 6, p. 21, © 2010.)

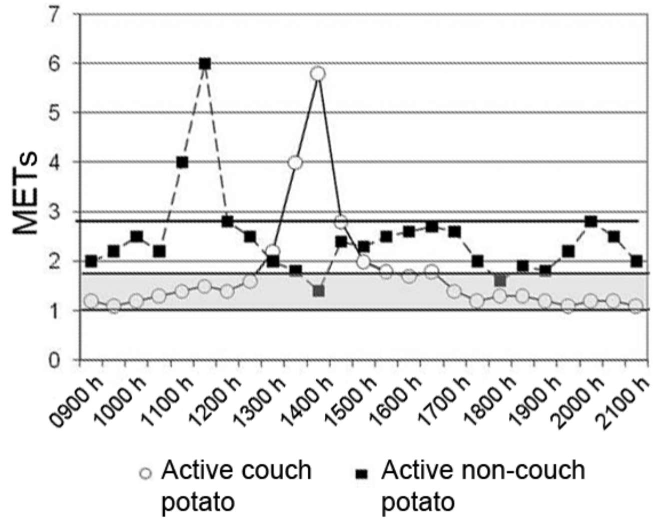
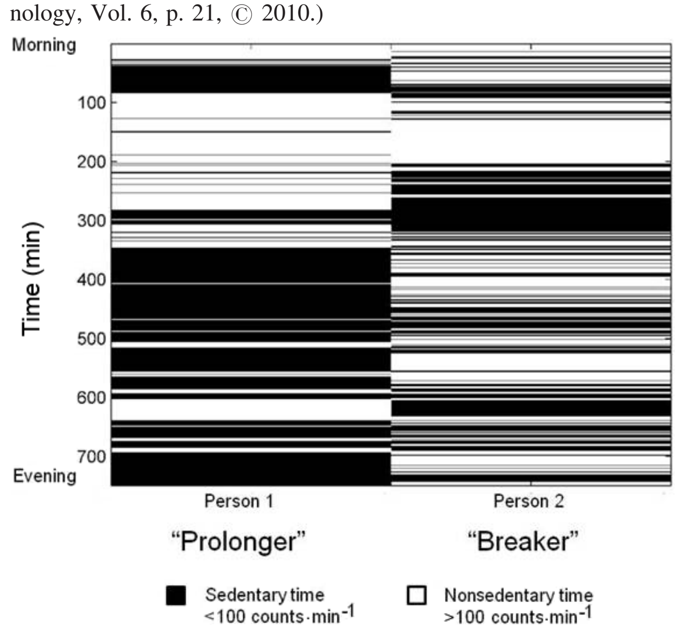


Fig. 4. Portrayal of significantly different patterns of breaks in sedentary time, based on accelerometer data from 2 different individuals (a "prolonger" and a "breaker"). (From Dunstan et al. 2010*a*, reproduced with permission of Touch Briefings, European Endocrinology, Vol. 6, p. 21, © 2010.)



Sedentary physiology

Recent evidence suggests that sedentary behaviour has a direct influence on metabolism, bone mineral content, and vascular health. The physiological effects of sedentary behaviour on these functions and the biologically plausible mechanisms that are thought to mediate these effects are reviewed below.

Sedentary behaviour and cardiometabolic biomarkers

One of the demonstrated effects of sedentary behaviour is metabolic dysfunction, characterized by increased plasma triglyceride levels, decreased levels of high-density lipoprotein (HDL) cholesterol, and decreased insulin sensitivity. For example, Hamburg et al. (2007) examined the effect of 5 days of complete bed rest on metabolic health in 22 adult volunteers. Study participants remained in bed for over 23.5 h per day, rising only for matters of personal hygiene. At the completion of the study, despite no changes in body weight, they experienced significant increases in total cholesterol, plasma triglycerides, glucose, and insulin resistance. The changes in carbohydrate metabolism were particularly pronounced, with participants experiencing a 67% greater insulin response to a glucose load following the 5-day intervention.

The results of Hamburg et al. (2007) suggest that an extended dose of sedentary behaviour can result in dramatically increased metabolic risk. Similar results have been reported by Yanagibori et al. (1998), who found that 20 days of bed rest resulted in a significant increase in plasma triglycerides and a significant decrease in HDL cholesterol levels. These findings are further corroborated by reports suggesting that individuals with spinal cord injuries, a condition characterized by high amounts of time spent sedentary, also suffer from an increased risk of cardiovascular disease (Bauman and Spungen 2008).

The deleterious effects of sedentary behaviour on metabolic health appear to be at least partially mediated by changes in lipoprotein lipase (LPL) activity. LPL is an enzyme that facilitates the uptake of free fatty acids into skeletal muscle and adipose tissue (Hamilton et al. 2007). Low levels of LPL are associated with increased circulating triglyceride levels, decreased HDL cholesterol, and an increased risk of cardiovascular disease (Hamilton et al. 2007). LPL activity appears to be reduced in response to both acute and chronic sedentary behaviour.

Bey and Hamilton (2003) employed hind-limb unloading to examine the influence of sedentary behaviour on LPL activity in rats. With this technique, rats are suspended by their tail, preventing any weight-bearing activities of the lower limbs and allowing researchers to tightly control when sedentary behaviour in those limbs begins and ends. They reported that intracellular LPL activity in lower-limb skeletal muscle was reduced by more than 25% after just 6 h of hind-limb unloading and continued to decrease in a dose–response fashion, with an approximate 75% reduction in LPL activity after 18 h. Interestingly, although 12 h of hind-limb unloading resulted in more than a 50% decrease in LPL activity, it took just 4 h of light-intensity walking and normal cage activity to return LPL activity in the lower limbs to baseline levels. Bey and Hamilton (2003) reported that these changes appear to be due to transcriptional changes rather than to changes in LPL mRNA levels.

Similar findings have also shown LPL activity to be reduced in response to sedentary behaviours in humans. For example, following 11 days of bed rest in healthy Japanese subjects, Yanagibori et al. (1998) observed an 18% decrease in LPL activity, accompanied by significant increases in plasma triglycerides and decreases in HDL cholesterol. Significant decreases in muscle LPL activity have also been observed in response to 2 weeks of detraining in endurance athletes (Simsolo et al. 1993). Taken together, these results suggest that prolonged sedentary time, without vigorous activity, results in a substantially elevated cardiometabolic risk.

What is intriguing about the links between LPL activity and sedentary behaviour is that they are qualitatively different from the links between LPL activity and physical activity (Hamilton et al. 2007). For example, the reduction in LPL activity in response to sedentary behaviour is largely restricted to oxidative muscle fibers, while increases in LPL activity in response to physical activity are found mainly in glycolytic fibers. Further, the relative decreases in LPL activity seen in oxidative fibers following sedentary behaviour are more than 4-fold greater than the increases observed in glycolytic fibers following vigorous exercise (Hamilton et al. 1998, 2007; Bey and Hamilton 2003). Finally, exercise has been reported to increase LPL activity by increasing LPL mRNA levels, while sedentary behaviour does not appear to influence LPL mRNA levels, acting instead through transcriptional mechanisms (Hamilton et al. 1998, 2007; Bey and Hamilton 2003). These results strongly suggest that the mechanisms linking LPL activity with sedentary behaviour are distinct from those linking LPL activity to physical activity.

In addition to LPL activity, several reports suggest that sedentary behaviour affects carbohydrate metabolism through changes in muscle glucose transporter (GLUT) protein content. These proteins are critical to basal (GLUT-1), insulin (GLUT-4), and exercise (GLUT-4) stimulated glucose uptake (Henriksen et al. 1990; Klip and Pâquet 1990; Kawanaka et al. 1997). Studies have shown that denervation of skeletal muscle results in rapid decreases in both muscle GLUT-4 content and insulin-stimulated glucose uptake (Megeney et al. 1993), and glucose transporter protein concentration is also depressed in individuals with spinal cord injuries (Chilibeck et al. 1999; Phillips et al. 2004).

GLUT content is reported to increase dramatically in response to very low intensity exercise in individuals with spinal cord injury, who are likely to exhibit a high level of sedentary behaviour (Chilibeck et al. 1999; Phillips et al. 2004). Phillips and colleagues (2004) examined changes in muscle GLUT content in response to 6 months of body weight supported treadmill exercise in individuals with spinal cord injury. Following the exercise intervention, the authors reported a 126% increase in muscle GLUT-4 content, as well as improved oral glucose tolerance (Phillips et al. 2004). Similarly, Chilibeck and colleagues reported a 52% increase in GLUT-1 content and 72% increase in GLUT-4 content following 8 weeks of functional electrical stimulation exercise in paralyzed human skeletal muscle in addition to increased oxidative capacity and insulin sensitivity (Chilibeck et al. 1999). Of note, the intensity of exercise in both these intervention studies was extremely low. For example, the walking speed employed by Phillips et al. (2004) was less than 0.6 $km \cdot h^{-1}$, while the intensity of exercise used by Chilibeck and colleagues (1999) was equivalent to 6 W. Both these work rates resulted in dramatic increases in GLUT content despite being far lower than what would be considered moderate physical activity. Together, these studies suggest that even minor increases in contractile activity can dramatically increase muscle GLUT content and glucose tolerance in sedentary individuals.

Bone health

Another well-documented deleterious effect of sedentary behaviour is a reduction in bone mineral density (Caillot-Augusseau et al. 1998; Morey-Holton and Globus 1998; Zerwekh et al. 1998; Kim et al. 2003; Smith et al. 2003; Zwart et al. 2007). Both humans and animals experience dramatic reductions in bone mass following long periods of time spent in orbit, and significant decreases have also been reported in individuals following spinal cord injuries (Garland et al. 1992) and during long-term bed rest (Zerwekh et al. 1998). Zerwekh and colleagues reported reductions in bone mineral density of 1% to 4% in the lumbar spine, femoral neck, and greater trochanter of healthy men and women following 12 weeks of bed rest (Zerwekh et al. 1998).

It is thought that the relationship between sedentary behaviour and reduction in bone mass is mediated by changes in the balance between bone resorption and deposition. Markers of bone resorption, including urinary calcium and type I collagen cross-linked N-telopeptides, are reported to increase in healthy young males following 14 days of bed rest, while deoxypyridinoline may be elevated after just 6 days (Kim et al. 2003). In contrast, Kim and colleagues noted that markers of bone formation are largely unaffected by sedentary behaviour. Similar findings have been reported by Smith et al. (2003) and Zwart et al. (2007) in groups of male and female identical twins. Both these studies showed that bouts of daily aerobic exercise failed to completely prevent the deleterious changes in bone metabolism resulting from prolonged bed rest. For example, although exercise prevented the loss of bone mineral density in the hip and femoral shaft in women, it had little impact on most markers of bone and calcium metabolism (Zwart et al. 2007). These studies suggest that sedentary behaviour leads to a rapid increase in bone resorption without concomitant changes in bone formation, eventually resulting in reduced bone mineral content and increased risk of osteoporosis. Further, it appears that vigorous physical activity alone is not enough to prevent these changes in bone metabolism; less sedentary behaviour may also be required.

Vascular health

Although it has yet to receive the same attention as bone mineral density or metabolic health, limited evidence indicates that sedentary behaviour may also have deleterious effects on vascular health (Purdy et al. 1998; Bleeker et al. 2005; Demiot et al. 2007; Hamburg et al. 2007; Schrage 2008). Hamburg and colleagues (2007) examined changes in vascular function following 5 days of bed rest in 20 healthy subjects. They found that reactive hyperemia (a measure of peripheral vascular function) was reduced by roughly 20% in the legs and 30% in the arms following a bed-rest protocol. Subjects also experienced a significant increase in blood pressure and significant decrease in brachial artery diameter. These findings are supported by results from the Women and International Space Simulation for Exploration (WISE) study, which found that 56 days of head-down bed rest resulted in decreased endothelium-dependent vasodilation and increased endothelial cell damage in healthy women (Demiot et al. 2007). Interestingly, the WISE study found that these deleterious changes in vascular function were prevented by a combination of aerobic and resistance exercise, suggesting that a common mechanism may link vascular health to both sedentary behaviour and vigorous activity.

To date, most studies that have examined the influence of sedentary behaviour on vascular function have used protocols that simulate the effects of microgravity (e.g., maintaining the head below heart level), which is known to influence both blood volume and blood flow distribution (Schrage 2008). Thus, at present it is unclear whether the reported changes in vascular function following bed rest are due to the sedentary behaviour or to the postural conditions imposed on the subjects. However, given the dramatic changes in vascular function observed by Hamburg et al. (2007), who used a protocol that did not lower participants' heads to simulate microgravity, it appears that sedentary behaviour is likely to have at least some direct influence on vascular health, and future research in this area is clearly needed.

Relationships of sedentary behaviour with major health outcomes

A dose–response relationship was recently observed between time spent in sedentary behaviours (e.g., TV viewing time, sitting in a car, overall sitting time) and all-cause and cardiovascular disease mortality (Katzmarzyk et al. 2009; Dunstan et al. 2010*b*; Warren et al. 2010). This growing epidemiological evidence linking sedentary behaviour to health outcomes, including obesity, cardiovascular and metabolic diseases, cancer, and psychosocial problems, is summarized below. Where available, data are reported for both children and adults. Although the majority of epidemiological studies have used self-report measures of sedentary behaviour, there is emerging evidence linking objectively measured (via accelerometers and heart rate monitoring) sedentary time with these health outcomes. Importantly, for the majority of studies, the findings presented are independent of MVPA levels.

Sedentary behaviour and obesity

Children

There is substantial evidence linking the number of hours of TV viewing and being overweight or obese in children and adolescents. For example, in a representative sample of 7216 children aged 7 to 11 years, TV watching and video game use were risk factors for being overweight (17% to 44% increased risk) or obese (10% to 61%) (Tremblay and Willms 2003). One review concluded, however, that the association between TV viewing time and obesity in children is weak and unlikely to be clinically relevant (Marshall et al. 2004). The authors emphasized the need to examine more than a single sedentary behaviour (i.e., TV viewing), particularly because not all sedentary behaviours have been associated with obesity (Shields and Tremblay 2008*b*).

Adults

The study by Hu and colleagues using data from the Nurses' Health Study provides key evidence regarding the relationship between sitting and health outcomes, including obesity (Hu et al. 2003). A total of 50 277 women, who were not obese at baseline, were followed over a 6-year period. In analyses adjusting for other lifestyle factors, including diet and physical activity, each 2 $h \cdot day^{-1}$ increase in TV viewing time was associated with a 23% increase in obesity (Hu et al. 2003). Importantly, this study also examined other sedentary behaviours, where each 2 h·day^{-1} increase in sitting at work was associated with a 5% increased risk of obesity. Similar findings were observed in an Australian study, where the odds of substantial weight gain (>5 kg over 5 years) was significantly higher in those whose average sitting time per day was very high (≥8 h·day^{-1}) compared with those for whom it was very low (<3 h·day^{-1}) (Brown et al. 2005).

These prospective findings have been supported by several cross-sectional studies. For example, in 42 612 adults from the 2007 Canadian Community Health Survey, the odds of being obese increased as weekly hours of TV viewing time increased (Shields and Tremblay 2008*b*). Independent of leisure-time physical activity and diet, the prevalence of obesity among men rose from 14% for those who averaged ≤5 h·week^{-1} of TV viewing to 25% for those averaging ≥21 h·week^{-1}; similarly, among women the prevalence increased from 11% to 24% (Shields and Tremblay 2008*b*). In the Australian Diabetes, Obesity, and Lifestyle Study (AusDiab), high TV viewing time was more strongly associated with overweight and obesity than lack of leisure-time physical activity (Cameron et al. 2003).

Sedentary behaviour and cardiovascular and metabolic health

Children

Mark and Janssen (2008) reported a dose–response relationship between screen time (TV and computer) and metabolic syndrome in adolescent (aged 12–19 years) participants of the 1999–2004 NHANES survey. Independent of physical activity time, the odds of having the metabolic syndrome were 3 times higher in those with at least 5 h·day^{-1} of screen time compared with those with 1 h or less (Mark and Janssen 2008). TV viewing time has also been linked to hypertension in obese children, where those who watched TV ≥4 h·day^{-1} had 3.3 times the risk of hypertension compared with those who watched less than 2 h·day^{-1} (Pardee et al. 2007).

Adults

Several studies have examined the relationship between TV viewing time and cardiometabolic health in adults. The majority of these have reported detrimental associations, while none have reported beneficial associations. Specifically, TV viewing time has been associated with an increased risk of type 2 diabetes (Hu et al. 2001, 2003), acute coronary syndrome (Burazeri et al. 2008), metabolic syndrome (Bertrais et al. 2005; Dunstan et al. 2005; Ford et al. 2005; Gao et al. 2007), and abnormal glucose tolerance (Dunstan et al. 2004), as well as biomarkers of cardiometabolic risk (Jakes et al. 2003; Aadahl et al. 2007; Dunstan et al. 2007; Healy et al. 2008*b*). In the Nurses' Health Study, each 2 h·day^{-1} increase in TV viewing time was associated with a 14% increase in type 2 diabetes, while each 2 h·day^{-1} increase in sitting at work was associated with a 7% increase (Hu et al. 2003). A similar finding was observed in 37 918 participants of the Health Professional's Follow-up Study (HPFS), where, independent of physical activity, each 2 h·day^{-1} increase in TV viewing time was associated with a 20% increase in the risk for diabetes (Hu et al. 2001). In recent studies that have used accelerometer-derived measures, high levels of adults' sedentary time have been detrimentally associated with waist circumference, triglycerides, 2-h plasma glucose (Healy et al. 2007, 2008*c*), and insulin (Ekelund et al. 2007; Balkau et al. 2008). Importantly, more breaks in sedentary time were beneficially associated with several of these outcomes (Healy et al. 2008*a*). These associations are consistent with the proposed mechanisms detailed in the previous section, through which sedentary behaviour may influence cardiometabolic biomarkers of risk.

To date, few studies have examined these objective relationships prospectively, and findings are mixed (Ekelund et al. 2009; Helmerhorst et al. 2009). This may be partly due to differences in study samples and methods, and further research is required to establish the causal relationship between sedentary time and cardiometabolic health. The adverse associations of more sedentary time with impaired cardiometabolic health have also been observed in adults that participate in physical activity at or above recommended levels (Hu et al. 2001; Healy et al. 2008*c*; Katzmarzyk et al. 2009). This phenomenon, dubbed "the active couch potato", further distinguishes sedentary behaviour as a unique health risk and emphasizes the importance of measuring both this and physical activity level in lifestyle assessments.

Sedentary behaviour and cancer

The National Institutes of Health–American Association of Retired Persons Diet and Health Study cohort has given important insights into the link between sedentary behaviour and cancer. It consisted of a prospective cohort study of 488 720 men and women aged 50 to 71 years at baseline from 1995 to 1996. High levels of TV and (or) video watching were associated with an increased risk of colon cancer for men and women and endometrial cancer in women (Howard et al. 2008; Gierach et al. 2009). Additionally, women who spent ≥7 h·day^{-1} sitting had an increased risk of endometrial cancer compared with those who were sitting less than 3 h·day^{-1} (Gierach et al. 2009). Other studies have confirmed these findings, with detrimental associations between self-reported sedentary behaviours and risk of ovarian (Patel et al. 2006) and endometrial cancer (Friberg et al. 2006); higher percent breast density (Wolin et al. 2007); and with postdiagnosis weight gain in colorectal cancer survivors (Wijndaele et al. 2009).

Sedentary behaviour and psychosocial health

Physically active children report greater body satisfaction, self-esteem, and physical self-perceptions than their sedentary peers (Health Education Authority 1998), and increasing physical activity and exercise improves global self-esteem in youth, independent of changes in body weight (Ekeland et al. 2004). Similarly, a positive dose–response relationship between amount of exercise and both physical and mental quality of life measures has been observed in healthy adults (Martin et al. 2009). There is considerably more evidence linking increases in physical activity to improved mental health and psychosocial outcomes than to decreases in sedentary behaviours. Whether the positive psychosocial effects of increasing physical activity are a result of the physical activity itself or a decrease in the sedentary pursuits it is replacing is unknown. The following section summarizes what is currently understood regarding the independent psychosocial effects of engaging in sedentary pursuits from infancy through adulthood.

Early TV exposure

In 1971, the average age at which children began to watch TV was 4 years; today, it is 5 months (Zimmerman et al. 2007*b*). Currently, it is estimated that more than 90% of children begin watching TV before the age of 2 years, in spite of recommendations to the contrary (Christakis 2009). Exposure to TV before the age of 3 years has been shown to have detrimental effects on attention (Christakis et al. 2004), language (Zimmerman et al. 2007*a*), and cognitive development (Zimmerman and Christakis 2005). For example, a large longitudinal study found that TV exposure at ages 1 and 3 years were both associated with attention problems at age 7 years (Christakis et al. 2004). Among infants aged 8 to 16 months, each hour per day of viewing baby DVDs or videos was associated with a decrease in language development scores (Zimmerman et al. 2007*a*). Similarly, each hour of TV viewing before 3 years of age was associated with deleterious effects on reading recognition, comprehension, and memory, associations that persisted after controlling for parental cognitive stimulation, IQ, and maternal education (Zimmerman and Christakis 2005). Each additional hour of TV viewing per day at age 4 years was associated with an increase in subsequent bullying in grade school (Zimmerman et al. 2005).

TV exposure during childhood and adolescence

A review of 130 quantitative studies examining the relationship between media exposure and health outcomes found that there was strong evidence linking media exposure with obesity, tobacco use, and violence (Nunez-Smith et al. 2008). Moderate relationships were observed between media and drug use, alcohol use, low academic achievement, and sexual behaviour. Thirty-one studies evaluated media and academic performance, and 65% reported a significant association between increased media exposure and poor academic outcomes. Of the 26 studies that examined the effect of watching TV, 62% reported a strong link between greater media exposure and lower academic performance. While more research is needed in this area, no studies to date have demonstrated benefits associated with infant or childhood TV viewing. In fact, the majority of existing evidence suggests the potential for harm (Nunez-Smith et al. 2008).

Further evidence of the impact of TV exposure on academic outcomes comes from a prospective birth cohort study, which found that the likelihood of earning a bachelor's degree (or higher) by age 26 years decreased as the mean hours of TV per weekday increased between the ages of 5 and 15 years (Hancox et al. 2005). Earlier exposure (aged 5–11 years) was a stronger predictor of nonattainment of a university degree, while later exposure (aged 13 and 15 years) was a stronger predictor of leaving school without qualifications (Hancox et al. 2005).

Previous literature has shown a clear link between media exposure and psychosocial well-being (Strong et al. 2005; Janssen and Leblanc 2010). High levels of media exposure (i.e., TV viewing, video game playing, magazine reading) are correlated with lower self-esteem, decreased prosocial behaviour, and increased aggression (Holder et al. 2009; Iannotti et al. 2009; Russ et al. 2009; Strasburger et al. 2010). According to the American Academy of Pediatrics (2001), reducing TV viewing minimizes exposure to unhealthy messages conveyed through the TV, which have been associated with reduced self-image and increased aggressive behaviours. Reductions in screen time may improve self-esteem and prosocial behaviours in children via reduction in exposure to unhealthy messages, unrealistic body images, and aggressive behaviours (Russ et al. 2009). Alternatively, reduction in TV viewing may facilitate increases in physical activity, which in turn may lead to improvements in self-esteem and self-efficacy (Epstein et al. 2005).

Sedentary behaviour and psychosocial outcomes in adults

Compared with physical activity and psychosocial outcomes, the relationship between engaging in sedentary pursuits and psychosocial outcomes has been less studied. In a prospective cohort study of Spanish university students, researchers found that the odds of having a mental disorder was 31% higher for subjects spending more than 42 $h \cdot week^{-1}$ watching TV compared with those watching less than 10.5 $h \cdot week^{-1}$ (Sanchez-Villegas et al. 2008). The results also showed a clear graded relationship between a sedentary index (hours per week watching TV or using a computer) and the risk of developing a mental disorder, with those at the highest level of the sedentary index having a 31% higher risk of mental disorder when compared with less sedentary individuals (Sanchez-Villegas et al. 2008).

While there is a paucity of data looking specifically at sedentary behaviours and psychosocial outcomes in adults, there is enough emerging evidence to justify further work in this area. In addition, what is known about physical activity and psychosocial outcomes lends further support to exploring this area. For example, epidemiological studies suggest that physical activity is associated with a decreased prevalence of mental health disorders (Goodwin 2003; Galper et al. 2006; Stathapoulou et al. 2006). Women accumulating ≥7500 $steps \cdot day^{-1}$ had a 50% lower prevalence of depression when compared with women accumulating <5000 $steps \cdot day^{-1}$ (McKercher et al. 2009). Similarly, randomized controlled trials have observed increases in mental health and quality of life scores when previously sedentary middle-aged women adopted an exercise program (Bowen et al. 2006; Martin et al. 2009). Clear distinctions and definitions of sedentary behaviour are critical to ensure that lack of physical activity and purposeful engagement in sedentary pursuits are not treated as one and the same.

Population prevalence and variations in sedentary behaviour

Unlike physical activity, there are limited data on population levels of sedentary time and sedentary behaviours. Nevertheless, time-use data from different countries provide evidence of the pervasiveness of sedentary behaviours.

Prevalence of sedentary behaviours

Recent population-based estimates of accelerometer-derived sedentary time have reported that American children and adults spend, on average, 54.9% of their waking hours sedentary (Matthews et al. 2008). A similar proportion was observed in a small sample of Australian adults, with the remainder of the day disproportionately spent in light-intensity activity and MVPA (Healy et al. 2008*c*).

When specific sedentary behaviours are examined, the most commonly measured (Clark et al. 2009), and the most common sedentary leisure-time behaviour (Harvey 1990; Salmon et al. 2003; Sugiyama et al. 2008*b*; Biddle et al. 2009), is TV viewing time. In Scottish adolescents, TV viewing time occupied one-third to one-half of all sedentary behaviour time compared with other sedentary behaviours, including homework, computer or video games, and motorized transport (Biddle et al. 2009). Similar findings were observed in Hungarian (Hamar et al. 2010) and British (Gorely et al. 2009) youths.

The Canadian Pediatric Society (2003) and American Academy of Pediatrics (2001) recommend that children and youth spend no more than 2 $h \cdot day^{-1}$ in front of screens. The international Health Behavior in School-Aged Children (HBSC) Survey asked adolescents between ages 11 and 15 years how many hours per day they watch TV (including DVDs and videos) in their spare time on weekdays and on weekend days (HBSC International Coordinating Centre 2008). Overall, quantities of TV exposure above what is recommended are common around the world among youth. The proportion of 11-, 13-, and 15-year-olds who watch TV for ≥2 h daily is 61%, 70%, and 68%, respectively (HBSC International Coordinating Centre 2008). These values range from 30% in Switzerland to 81% in Bulgaria for 11-year-olds (HBSC International Coordinating Centre 2008). Similar trends are evident in 13- and 15-year olds, with the proportions reaching as high as 84% in Slovakia (HBSC International Coordinating Centre 2008).

Given the rapid proliferation of computer ownership and use (Shields and Tremblay 2008*a*), it is important to consider and measure total screen time, not just TV viewing time. In Canada, the average screen time reported in the 2009 Active Healthy Kids Canada Report Card on Physical Activity was 6 h per weekday and 7.5 h on weekend days (Active Healthy Kids Canada 2009) based on self-reported data on TV viewing, computer use, and video game playing during free time. From the 2001 to 2006 NHANES data, 47.3% of children and adolescents (aged 2–15 years) were found to report at least 2 $h \cdot day^{-1}$ of screen time (Sisson et al. 2009). Gender, age, ethnicity, obesity, and income differences were evident in those that exceeded the <2 $h \cdot day^{-1}$ recommendation (Sisson et al. 2009).

For adults, data from the United States indicate a dramatic rise in TV ownership from 1950 to 2000 that was matched by an approximate doubling of average viewing hours per day from an estimated 4.5 $h \cdot day^{-1}$ to nearly 8 $h \cdot day^{-1}$ (Brownson et al. 2005). In contrast to the findings from the United States, TV viewing time appears to have declined in Canada over the 1986 to 2005 period (Shields and Tremblay 2008*a*). However, this has been accompanied by the rapid proliferation of home computers and availability of the Internet, such that actual screen time is on the rise (Shields and Tremblay 2008*a*).

The last decade has seen rapid declines in household-related activity in women and work-related activity in both men and women (Brownson et al. 2005). Unfortunately, given the rapid change in technological innovation, it has been suggested that we have not yet reached the historical pinnacle of sedentary behaviour levels (Hamilton et al. 2007, 2008). A longitudinal study in British adolescents (N = 5863; aged 11–12 years at baseline) showed marked increases in sedentary behaviour (including watching TV and playing video games) at the 5-year follow-up (Brodersen et al. 2007). Black students were more sedentary than white students, and sedentary behaviour levels were higher in those from families of low socioeconomic status (Brodersen et al. 2007).

Continued monitoring of population levels of screen time (including both TV and computers) and other sedentary behaviours, such as car time, occupational sitting time, and overall sitting time, is essential to monitor trends, guide behavioural change and policy strategies, and assess future interventions.

Characteristics of those with high levels of sedentary behaviour

Using accelerometer-derived measures of sedentary time, the most sedentary groups in the United States were older adolescents (aged 16–19 years) and adults ≥60 years, while Mexican–American adults were significantly less sedentary than other American adults (Matthews et al. 2008). Overall, females were more sedentary than males before age 30 years, with this pattern reversed after age 60 years (Matthews et al. 2008).

Recent surveys from the United States, Australia, and Canada show that TV viewing time increases with age and that men watch more TV than women on average (Australian Bureau of Statistics 1997; Bureau of Labor Statistics 2008; Shields and Tremblay 2008*a*). Additionally, higher levels of TV viewing time have been observed among black than among white or Hispanic individuals (Sidney et al. 1996; Bennett et al. 2006).

The characteristics of those who watch high levels of TV are consistent across American (Bowman 2006), Canadian (Shields and Tremblay 2008*a*), and Australian adults (Salmon et al. 2000; Clark et al. 2010), namely low educational attainment (Salmon et al. 2000; Bowman 2006; Shields and Tremblay 2008*a*; Clark et al. 2010), unemployment (Salmon et al. 2000; Bowman 2006; Shields and Tremblay 2008*a*; Clark et al. 2010), low income (Bowman 2006; Shields and Tremblay 2008*a*), and more likely to eat in front of the TV (King et al. 2010). High body mass index (Salmon et al. 2000; Bowman 2006; Shields and Tremblay 2008*b*) is a common characteristic of those who watch high levels of TV; however, the causal direction of this relationship is undetermined.

The sociodemographic characteristics of those with high levels of other sedentary behaviours have been studied less. In Canadian adults, the characteristics of frequent computer users included high educational attainment, young age, and current unemployment (Shields and Tremblay 2008*a*). The high levels of TV viewing time and computer use among the unemployed is likely to reflect greater discretionary time.

Future population surveillance of sedentary behaviour

Based on the available evidence, key sedentary behaviours that ought to be captured in population surveillance include TV and screen time, workplace sitting time, indoor time, and time spent sitting in automobiles. The evidence on the reliability and validity of brief self-report measures of TV viewing time, leisure-time computer use, and video game playing that would be suitable for use in population surveys is reasonably strong (Tremblay et al. 2007*a*; Shields and Tremblay 2008*a*; Clark et al. 2009), and these are ubiquitous sedentary behaviours in most developed countries. Surprisingly few studies have reported the reliability and criterion validity of occupational sitting-time questions (Marshall et al. 2010), and further research is needed in this area. Similarly, questions on time spent in automobiles are less commonly used but are important because of the pervasive car dependency in most contemporary cultures and because of new evidence on the relationship of time sitting in cars with premature mortality (Warren et al. 2010).

Inclusion of accelerometer measures into the NHANES and the Canadian Health Measures Survey (Tremblay et al. 2007*b*; Colley et al. 2010) has also demonstrated the feasibility of incorporating objective measures of both physical activity and sedentary time into large, population-based studies. The use of objective (accelerometer) measures in population surveillance systems provides an exciting new development in not only the measurement of sedentary time (Wong et al., in press), but also in examining its associations with health outcomes in representative population sample and high-risk subgroups.

Future population surveillance work should explore the importance and relevance of total sitting time, indices of indoor time and sedentary-time interruptions to health indicators, and also explore their interactions with measures of light activity and MVPA.

Conclusions: research issues, opportunities, and future directions

Emerging evidence identifies sedentary time as a ubiquitous attribute of contemporary lifestyles, which appears to have a unique relationship with health risk that is independent of MVPA. There is a particular need for further research with humans on the biological mechanisms that underlie deleterious impacts on health. Rigorous experimental studies are needed that manipulate sedentary time and examine the acute and cumulative biological consequences (Hamilton et al. 2007, 2008). Evidence from laboratory studies, combined with evidence from prospective epidemiological studies and controlled intervention trials designed to change sedentary time in free-living children and adults, will provide important insights on population health.

Understanding the relationships between sedentary behaviours and health outcomes and monitoring these behaviours in populations are fundamental research challenges. However, to develop evidence-based public health strategies and implement large-scale interventions to reduce population-wide levels of sedentary behaviours, there is a need to understand the determinants of the behaviours themselves. Prospective studies and intervention trials should also be carried out to identify the environmental, social, and personal factors that lead to prolonged time spent in particular sedentary behaviours.

Studies have shown that environmental, social, and personal attributes contribute independently and interactively to predicting physical activity behaviours. For sedentary behaviours (TV viewing time, total screen time, automobile use, occupational sitting time), there is a range of opportunities for research studies to examine the relevant determinants likely to operate at multiple levels (Sugiyama et al. 2007). In this context, ecological models of health behaviour applied to physical activity (Sallis et al. 2008) can provide some relevant guidance, but there is the need for models that are specific to sedentary behaviour to systematize relevant evidence from the multiple domains that are likely to influence sedentary time in particular settings (e.g., personal preferences and other time uses in relation to domestic TV viewing time; transportation infrastructure in relation to time spent in automobiles).

To properly address prolonged sedentary behaviour as a new public health issue, evidence is needed from actual intervention trials, in which the factors known to influence sedentary behaviour are manipulated. It seems likely that it will be feasible to induce people to shift some proportion of their sedentary time into higher volumes of light- or moderate-intensity physical activity. However, this needs to be determined empirically. In populations where most adults are physically inactive, the feasibility and acceptability of such changes needs to be examined carefully in rigorous studies using objective measurement methods. Additionally, it needs to be determined whether there might be any untoward consequences of shifting some significant proportion of sedentary time to time spent in standing or light ambulation. For example, older or obese adults may be at greater risk of lower-body musculoskeletal problems if they reduce sitting time and increase the proportion of time that they spend on their feet. These are important research questions that go beyond basic concerns about excessive sedentary behaviours and cardiometabolic health, opening up opportunities for studies in occupational ergonomics, musculoskeletal health, and other areas.

The science of sedentary behaviour merits increased attention as a complementary, but distinct, area of research with significant potential to not only inform the understanding of biological underpinnings of movement, but to also suggest novel options for the prevention of noncommunicable disease and to suggest environmental innovations and new policies for preserving and enhancing population health.

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