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A Step-defined Sedentary Lifestyle Index:

< 5,000 Steps/day

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Abstract

Step counting (using pedometers or accelerometers) is widely accepted by researchers, practitioners, and the general public. Given mounting evidence of the link between low steps/day and time spent in sedentary behaviours, how few steps/day some populations actually perform and the growing interest in the potentially deleterious effects of excessive sedentary behaviours on health, an emerging question is: "how many steps/day are too few?" This review examines the utility, appropriateness, and limitations of using a re-occurring candidate for a step-defined sedentary lifestyle index: < 5,000 steps/day. Adults taking < 5,000 steps/day are more likely to have a lower household income, and be female, older, African American versus European American ethnicity, a current versus never smoker, and/or be living with chronic disease and/or disability. Little is known about how contextual factors (e.g., built environment) foster such low levels of step-defined physical activity. Unfavorable indicators of body composition and cardiometabolic risk have been consistently associated with taking < 5,000 steps/day. The acute transition (3-14 days) of healthy active young people from higher (>10,000) to lower daily step counts (<5,000 or as low as 1,500) induces reduced insulin sensitivity, glycemic control, increased adiposity and other negative changes in health parameters. Although few alternative values have been considered, the continued use of < 5,000 steps/day as a step-defined sedentary lifestyle index for adults is appropriate for researchers, practitioners, and communicating with the general public. There is little evidence to advocate any specific value indicative of a step-defined sedentary lifestyle index in children/adolescents.

Keywords: Physical activity, Physical Inactivity, Exercise, Walking, Ambulation, Sitting, Pedometer, Accelerometer

Introduction

Step counting (using pedometers or accelerometers) is widely accepted by researchers, practitioners, and the general public alike for assessing, tracking, and communicating physical activity doses. For example, researchers recently reported 5-year changes in body mass index (BMI), waist-to-hip-ratio, and insulin sensitivity related to 1,000 step incremental changes in step-defined physical activity (Dwyer et al. 2011); a practice-based journal published a unique collection of articles largely focused on step counting applications in a variety of special populations (Bassett Jr and John 2010; Bradley et al. 2010; Gardner et al. 2010; Jakicic et al. 2010; Lutes and Steinbaugh 2010; Motl and Sandroff 2010; Richardson 2010; Rogers 2010; Shephard and Aoyagi 2010; Temple 2010; Tully and Tudor-Locke 2010); and government/agency/professional organizations from around the world have published different step-based recommendations (Tudor-Locke et al. 2011h). This widespread adoption and practice of step counting provides a unique opportunity for bridging research to clinical practice and ultimately to real-world application since it allows a range of users to communicate using the same metric that captures an objective measure of ambulatory activity accumulated throughout the day. To further facilitate this communication, the purpose of this review is to present the rationale, utility, appropriateness, and limitations of a “step-defined sedentary lifestyle index.” The content reflects our collective understanding of the ever increasing scope and nature of the step-based literature; specific articles are cited to support arguments and offer examples.

Why ambulatory activity?

Although there are other types of movements in the human behavioural repertoire, it is logical to focus on assessing and promoting ambulatory activity. Relatively few (or no) steps are accumulated during sedentary behaviours (Tudor-Locke et al. 2009a; Wong et al. 2011) and relatively more steps/min are accumulated during increasingly intense ambulatory activity (Abel et al. 2011; Beets et al. 2010b; Marshall et al. 2009; Rowe et al. 2011; Tudor-Locke et al. 2005), with the highest rates of accumulation occurring during performance of moderate-to-vigorous physical activity (MVPA) (Abel et al. 2011; Beets et al. 2010b; Marshall et al. 2009; Rowe et al. 2011; Tudor-Locke et al. 2005). The relationship between accelerometer-determined activity counts/day and steps/day is strong (r^2=0.87) (Tudor-Locke et al. 2011a). Steps/day explains approximately 62% (women) to 67% (men) of the daily variability in time spent in MVPA (Tudor-Locke et al. 2011a). Further, attaining approximately 7,000-8,000 steps/day is a reasonable approximation of also obtaining at least 30 minutes/day of MVPA (or at least 150 minutes/week) (Tudor-Locke et al. 2011d). Attainment of at least 7,000 steps/day is listed amongst the most recent evidence-based exercise recommendations issued by the American College of Sport Medicine (Garber et al. 2011).

Can steps/day be used to indirectly infer sedentary time?

Low step counts also imply that individuals have spent more time in sedentary behaviour. This approach to inferring time spent in sedentary behaviour from a relative lack of movement is the same concept used in accelerometry; a relatively low accelerometer activity count/min (e.g. < 100) is typically used to define time spent in sedentary behaviours (Matthews et al. 2008). On a daily basis, participants who took < 5,000 steps/day in the accelerometer monitoring component of the 2005-2006 National Health and Nutrition Examination Survey (NHANES) averaged 522 to 577 minutes/day in sedentary behaviours, compared to 348 to 412 minutes/day in those who took ≥ 10,000 steps/day, translating to a 2.75 to 2.9 hours/day difference in sedentary behaviours associated with these different categories of step-defined physical activity (Tudor-Locke et al. 2011a). Twenty-five percent of the variability in time (i.e., minutes) spent in daily sedentary behaviours as collected in these NHANES data is explained by a simple count of steps/day (Tudor-Locke et al. 2011a). Although this explanatory power might appear to be low in contrast to the stark differences in time estimates presented above, it is important to clarify that a single minute of "sedentary activity" (defined by Wong et al. (2011) as a minute where zero steps are taken, which they considered the "criterion measure" of this classification), is a missed opportunity to accumulate any number of steps taken between 1 and 120+ steps/minute (Tudor-Locke et al. 2011e).

It may be more meaningful to look beyond cross-sectional associations and examine the effects of changes in steps/day on time spent in sedentary behaviours. Gilson et al. (2009) did not show changes in self-reported sitting time at work with pedometer-enabled walking strategies, however, the intervention was confined only to working hours (which may have limited success) and the method of assessing time was not likely sensitive to potential real changes in behaviour. De Cocker et al. (2008) evaluated changes in self-reported sitting time by participants engaged in a pedometer-based community intervention focused on increasing steps/day. In 254 participants who increased their steps/day, an increase of 2,840 steps/day was associated with a self-reported decrease of 18 min/day in sitting time (both changes were statistically significant). De Greef et al. (2010) documented an increase of 2,502 steps/day in 20 individuals with Type 2 diabetes as a result of a pedometer-based intervention that also produced a > 1 hour decrease in accelerometer-determined sedentary behaviour (again, both changes were statistically significant). In another pedometer-based intervention study of 92 individuals with Type 2 diabetes, De Greef et al. (2011) reported significant increases of 2,744 steps/day and decreases in accelerometer-determined sedentary behaviour of 23 min/day. Finally, Mikus et al. (2012) recruited young adult volunteers who habitually took > 10,000 steps/day and instructed them to temporarily reduce their activity to < 5,000 steps/day based on self-monitored pedometer feedback. Concurrent accelerometer monitoring during this transition captured an average 2.5 hour increase in sitting time (from 593 minutes/day to 745 minutes/day). Although the difference was not statistically significant (the sample size of 12 participants was not powered to evaluate this specific outcome), few would suggest that a 2.5 hour/day increase in sitting time is an unremarkable change. Combining the results from the studies using objective monitoring, one would expect an increase of 2,500 steps/day to be associated with a 37-45 min/day reduction in sedentary behaviour.

How many steps/day are too few?

Recently a series of papers have explored the concept or question "how many steps are enough?" in terms of a step-based translation of current public health physical activity guidelines (Tudor-Locke et al. 2011f; Tudor-Locke et al. 2011g; Tudor-Locke et al. 2011h), which have historically focused on engagement in activities that are of at least moderate intensity. Although recent U.S public health guidelines continue to emphasize the benefits of time spent in MVPA, they also acknowledge that some activity is better than none (regardless of any intensity criterion), even while encouraging that more is better (Physical Activity Guidelines Advisory Committee 2008). Canadian Physical Activity Guidelines produced by the Canadian Society of Exercise Physiology (CSEP) (Tremblay et al. 2011b) focus on the health benefits of MVPA, however, they also state that for adults and older adults "who are physically inactive, doing amounts below the recommended levels can provide some health benefits." At the same time, interest continues to grow in the independent and potentially deleterious health effects of excessive time spent in sedentary behaviours (Katzmarzyk 2010; Katzmarzyk et al. 2009). CSEP's recent release of Sedentary Behaviour Guidelines for children and adolescents advocate sitting less (Tremblay et al. 2011a; Tremblay et al. 2012). The accompanying CSEP-endorsed press release clearly interpreted this as an opportunity to move more: "the majority of sedentary time can be replaced with light intensity activity and this can be done in a variety of ways" (CSEP 2011). Given that steps/day explains a large part of time spent in light and moderate intensity activities (Tudor-Locke et al. 2011a), and that there is an inverse relationship between accumulation of daily steps and time spent in sedentary behaviours, it has been suggested that asking "how many steps are too few?" may be a more relevant public health question, especially given mounting evidence of just how little physical activity some populations actually perform (Tudor-Locke et al. 2011h).

Tudor-Locke and colleagues (2001) first suggested that taking < 5,000 steps/day might be a useful metric indicative of a "sedentary lifestyle index." In that study they examined the distribution of BMI-defined weight status categories across step-defined physical activity in approximately 100 adults. They observed that individuals taking < 5,000 steps/day were more frequently classified as obese compared to all other BMI-defined weight status categories. Subsequently, Tudor-Locke and Bassett (2004) used 5,000 steps/day as the anchor for their proposed graduated step index that included < 5,000 (labeled "sedentary"), 5,000-7,499 ("low active"), 7,500-9,999 ("somewhat active"), 10,000-12,499 ("active"), and 12,500+ ("highly active") steps/day. Using < 5,000 steps/day as an "sedentary lifestyle" indicator was repeated again in 2008 (Tudor-Locke et al. 2008b). In 2009, Tudor-Locke et al. (2009a) suggested additional categories below this very broad category capped by 5,000 steps/day labeled as "basal activity" (<2,500 steps/day) and "limited activity" (2,500-4,999 steps/day).

Terminology

When the term "sedentary lifestyle index" was first proposed (Tudor-Locke et al. 2001), it was appropriate given where the state of knowledge was at that time. The sedentary behaviour research field has grown substantially and rapidly since then and the explosion of work focused on this low-end of the movement spectrum has inevitably led to debate around terminology. Specifically, recent calls for standardized use of terms "sedentary" and "sedentary behaviours" (Sedentary Behaviour Research Network 2012) have added complexity to the idea of using any number of steps/day to define a "sedentary lifestyle index." What follows is the case to retain the original terminology applied to a step-based index.

Caspersen, Powell, and Christenson (1985) first clarified the terms "physical activity" ("any bodily movement produced by the skeletal muscles that results in energy expenditure") and "exercise" ("a subset of physical activity that is planned, structured, and repetitive and has as a final or intermediate objective the improvement or maintenance of physical fitness"). In 2000, Owen et al. called for a shift in traditional approaches to studying exercise and sport and introduced the concept of studying sedentary behaviour as distinct from physical activity. They defined sedentary behaviours in terms of "low levels of energy expenditure," specifically those activities that expend energy at 1.0 to 1.5 metabolic equivalent units (METs); one MET being the energy cost of resting quietly, or 3.5 mL of oxygen uptake per kg body weight per minute. Pate, O'Neill, and Lobelo echoed this MET-based definition of sedentary behaviour in 2008. Hamilton, Hamilton, and Zderic (2007) pushed to recognize that the study of "acute and chronic physiological effects of sedentary behaviors" included the study of "*nonexercise activity deficiency*". Thus, these pioneering researchers recognized that the effects of sedentary behaviour might extend beyond its impact only on energy expenditure, and included in their definition a focus on relative lack of movement (which they termed "nonexercise activity" or, elsewhere in the manuscript, as "nonexercise physical activity.")

Tremblay et al. assembled terms they believed important to describing and measuring sedentary behaviour in their 2010 publication. They defined "sedentary" as "*characterized by little physical movement and low energy expenditure."* Further, "sedentarism" was defined as "extended engagement in behaviours *characterized by minimal movement, low energy expenditure,* and rest." To be clear, both definitions recognized the *relative lack of physical movement* associated with sedentary behaviours. In contrast with the broader definition of "physical activity" advocated by Caspersen, Powell, and Christenson (1985), Tremblay et al. (2010) specifically defined "physical activity" as "activities of at least moderate intensity." In addition, these authors defined "physically active" as "meeting established guidelines for physical activity (usually reflected in achieving a threshold number of minutes of moderate to vigorous physical activity per day)." They also clarified "physical inactivity" as "the absence of physical activity: usually reflected as the amount or proportion of time not engaged in physical activity of some predetermined intensity." Since they had defined "physically active" in terms of MVPA attainment, it follows that the subsequently listed definition of "physical inactivity" also referred to this specific intensity. The authors specifically argued against using the term sedentary to confer "the absence of MVPA." Owen et al. (2010) also stated: "it is our contention that sedentary behaviour is not simply the absence of moderate-to-vigorous physical activity."

They also summarized objectively-assessed sedentary behaviour from the AusDiab findings (Healy et al. 2007; Healy et al. 2008) and concluded:

> "As logically would be expected, sedentary time and light-intensity activity time were highly negatively correlated (r = -0.96): more time spent in light-intensity activity is associated with less time spent sedentary. This suggests that it may be a feasible approach to promote light intensity activities as a way of ameliorating the deleterious health consequences of sedentary time. Our evidence suggests that having a positive light intensity/sedentary time balance (that is; spending more time in light-intensity than sedentary time) is desirable, since light-intensity activity has an inverse linear relationship with a number of cardio-metabolic biomarkers."

Although the term "sedentary time" has been used interchangeably with "sitting" (Healy et al. 2011), examples of postures that expend < 1.5 METs include lying down/reclining and standing still (e.g., standing quietly, standing in line, Compendium Code 07040) in addition to seated postures (Ainsworth et al. 2011). There are a number of original references catalogued in the 2011 Compendium on-line resources (located at https://sites.google.com/site/compendiumofphysicalactivities/) reporting that standing behaviours expend < 1.5 METs; two recent examples include Levine, Schleusner, and Jensen (2000) (average 1.1 METs) and Crouter, Clowers, and Bassett (2006) (average 1.19 METs). More recently, however, Owen et al. (2011) explicitly defined sedentary behaviours as "sitting without being otherwise active." Researchers expressly interested in sitting behaviours are able to more precisely assess such postures using inclinometers (Kozey-Keadle et al. 2011).

Sedentary behaviour has also been defined by relatively low accumulation of accelerometer-determined activity counts/min. Specifically, Matthews et al. (2008) wrote about defining sedentary behaviour in their well-known U.S.-based descriptive epidemiology paper: "Activity counts recorded while sitting and working at a desk are very low (≤ 50 counts/minute), and counts recorded while driving an automobile are typically below 100 counts/min (unpublished observations)." Since that time 100 counts/min has been routinely used to define sedentary behaviours from accelerometer data (Tudor-Locke et al. 2012). Crouter, Clowers, and Bassett (2006) reported that standing averaged 13.4 activity counts/min and filing averaged 59.8 activity counts/min, so it is apparent that these types of activities would also be classified as "sedentary behaviours" by this activity count/min definition. Regardless, the use of the terms "sedentary behaviours" and "sedentary time" attempt to capture time allocation to specific types of behaviours (at any particular point in time or accumulated over a specified period of time), and defined by relatively low rates of energy expenditure, posture, or relatively low accumulated activity counts/min.

Since time spent in such behaviours appears to be ubiquitously high in population-level data (Matthews et al. 2008), an index is needed to help classify what is potentially excessive in terms of habitual daily behaviour (i.e., an index of lifestyle in contrast to a measured behaviour captured at any particular point in time or accumulated duration of time). For example, a joint report (2001) of the Food and Agriculture Organization of the United Nations (FAO), the World Health Organization (WHO), and the United Nations University (UNU) uses the ratio of total energy expenditure to basal metabolic rate to estimate "physical activity level" or PAL, and then defines "sedentary or light activity lifestyle" as a PAL of 1.40-1.69 (the lower end of the range implies a sedentary lifestyle and the upper end implies a light activity lifestyle). Since direct measures of energy expenditure are less accessible to many practitioners and the general public, it is rational to attempt to provide a reasonable lifestyle index using more available instrumentation, for example, step counting devices. Specifically, objectively determined PAL (using multisensory armband accelerometer technology) is the strongest individual level predictor of all-cause mortality in patients with chronic obstructive pulmonary disease (COPD) (Waschki et al. 2011), and < 4,580 steps/day has been identified as the best cut-point for predicting a "sedentary" PAL of < 1.40 in this population (DePew et al. in press). Just as METs is to PAL (i.e., metabolic cost of behaviours captured at any particular point in time vs. lifestyle indicators of energy expenditure), steps/min is to steps/day. A cadence of 100 steps/min has been consistently associated with an absolutely definition of moderate intensity (i.e., 3 METs) (Abel et al. 2011; Beets et al. 2010b; Marshall et al. 2009; Rowe et al. 2011; Tudor-Locke et al. 2005) and zero steps/min is considered to be the "criterion measure" of "sedentary activity" (Wong et al. 2011). A low level of PAL is indicative of a sedentary lifestyle (FAO/WHO/UNU 2001), and a low level of steps/day should likewise be interpreted as a sedentary lifestyle if some degree of consistency is to be maintained. Although we considered alternative terminology, the continued use of "sedentary lifestyle index" applied to a low level step-defined threshold is harmonious with the use of the term "sedentary lifestyle" defined by relatively low levels of daily energy expenditure as previously established by the FAO, WHO, and UNU. Further, as will be presented in the following sections, it has already been consistently applied in a growing number of studies and to re-label it now would only add to the confusion.

To ease communication, we offer a simple schematic (Figure 1) to graphically present the combined application of these various definitions in defense of a "step-defined sedentary lifestyle index." Since we have demonstrated that NHANES participants who accumulate 7,000 to 8,000 steps/day meet MVPA guidelines (Tudor-Locke et al. 2011d), we have set the "physically active lifestyle" threshold at 7,500 steps/day. This is also congruent with an international review of steps/day values associated with attainment of public health recommendations of time in MVPA (Tudor-Locke et al. 2011h). Since the FAO, WHO, and UNU (2001) consider a "light activity lifestyle" to be relatively more active than a "sedentary lifestyle," and others have persuasively argued that the term "inactive" should be specifically reserved for non-attainment of MVPA recommendations (Owen et al. 2010; Tremblay et al. 2010) (indeed, a letter has been written urging journal editors and reviewers to oversee this appropriate use (Sedentary Behaviour Research Network 2012)), we therefore consider "physical inactivity" to refer to the spectrum of behaviour below the MVPA recommendation and have assigned the term "low active lifestyle" (terminology selected in keeping with previous recommendations (Tudor-Locke and Bassett 2004; Tudor-Locke et al. 2008b)) to fall immediately below this MVPA-associated threshold (i.e., 5,000 to 7,499 steps/day), but above the "sedentary lifestyle" (i.e., < 5,000 steps/day). Finally, since preceding and esteemed researchers have 1) recognized that the study of sedentary behaviours includes "nonexercise activity deficiency" (Hamilton et al. 2007), 2) acknowledged that more time in "light-intensity activity" is strongly associated with less time in sedentary behaviours,(Healy et al. 2007; Healy et al. 2008; Owen et al. 2010) and, 3) characterized "sedentarism" (Tremblay et al. 2010) by minimal movement and low energy expenditure, we remain resolute in identifying a steps/day value that could be used as a "sedentary lifestyle index." An "index" is considered to be a guide, an indicator, a sign, or a pointer. We wish to emphasize that this is a "*step-defined* sedentary lifestyle index." In much the same way, others have offered a "PAL-defined sedentary lifestyle index" (FAO/WHO/UNU 2001). In the future, still others may offer a "posture-defined sedentary lifestyle index," etc. Finally, we believe that the use of "sedentary lifestyle" does not detract from the continued use of "sedentary behaviour" to define behaviours captured at any particular point in time (or the accumulation of time spent in such behaviours), and defined by a relative lack of energy expenditure, a seated posture, or relatively low accumulated activity counts/min.

Utility, appropriateness, and limitations of < 5,000 steps/day

Semantics aside, the purpose of this review is not only to present the rationale, but to also examine and update the utility, appropriateness, and limitations of using the originally proposed cut-point of < 5,000 steps/day as a step-defined sedentary lifestyle index. The need for this selective focus is evident from the simple fact that there are few other contenders at this time, as will be presented in more detail below. The remainder of the article is organized into the following sections, categorized according to emergent themes identified in the step-based literature: 1) studies reporting sample proportions taking < 5,000 steps/day; 2) characteristics of people taking < 5,000 steps/day; 3) contextual factors that can limit accumulation of step-defined physical activity to values of < 5,000 steps/day; 4) health risks associated with taking < 5,000 steps/day; 5) health effects of increasing physical activity levels from < 5,000 steps/day to > 5,000 steps/day; 6) health effects of reducing physical activity levels to < 5,000 steps/day; 7) alternative step-based definitions for a sedentary lifestyle index, 8) relevance for children/adolescents, and 9) limitations to this approach. Throughout, we distinguish terminology used in original research studies in quotations (e.g., "sedentary").

Prevalence of taking < 5,000 steps/day

The descriptive epidemiology of various steps/day cut-points has been previously compiled (Tudor-Locke et al. 2011h), but is re-assembled, updated, and extended here to focus on 25 studies that included a specific report of the proportion of the study sample taking < 5,000 steps/day (Table 1). Only one (with the largest most inclusive sample reported) of the related Cook and colleagues' papers (Cook et al. 2010a; Cook et al. 2011; Cook et al. 2010b) of rural Black South Africans taking < 5,000 steps/day is presented in the table. Proportions classified by this step-defined sedentary lifestyle index ranged from 2% in a small sample of male university students in the U.S. (Mestek et al. 2008) and < 5% in a male South African sample (Cook et al. 2010b) and also in a Czech Republic sample (Sigmundova et al. 2011) to 56% in a U.S. sample of multi-ethnic low-income housing residents 18 to 70+ years of age (Bennett et al. 2006)), 71% in a small sample of African American Medicaid recipients aged 31-63 years (Panton et al. 2007), and 76% in overweight/obese individuals recruited to a physical activity intervention to promote weight maintenance following a behavioural and weight loss program (Villanova et al. 2006). Since at least eight analyses of the 2005-2006 National Health and Nutrition Examination Survey (NHANES) accelerometer step data (adjusted to come more in line with a pedometer scaling) have also focused on < 5,000 steps/day as at least one studied step-based cut-point (Sisson et al. 2012; Sisson et al. 2010; Tudor-Locke et al. 2009a; Tudor-Locke et al. 2011a; Tudor-Locke et al. 2011b; Tudor-Locke et al. 2010b; Tudor-Locke et al. 2011d; Yang et al. 2011), the table only includes the study with the most inclusive (i.e., largest) sample from the original data source that also specifically reported the weighted proportion classified as taking < 5,000 steps/day (Sisson et al. 2012). Accordingly, this nationally representative adult sample indicated that 36.1 % of U.S. adults took <5,000 steps/day. In a separate analysis of these

NHANES data, it appears that approximately 17% of the U.S. population takes < 2,500 steps/day (considered indicative of "basal activity") (Tudor-Locke et al. 2009a).

Not included in this table are two studies that reported number of days < 5,000 steps/day in monitored samples. Analyses performed on 8,197 person-days of data collected over a year-long study of 23 participants from two southern U.S. universities (Tudor-Locke et al. 2004d). indicated that 15.9% of all person-days were < 5,000 steps/day while the sample mean was 10,082 ± 3,319 steps/day. Only a single individual's values from this small and ostensibly healthy sample averaged < 5,000 steps/day over the course of the year. Finally, Barreira et al. (in press-b) collected 93 person-days of pedometer-determined data from 23 overweight/obese individuals. The sample average was 8,025 ± 3,967 steps/day and 25% of all person-days were <5,000 steps/day.

Characteristics of people taking < 5,000 steps/day

Sisson et al. (2012) reported that U.S. adults taking < 5,000 steps/day were more likely to have a relatively lower household income and be female, older, African American versus European American ethnicity, and a current versus never smoker. Hornbuckle et al. (2005) also reported significant age differences between those taking < 5,000 steps/day (relatively older) and those taking ≥ 7,500 steps/day (relatively younger). The lowest reported mean pedometer-determined physical activity reported in a review of expected values for older adults was 2,015 steps/day in a sample of 85+ year olds (Croteau and Richeson 2005). More recently, a value of 12,727 ± 9387 steps/week (translating to 1,818 steps/day) was reported for a sample of older African American women (73.3 ± 9.6 years) engaged in a faith-based intervention (Duru et al. 2010). A review of cross-sectional studies of individuals living with heart and vascular diseases, chronic obstructive pulmonary disease (COPD), dialysis, arthritis, joint replacement, fibromyalgia, and physical disability indicate that all average < 5,000 steps/day (Tudor-Locke et al. 2009b). Recent additions to this body of research indicate that patients with COPD average 3,826 (DePew et al. in press) to 5,680 steps/day (Moy et al. in press), those with diabetes (without mobility limitations) average 6,429 steps/day (van Sloten et al. 2011), and those undergoing total joint arthroplasty average 6,721 steps/day (Naal and Impellizzeri 2010). Even in these samples showing average values somewhat greater than 5,000 steps/day, lower values were associated with compromised health-related outcomes (Moy et al. in press; van Sloten et al. 2011).

In a recent review of pedometer-based physical activity interventions for older adults (age 65+) (Tudor-Locke et al. 2011g), 10/12 studies identified reported baseline values < 5,000 steps/day, and only 3 of those studies with samples averaging < 5,000 steps/day at baseline were able to elicit a level of increase that put the average over 5,000 steps/day post-intervention. Pedometer-based intervention studies conducted with special populations were included in the same review (Tudor-Locke et al. 2011g). Baseline values were < 5,000 steps/day for 2/9 cancer/cancer survivor studies identified, 1/3 COPD studies, 0/2 coronary heart disease and related disorder studies, 4/15 diabetes and related disorder studies, and 3/3 joint and muscle disorder studies. It appears that not all of these interventions were focused on recruiting physically inactive individuals, at least as defined by taking < 5,000 steps/day at baseline.

Finally, morbidly obese individuals have been shown to take, on average, < 5,000 steps/day (Damschroder et al. 2010; Duru et al. 2010; Maraki et al. 2011). For instance, Vanhecke et al. (2008) reported that 10 morbidly obese (BMI = 53.6 ±11.7) individuals averaged 3,763 ± 2,223 steps/day.

Contextual factors related to < 5,000 steps/day

Contextual factors that shape sedentary behaviour and physical inactivity include social, natural, or built environments, and organizational or situational factors (Spence and Lee 2003). The built environment is associated with sedentary behaviour in both children (Timperio et al. 2012) and adults (Kozo et al. in press; Sugiyama et al. 2007). Lower steps/day are also associated with inaccessible and/or a lack of destinations in children (McCormack et al. 2011a), adults (Kondo et al. 2009) and older adults (King et al. 2003). A negative perception of neighbourhood environment is associated with lower steps/day in older adults (Oka and Shibata 2012). Further, mode of transport influences steps/day: Wener and Evans (2007) reported that car commuters took 30% fewer steps/day than those who commuted by train. Van Dyck et al. (2009) showed that residents of low walkable neighbourhoods took fewer steps/day and also walked less frequently for transportation in their neighbourhood. As well, Bennett et al. (2007) reported that steps/day were positively associated with perceived night-time safety; thus, those with the greatest safety concerns also took the lowest steps/day. Despite these accumulating reports, few studies have directly examined the effects of these contextual factors on taking < 5,000 steps/day. Perhaps most illuminating, however, is a study examining differences in pedometer-determined physical activity of a submarine crew when free-living and stationed on land vs. deployed to sea and engaged in structured tasks conducted in a confined and crowded space; 109 crew members from two submarines averaged approximately 7,000 steps/day while stationed on land and this was reduced to approximately 2,000 steps/day when deployed (Choi et al. 2010).

The weather (e.g., ambient temperature, rainfall) is another contextual factor related to pedometer-determined physical activity (Chan et al. 2006; Duncan et al. 2008). Specifically, Dasgupta et al. (2010) demonstrated that average step-defined physical activity dips to < 5,000 steps/day in fall/winter in individuals with Type 2 diabetes living in Montreal, Canada. Similarly, daily steps in a sample of older adults (aged 75-83 years) decreased below 5,000 steps/day during the winter months of December and January in Japan (Yasunaga et al. 2008). In another study, male office workers in rural Japan walked fewer steps/day in the winter compared with the summer, and this dropped below 5,000 steps/day on non-working days (Mitsui et al. 2010).

Health risks associated with taking < 5,000 steps/day

As indicated previously, Tudor-Locke and colleagues (2001) first reported that U.S. individuals taking less than approximately 5,000 steps/day (representing the 25th percentile for distribution of steps/day in that particular sample) had a significantly higher BMI than those categorized into two higher step-defined physical activity categories (between 25th and 75th percentiles and above 75th percentile). Cook et al. (2008) also reported the increased risk of BMI-defined obesity for South African individuals taking < 5,000 steps/day compared to all other levels of step-defined physical activity. Higher BMIs in those taking < 5,000 steps/day have also been reported by Mitsui et al. (2008) studying a Japanese sample, Wyatt et al. (2005) in a Colorado-based sample, Hornbuckle et al. (2005) in African American women, and Krumm et al. (2006) in a post-menopausal sample. Similarly, the odds of experiencing excessive gestational weight gain were higher in pregnant Chinese women taking < 5,000 steps/day (defined as "sedentary") than active women (> 10,000 steps/day) in the 2nd trimester and "somewhat active" women (7,500-10,000 steps/day) in the 3rd trimester (Jiang et al. 2012). Similar findings have been reported for percent body fat (Hornbuckle et al. 2005; Tudor-Locke et al. 2001) and waist circumference (Dwyer et al. 2007; Hornbuckle et al. 2005).

Schmidt et al. (2009) reported that, with the exception of younger men, individuals taking < 5,000 steps/day had a substantially higher prevalence of cardiometabolic risk factors (including metabolic syndrome and 3+ elevated risk factors such as waist circumference, systolic blood pressure, and fasting glucose, triglyceride, and HDL cholesterol values) than those taking higher steps/day. Sisson et al. (2010) also showed that each higher category of step-defined physical activity showed lower odds of having metabolic syndrome compared to the category defined by taking < 5,000 steps/day. For example, the odds were 40% lower for individuals taking 5,000-9,999 steps/day and 72% lower for those taking ≥ 10,000 steps/day compared to those taking < 5,000 steps/day. Recently, Jennersjo et al. (in press) reported that individuals with Type 2 diabetes who took < 5,000 steps/day had higher BMI, waist circumference, C-reactive protein, interleukin-6, and pulse wave velocity than those who took ≥ 10,000 steps/day.

Finally, McKercher et al. (2009) reported a 50% higher prevalence of depression associated with taking < 5,000 steps/day compared to taking ≥ 7,500 steps/day in women, and taking ≥ 12,500 steps/day in men.

Effects of increasing from < 5,000 steps/day to > 5,000 steps/day

Interventions designed to move people from taking < 5,000 steps/day to relatively higher values have demonstrated positive health outcomes. Swartz et al. (2003) reported improved glucose tolerance with an 8 week pedometer-based walking program in 18 postmenopausal women who averaged 4,491 ± 2,269 steps/day at baseline and ended up averaging 9,213 ± 362 steps/day. Participants in a 12-week worksite pedometer program who increased their daily steps from 4,244 ± 899 to 9,889 ± 1609 experienced significant decreases in body weight, BMI, and resting heart rate relative to a no-change comparison group (Musto et al. 2010). A non-significant increase from 4,471 ± 2,315 steps/day to 5,257 ± 2,355 steps/day among 14 obese middle-aged veterans was associated with a significant weight loss (-3.8 ± 3.6 kg) in a lifestyle coaching intervention that included nutritional goals, so the relative contribution of the change in steps/day to the weight change is unknown (Damschroder et al. 2010). Villanova et al. (2006) reported that 76% of 200 overweight/obese participants in a 9-month behaviour program took < 5,000 steps/day at baseline and only 16% were below this value at the end of the program; the probability of increased amount of weight loss was enhanced with increased steps/day. As far as we are aware, no other interventions have expressly recruited participants who take < 5,000 steps/day at baseline and studied the effects of attaining at least this cut-point or beyond.

Bell and colleagues (2010) compared the effectiveness of a walking program with a fitness training group and control group among "sedentary" (< 5,500 steps/day) individuals ranging in age from 20 to 65 years. At the end of a 6-month period, the walking group had achieved 9,221 ± 1,429 steps/day with the ultimate goal of averaging 10,000 steps/day. Though changes were observed in several health-related variables for all groups (even the control group) at the end of the intervention, the authors concluded the greatest reductions in body mass, waist circumference, and waist-to-hip ratio occurred in the two activity groups.

Finally, achieving a steps/day value > 5,000 steps/day may not be completely necessary to reap at least some health benefits in those who take < 2,500 steps/day (considered indicative of "basal activity"(Tudor-Locke et al. 2009a)). Duru et al. (2010) studied obese African American women who increased their physical activity by 1,411 steps/day from a baseline value of 1,818 steps/day as a result of a multicomponent faith-based intervention (a pedometer was used for measurement and as part of weekly pedometer competitions during the intervention, but pedometer readings were never revealed to participants). This modest improvement over seemingly very low initial baseline values was associated with a significant decrease in systolic blood pressure but no changes in body weight or diastolic blood pressure compared to a control group.

Effects of reducing to < 5,000 steps/day

Thyfault and Krogh-Madsen (2011) reviewed a number of recent studies that examined the health effects of recruiting relatively healthy and active subjects and temporarily transitioning them to very low values of steps/day. These and a few recent additions are described briefly here.

Seminal animal studies from Dr. Frank Booth's laboratory showed that transitioning rodents from naturally high daily activity (access to running wheels) to low activity (locking running wheels) induced fast and dramatic changes in body composition, insulin sensitivity, and tissue metabolism, suggesting that the conversion to inactivity brought about by an abrupt removal of opportunity for activity triggers potentially harmful metabolic changes in a short period of time (Kump and Booth 2005a; Kump and Booth 2005b; Kump et al. 2006; Laye et al. 2007). These rodent studies prompted another group led by Dr. Bente Pedersen to determine if transitioning young, active, but non-exercising men to a lower daily ambulatory activity would result in similar results. In the first study, Olsen et al. (2008) examined metabolic responses in 8 young men whose step-defined physical activity was reduced from a mean value of 6,203 steps/day to 1,394 steps/day for 22 days. Plasma insulin area under the curve (AUC), assessed by oral glucose tolerance test, increased significantly from 757 pmol/L/3h to 1,352 pmol/L/3h after 3 weeks of reduced step activity. Olsen et al. (2008) also reported a second study conducted with 10 healthy young men transitioned from a mean activity level of 10,501±808 steps/day to

1,344±33 steps/day for two weeks. Plasma insulin AUC increased significantly from 599 pmol/L/3h to 942 pmol/L/3h. In addition, plasma C-peptide AUC increased significantly from 4,310 pmol/L/3h to 5,795 pmol/L/3h. These results suggested that it took a greater insulin response to dispose of blood glucose during postprandial conditions, due to reduced insulin sensitivity in skeletal muscle. The 2-week intervention was also associated with a 7% increase in intra-abdominal fat mass with no change in total fat mass, and a decrease in both total fat-free mass and BMI. Krogh-Madsen et al. (2010) analysed additional data collected from this same sample of 10 men and confirmed that there was indeed reduced insulin sensitivity in skeletal muscle (17% reduction in glucose infusion rate during a hyperinsulinemic-euglycemic clamp) and reduced activation of insulin signalling in biopsied skeletal muscle samples. Moreover, they reported a 7% decline in VO_2 max, and a 0.5 kg decrease in leg lean mass following a 2-week decrease of about 9,000-10,000 steps/day. Although the decrease to < 1,500 steps/day is much lower than 5,000 steps/day, this study shows that reducing daily ambulatory activity to such very low levels causes dramatic changes in health indices known to powerfully influence risk for morbidity and mortality.

The same research group has performed follow-up studies to determine if reducing daily steps from >10,000 to <1,500 combined with a higher calorie diet (+50% kcal) would induce greater changes in insulin sensitivity and body composition (Knudsen et al. in press). They also performed OGTTs and measured body fat, visceral adiposity, and body mass at baseline and 3, 7 and 14 days after the transition to reduced steps/day to determine if a change in insulin sensitivity occurred before or after significant changes in adiposity and body weight. Insulin sensitivity, derived from an index of the glucose and insulin responses to the OGTT, was significantly reduced by 37% after only 3 days of inactivity, and occurred prior to significant increases in body mass and adiposity (both whole body and visceral) that trended up at days 3 and 7 but were not significantly greater than baseline until day 14, at which time visceral adiposity had increased by 49% above baseline. Importantly, this study confirmed earlier findings that an acute transition to very low daily steps induces significant changes in insulin sensitivity and adiposity. Another interesting outcome of this study was that measures were again collected 16 days after the two weeks of inactivity to determine if a return to the subject's normal daily step count returned measured variables to baseline levels. Interestingly, despite insulin sensitivity returning to normal, both body mass and body fat were still elevated (visceral adiposity was not assessed) suggesting that acute periods of inactivity may lead to an incremental increase in adiposity and body mass over time.

Reduced skeletal muscle insulin sensitivity plays a fundamental role in impaired postprandial glycemic control. An increased postprandial glucose response is both a risk factor for the development of Type 2 diabetes and an independent risk factor for cardiovascular disease in people with and without Type 2 diabetes. A study conducted by Mikus et al. (2012) transitioned healthy, active individuals who were obtaining >10,000 steps/day to <5,000 steps/day for only 3 days to determine if this abrupt and temporary change in daily physical activity would modify postprandial and overall glycemic control as measured by continuous glucose monitors, devices that measure blood glucose minute-by-minute during free-living conditions. The study found that only 3 days of reduced activity led to significant increases in average glucose excursions following meals. Moreover, daily measures of glucose control including maximal and minimal glucose levels, and the duration of time above a high threshold of euglycemia were also significantly altered. In summary, these findings suggest that taking even temporary transitions to < 5,000 steps/day dramatically alters glycemic control and may play a fundamental role in the increased risk for diabetes and other metabolic diseases witnessed in people who chronically take < 5,000 steps/day.

Another research group has recently examined the combined effects of inactivity and overeating on body composition and mental health. Ernersson et al. (2010a; 2010b; 2010c) reported that young healthy individuals who adopted obesity-provoking behaviours for 4 weeks that included doubled energy intake (primarily from fast food) and taking < 5,000 steps/day increased their body weight (Ernersson et al. 2010a; Ernersson et al. 2010c), increased both fat free mass and fat mass (Ernersson et al. 2010a), decreased their health-related quality of life (Ernersson et al. 2010c), and reported developing a lack of energy (related to emotional life, relations and life habits) (Ernersson et al. 2010b). One year after this brief intervention, the body weight increase remained higher relative to a control group (Ernersson et al. 2010a). In addition, fat free mass was unchanged relative to baseline, but the increase in fat mass remained (Ernersson et al. 2010a). This study again suggests that acute periods of inactivity and dietary excess may lead to an incremental increase in body mass that is then sustained over time. The relative contribution of the decreases in step-defined physical activity compared to the energy intake hyper-alimentation was not determined.

Alternative definitions

Thompson et al. (2004) defined "inactive" as < 6,000 steps/day in a study of middle-aged American women. Others have used this cut-point too (Graff et al. 2012; Lara et al. 2010) with Lara and colleagues (2010) labelling it as "sedentary." Tudor-Locke et al. (2008a) defined < 7,500 steps/day as "inactive" in an Australian sample with a relatively high mean steps/day. This same steps/day cut-point has been labelled "sedentary" (Barbat-Artigas et al. 2012) and also "sedentary to low active" (Inoue et al. 2011b). In an intervention study conducted in a Canadian sample with Type 2 diabetes, Tudor-Locke et al. (2004b) defined "insufficiently active" as < 8,800 steps/day for recruitment purposes based on a previous cross-sectional study of individuals with Type 2 diabetes where this level approximated the 75^{th} percentile of distribution (Tudor-Locke et al. 2002). Oka et al. (2012) defined "insufficiently active" as < 6,700 steps/day (men) and < 5,900 steps/day (women) based on not attaining a Japanese national physical activity objective applied specifically to older adults ≥ 70 years of age. Finally, a number of other Japanese researchers have defined "sedentary" as < 4,000 steps/day (Inoue et al. 2011a; Ishikawa-Takata et al. 2010; Park et al. 2007). Differences in exact steps/day values used and associated terminology reflect earlier thinking and/or a need to accommodate study specific and unique sample distribution parameters. The variation in terminology between original research studies and review articles relating to what relatively low daily step values mean lends support as to why the present review is so important.

There are weaknesses to using < 5,000 steps/day as a step-defined sedentary lifestyle index. First and foremost, the evidence supporting it use has largely been derived as a result of a "self-fulfilling prophecy." For example, the demographic results reported by Sisson et al. (2012) would not likely have changed if alternative cut-points of 4,000 or 6,000 steps/day had been considered. Further, the detrimental effects of taking even fewer steps/day (e.g., < 1,500 steps/day) are emerging (Knudsen et al. in press; Krogh-Madsen et al. 2010; Olsen et al. 2008). Since < 5,000 steps/day has been the most common candidate for a step-defined sedentary lifestyle index presented to date, however, it gets reinforced simply by repetition. Widespread use and repetition are not evidence of veracity. Alternative thresholds might be more valid, but have not been used extensively, and are therefore lacking confirmation. A creative analysis would attempt to identify a specific steps/day value associated with select disease conditions or specific health parameters. This is a challenging pursuit however, since, hypothetically, relatively (and incrementally) lower values will always be associated with increasingly negative results and relatively (and incrementally) higher values will be associated with increasingly positive results. Moreover, related changes in some health parameters may mediate or modify changes in other health parameters (i.e., waist circumference and insulin sensitivity or blood lipids). Where the line is drawn becomes somewhat subjective against this indistinct background; there are likely to be samples with even lower steps/day values than any identified cut-point. On the other hand, the usefulness of any index is compromised if it is too low; if it is so low that few people are affected by it, then its public health relevance is limited. For example, U.S. data suggest that approximately only 17% of the population take < 2,500 steps/day (Tudor-Locke et al. 2009a), and we could only assume this percentage would be much lower in other, more active populations. Ultimately, validation with longitudinal data with various health outcome measures is warranted. While it may continue to be debated, and despite its simplistic origins, the consistent use of a standardized definition of a sedentary lifestyle index as < 5,000 steps/day would facilitate comparisons between studies and population groups.

Relevance for children/adolescents

NHANES accelerometer data indicate that, during the monitored day, U.S. children and adolescents (6-19 years of age) spend on average approximately 4 hours at zero steps/min (non-movement), 8.9 hours/day between 1-59 steps/min, 22 min/day at 60-79 steps/min, 13 min/day at 80-99 steps/min, 9 min/day at 100-119 steps/min, and 3 min/day at cadences ≥ 120 steps/min (Barreira et al. in press-a). However, unlike the growing evidence to support an adult step-defined sedentary lifestyle index, there are relatively few pertinent studies to inform a similar index for children and/or adolescents. Though the step-based pediatric literature is quite consistent with regard to:1) boys accruing more steps/day than girls (Craig et al. 2010; Tudor-Locke et al. 2009c), 2) steps/day declining from childhood to adolescence (Beets et al. 2010a; Craig et al. 2010), and 3) the inverse relationship between steps/day and body composition (Duncan et al. 2010; McCormack et al. 2011b; Tudor-Locke et al. 2011c; Tudor-Locke et al. 2004c), and between steps/day and aerobic fitness (Le Masurier and Corbin 2006; Lubans et al. 2008) in children and adolescents, the majority of the general pediatric physical activity literature is concerned with assessment of compliance with intensity-based guidelines or meeting specific physical activity targets other than any number of steps/day. However, the focus on "how many steps/day are enough?" in children/adolescents (Tudor-Locke et al. 2011f) has recently driven the pursuit of a steps/day translation of accumulating at least 60 minutes of daily MVPA, an accepted time-and-intensity based public health recommendation (Janssen and Leblanc 2010).

Using accelerometer data from the Canadian Health Measures Survey, Colley et al. (2012) recently proposed that 12,000 steps/day be used as this target for children and adolescents. Since the Sedentary Behaviour Research Network (2012) has recommended that journal editors and reviewers require that "authors use the term "inactive" to describe those who are performing insufficient amounts of MVPA (i.e. not meeting specified physical activity guidelines)", the implication of the research conducted by Colley et al. (2012) is that children and adolescents who take < 12,000 steps/day are physically inactive. This is only a single example, and whether or not it was these authors' intent, we believe it more prudent to move beyond a simple dichotomous classification of active vs. inactive. We suggest instead that there is a lower value (similar to that presented in Figure 1 but more relevant to a child/adolescent population), perhaps based on a low-level percentile of distribution, or tied to a deleterious health parameter, or a combination of these, that would be more useful for identifying those who are most likely to be putting their health at risk as a result of their behaviour.

Emerging research on the population distribution of steps/day among children and adolescents could inform a percentile-based definition of the index. Without question, the largest population study is the ongoing nationally representative Canadian Physical Activity Levels among Children and Youth study (CANPLAY) (Craig et al. in press; Craig et al. 2010), which has been collecting pedometer data on about 6,000 children annually since 2005-2006. Based on the criterion of a steps/day cut-point at the lowest 15th percentile of the distribution (equivalent to a mean values minus one standard deviation) derived from 17,314 boys and 16,913 girls (Craig et al. in press), "taking too few steps" may be defined as taking < 8,448 steps/day among boys 5-13 years, < 6,336 steps/day among boys 14-19 years, < 7,761 steps/day among girls 5-13 years, and < 5,867 steps/day among girls 14-19 years. Applying this distribution-based criterion to published data from a smaller national U.S. study (Tudor-Locke et al. 2010a), associated pedometer-equivalent step-based values are < 6,040 and 3,695 steps/day among boys 6-13 and 14-19 years, respectively, and < 4,855 and 2,850 steps/day among girls 6-13 and 14-19 years, respectively. Such distribution-based cut-points derived from population level data reflect current physical activity patterns of the specified population, which may also be associated with lower than ideal health measures within that population. For example, we know that physical fitness of children and youth has declined overtime in Canada (Craig et al. 2012) while obesity levels have increased (Janssen et al. 2011; Janssen et al. 2012). A step-defined sedentary lifestyle index derived from normative distributions of other populations engaging in more traditional lifestyles reflective of lower rates of obesity (such as the North American Amish (Bassett Jr et al. 2007)) would provide substantially different values. The above cut-points defined on national population data (both Canada and the U.S.) would identify outliers applied to an Amish population (mean minus *three* standard deviations = 6,385 and 5,450 steps/day for boys 6-12 and 13-18 years respectively and 7,250 and 3,155 steps/day for girls 6-18 years) whereas the mean minus one standard deviation criterion for establishing an Amish step-defined sedentary lifestyle index (<13,410 and 13,770 steps/day for boys 12 and 13-18 years and <11,840 and 9,165 steps/day for girls 6-12 and 13-18 years) exceeds the average daily steps of North American children. The variation among populations illuminates the problem with distribution-based thresholds and underscores the need to define a standardized index based on health-related outcomes.

An early suggestion (Tudor-Locke et al. 2008b) that values of < 10,000 and < 7,000 steps/day could be used to identify sedentary lifestyle for school-aged boys and girls (6-12 years) respectively, was loosely based on BMI-referenced anchors (Tudor-Locke et al. 2004c) and modeled after a proposed adult graduated step index (Tudor-Locke and Bassett 2004). This is consistent with a more recent finding from CANPLAY where the odds of obesity decreased for every 3,000 step increase in steps/day so that boys (5-13 years) taking roughly 10,000 steps/day and girls taking about 8,000 steps/day were 19% more likely to be obese than the average boy (mean = 12,813 steps/day for 5-9 year olds and 12,845 steps/day for 10-13 year olds) and girl (mean = 11738 steps/day for 5-9 year olds and 11,265 for 10-13 year olds), controlling for television viewing time (Tudor-Locke et al. 2011c).

Applying these sex-specific cut-points (i.e., < 10,000 and < 7,000 for boys and girls respectively) to 2,610 children's and adolescents' data collected as part of NHANES accelerometer monitoring, Tudor-Locke et al. (2010a) reported that as many as 42% of U.S. boys and almost 21% of girls may be considered "sedentary" when the accelerometer data were adjusted to come more in line with expected step values from pedometry. The appropriateness of a sex-specific definition may be debated. When both boys and girls were evaluated relative to a standard cut–point of 7,000 steps/day in the Canadian CANPLAY pedometer surveillance data of 19,789 children and adolescents, Craig et al. (2010) reported that approximately 25% of boys and 33% of girls were considered "low active" and 6% of both boys and girls took < 5,000 steps/day and were considered "sedentary." Although not specifically looking to examine the usefulness of these potential markers of a physically inactive lifestyle, Kambas et al. (2012) did demonstrate that preschool-aged children who accumulated approximately < 7,000 steps/day (discerned from a figure) were also categorized within the lowest quartile of motor proficiency. Although <7,000 steps/day has been more frequently repeated in the pediatric literature at this time as a potential low end candidate, unlike the adult data, the paucity of the additional evidence on this topic does not allow us to conclusively identify a minimum value of steps/day to inform a clear evidence-based child/adolescent-specific step-defined sedentary lifestyle index at this time. We anticipate that this will improve as this gap is recognized and the research process inevitably unfolds.

Limitations

There are a number of limitations to this approach of using a step-based definition as a sedentary lifestyle index that must be acknowledged. First, a variety of step-counting devices are available for use among researchers, practitioners, and the general public. Each one of these user groups has different but overlapping needs and it would be best if any unit of measurement could be simply translated at all levels. However, it has become increasingly apparent that there are differences in how these various objective monitors detect and present a "step" (Crouter et al. 2003; Feito et al. 2012; Le Masurier and Tudor-Locke 2003; Le Masurier et al. 2004). This is not limited just to step counting; estimates of time spent in sedentary behaviours and at any intensity of physical activity are also variable between different types of instrumentation that attempt to capture such data (Tudor-Locke 2010). Perhaps even more concerning, there is evidence that different generations of instrumentation are inconsistently sensitive (Rothney et al. 2008). As with all measures, a trade-off exists between sensitivity and specificity; increasing sensitivity to capture very low force movements in an attempt to be maximally inclusive leads to increased capture of "erroneous steps" (Le Masurier and Tudor-Locke 2003) and vice versa.

To be clear, the original graduated step index was presented in an article that specifically stated in the title: "Preliminary *pedometer* indices for public health" (Tudor-Locke and Bassett 2004). That article included the proposed values for (what was known at the time as) a "sedentary lifestyle index," which itself was originally formulated based on *pedometer* measures (Tudor-Locke et al. 2001). Most of the research (23 out of 25 studies) presented in Table 1 has been collected with *pedometers*. Further, 1 of the 2 remaining studies represented in the table that used accelerometers to collect the step data actually adjusted the output to be more translatable in terms of what might be expected using *pedometry* before applying the pedometer-based index to the data (Sisson et al. 2012). Since pedometers are less expensive, and therefore more accessible and feasible for use in practical applications, including widespread adoption by the general public, it is reasonable to provide index values to guide their use at this level. Physical activity recommendations expressed in terms of steps/day produced by various governmental and health organizations around the world (Tudor-Locke et al. 2011h) are ultimately intended for public consumption, and therefore have been logically designed for users of such low-cost and accessible technologies. Producing cut-points and other indices that are only to be used by other researchers with access to enhanced technological precision may be necessary to address specific research questions, but may ultimately have little application to the real-world condition outside of the laboratory.

Although many accelerometers have evolved to include step-based outputs in addition to their more traditional activity count outputs, we acknowledge that these similarly named outputs are not likely to be on the exact same scale as that captured by lower technology pedometers. Therefore, researchers should cautiously compare and interpret any steps/day value or apply any index to data collected using different types of instrumentation. This specifically means it may be just as debatable to cast an accelerometer-generated steps/day estimate as an un-adjusted index for pedometer users, as it is to interpret accelerometer-determined steps/day using an index originally intended to interpret pedometer data. For example, one of the studies listed in Table 1 used an ankle-worn StepWatch Activity Monitor to monitor steps/day in an older adult sample (mean age approximately 80 years) (Cavanaugh et al. 2010). This instrument is known to be highly sensitive to low force accelerations and detects 11-15% more daily steps in free-living than commonly used pedometers (Karabulut et al. 2005). Perhaps unaware of the implications of this difference in instrument sensitivity, Cavanaugh et al. (2010) applied the pedometer-based graduated step index (Tudor-Locke and Bassett 2004) to interpret their data without any form of adjustment. As a result, they concluded that only 26% of this aged sample took < 5,000 steps/day, and at least 29% were "highly active," that is, accumulating over 10,000 steps/day. Directly (and inappropriately) compared to U.S. national estimates (where average values were closer to 6,500 steps/day and comparable categories were 36% and 16%, respectively) collected with an accelerometer but adjusted to be more in line with a pedometer-based scale (Sisson et al. 2012), this smaller sample could be described as uniquely active for their age. However, it is more likely that differences in instrumentation explain the remarkable finding.

It is worth repeating that step counting devices are now widely available in a number of different commercially available formats including those worn at the waist, on the arm, at the wrist, on the ankle, in a pocket, as a piece of jewelry, as an ear piece, in cell phones, etc. Their measurement mechanisms are patent-protected, they change and become obsolete, and it has become clear that similarly named outputs do not necessarily capture the same behaviour between instruments (Tudor-Locke 2010). Industry standards have helped to make ambulatory monitoring more uniform in Japan (Crouter et al. 2003), however this is not the case elsewhere. Although it is lamentable, it may be that instrument-specific index values will be necessary. This is already known to be the case for application of accelerometer activity count cut-points. Methods of adjustment are sorely needed to aid translation and comparison between instruments. Despite these inconvenient truths, we must be careful not to "throw the baby out with the bathwater." Still, any value offered as a generic step-defined sedentary lifestyle index must be treated as a "heuristic" (i.e., guiding) value that must also be thoughtfully applied and communicated, keeping in mind the end user.

Another limitation also related to instrumentation and measurement is the concern for optimal amounts of wearing time. Instruments with time-stamping technology (typically accelerometer-type devices) provide researchers with additional information that can be processed and used to determine wear time and limit data queries to the best quality data using user-defined criteria. However, a number of researchers (Choi et al. 2011; Masse et al. 2005; Tudor-Locke et al. 2011b) have shown that it is the estimate of time spent in sedentary behaviour that is most affected by premature removal of accelerometers; the impact on detected movement, for example, steps/day is less profound (Schmidt et al. 2007; Tudor-Locke et al. 2011b). Nevertheless, researchers remain very cognizant of this potential threat to validity and addressing it is often a foremost consideration. From the practitioner's point of view, however, and especially from that of the general public, the potential impact of wear time on an estimate of steps/day is not likely to be as much of a concern; Schmidt et al. (2007) have demonstrated that adjustments for wear time did not alter correlations between pedometer steps/day and cardiovascular risk factors. Further, a wealth of health-related step data has been accumulated to date primarily using pedometers that have not had time-stamping technology, and the consistency and robustness of the findings have been clear (Tudor-Locke et al. 2011f; Tudor-Locke et al. 2011g; Tudor-Locke et al. 2011h). Perhaps most compelling, meta-analyses (Bravata et al. 2007; Kang et al. 2009; Richardson et al. 2008) of pedometer-based behaviour interventions demonstrate consistent statistically and clinically significant changes (i.e., approximately 2,000 to 2,500 steps/day) in ambulatory activity and related improvement in health outcomes using this simple technology, without any consideration of wearing time.

Finally, and as mentioned earlier, not all human movement is represented by a measure of daily steps taken. Step-counting devices do not characterize non-ambulatory activities (e.g., weight training, bicycling, swimming, skateboarding, roller blading, hockey, kite surfing) well (Miller et al. 2006). However, it is clear that ambulatory behaviours, and specifically walking, are fundamental to basic human mobility across all domains of daily life, including exercise, recreation, work, chores, shopping, social interactions, and cultural exchanges (Ainsworth et al. 2011; Tudor-Locke and Ham 2008). Further, although steps/day explains 61-67% of the variability in MVPA (Tudor-Locke et al. 2011a), and taking 5,000 steps/day is associated with approximately 10 minutes (not necessarily consecutive) of MVPA (Tudor-Locke et al. 2011a), a measure of total steps taken in a day is not a direct indication of physical activity intensity, a dominant precept of public health guidelines (Physical Activity Guidelines Advisory Committee

2008; Tremblay et al. 2011b). Nonetheless, step-counting devices, especially those accessible to the general public, are important health behaviour tools (Tudor-Locke and Lutes 2009). Their utility is limited, however, without provision of evidence-based, applicable, and reasonable index values to help guide and interpret their output.

Conclusions

A growing number of studies have used the < 5,000 steps/day cut-point to categorize individuals as “sedentary”(McKercher et al. 2009; Schmidt et al. 2009) or “inactive”(Cavanaugh et al. 2010; Hirvensalo et al. 2011) since it was first proposed (Tudor-Locke et al. 2001) and subsequently included in a more fully expanded graduated step index (Tudor-Locke and Bassett 2004; Tudor-Locke et al. 2008b). The profile of individuals more likely to be taking < 5,000 steps/day includes having a relatively lower household income and being female, older, African American versus European American ethnicity, a current versus never smoker and/or living with chronic disease and/or disability (including morbid obesity). Although the fall/winter season in the Northern hemisphere appears to discourage taking > 5,000 steps/day, little else is known about how other contextual factors foster such low levels of step-defined physical activity. Adverse measures of body composition have been consistently associated with taking < 5,000 steps/day in a range of population samples. Indicators of cardiometabolic risk, and specifically metabolic syndrome, have also been associated with taking < 5,000 steps/day. Using < 5,000 steps/day to identify and recruit physically inactive and/or sedentary individuals to interventions focused on increasing physical activity and/or reducing sedentary behaviours seems to be a prudent approach to maximizing potential for effect in a population most at need, but this approach has not yet been systematically adopted. Interventions have typically focused on attaining a singular and lofty goal (e.g., 10,000 steps/day) (Bravata et al. 2007) and not necessarily on shifting individuals who take relatively few steps/day to the next immediately higher categories (e.g., "low active" defined as 5,000-7,500 steps/day or "somewhat active" defined as 7,500-9,999 steps/day (Tudor-Locke and Bassett 2004; Tudor-Locke et al. 2008b)). Short term interventions to reduce step-defined physical activity to values < 5,000 steps/day conducted with small samples of young, healthy, and active individuals have shown dramatic adverse effects on a number of health parameters. Consistent implementation of a standardized steps/day definition for a sedentary lifestyle index would facilitate comparisons between studies and groups; however, unique sample distributions (i.e., generally active, or generally low active) may require tolerance for a degree of flexibility, including segmenting the < 5,000 steps/day category into "basal activity" (<2,500 steps/day) and "limited activity" (2,500- 4,999 steps/day) (Tudor-Locke et al. 2009a). A standardized definition would be useful for screening, recruiting, and tracking purposes as well. Although additional research is needed to further illuminate the appropriateness of using < 5,000 steps/day as a step-defined sedentary lifestyle index, especially its application across different types of objective monitoring technologies, it clearly demonstrates multiform utility for researchers, practitioners, and perhaps most importantly, communicating with the general public at this time. There is currently little evidence to advocate any specific value indicative of a step-defined sedentary lifestyle index in children or adolescents.

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Figure Captions:

Figure 1: Step-Defined Sedentary Lifestyle Index for Adults

Table 1: Studies that have included a specific report of percent of adults taking < 5,000 steps/day

Reference **Country** **Year**	**Sample Description**	**Step Counter*;** **Monitoring Frame**	**Percent taking** **< 5,000** **steps/day**
Tudor-Locke (2004b) USA	76 men, 133 women; 18+ years of age; population-based survey of Sumter County, South Carolina	Yamax SW-200; 7 days	44%
Hornbuckle (2005) USA	69 women; 40-62 years of age; self-identified African American volunteers	67 participants wore New Lifestyles Digi-Walker SW-200, 2 participants wore NL-2000; 7 days	37.7%%
Wyatt (2005) USA	344 men, 386 women; 18+ years of age; Colorado statewide representative sample	Yamax SW-200; 4 days	Men: 32% Women: 33%

Bennett (2006) USA	153 men, 280 women; 18+ years of age; multiethnic low-income housing residents	Yamax SW200; 5 days	56%
Villanova (2006) Italy	36 men, 164 women; 20-66 years of age; overweight/obese participants who had just completed a behavioural weight loss program and were beginning a physical activity intervention	Yamax DIGI Sport Instruments SW-200; 7 days	76% at baseline, 28% pre-intervention, 16% post-intervention
De Cocker (2007) Belgium	598 men, 624 women; 25 to 75 years of age; random sample drawn from public record office	Yamax Digiwalker SW-200 ; 7 days	12.9%
Panton (2007) USA	35 obese African American women; 31-63 years of age; Medicaid recipients	Yamax Digiwalker SW-701; 14 days	71%
Cook (2008) South Africa	121 women; convenience sample of rural, black South Africans; 15-55 years of age	Yamax DigiWalker SW-401; 7 days	13.7%

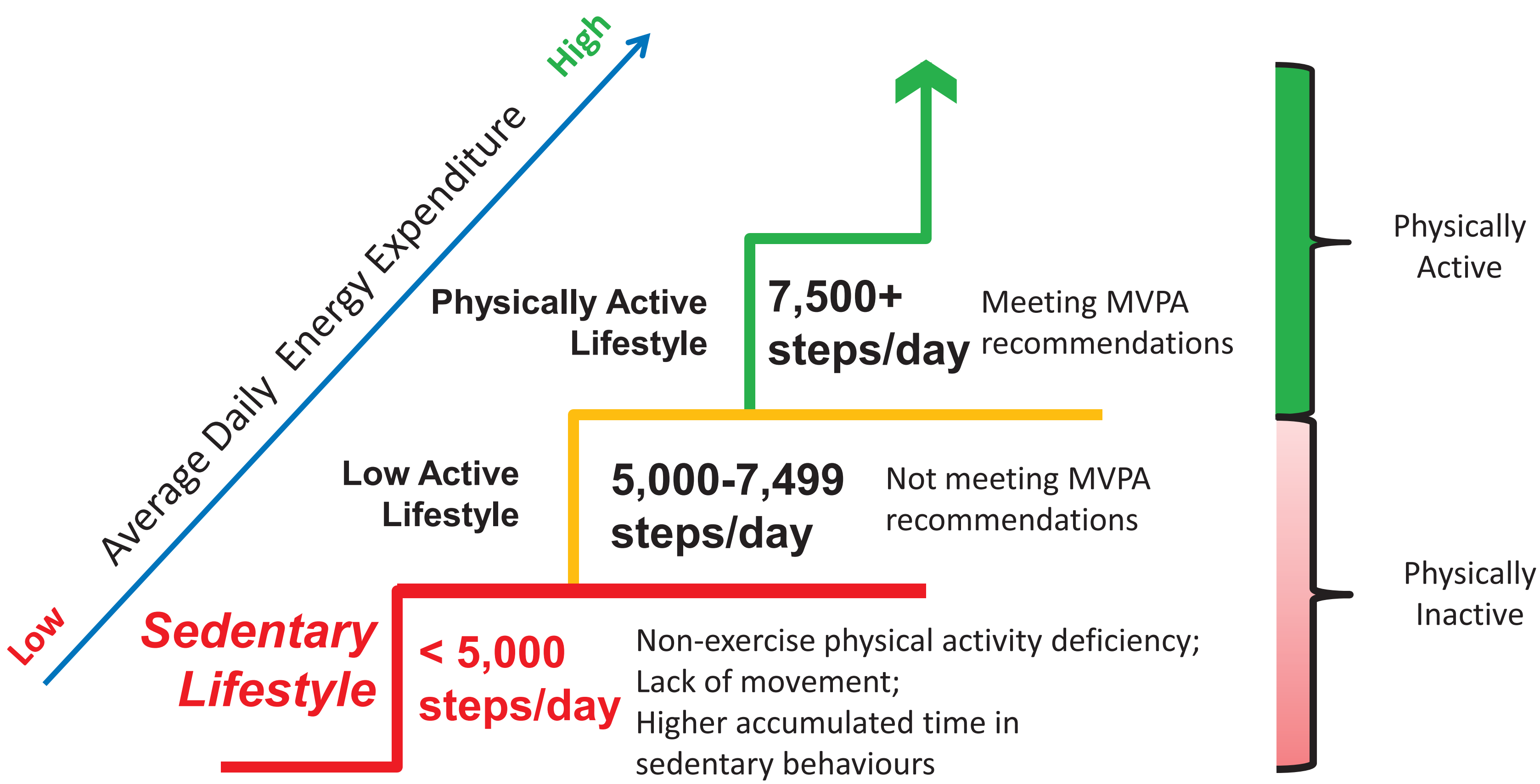
Mestek (2008) USA	44 men, 44 women; 19 to 25 years of age; convenience sample of students from a large, public southeastern university	New Lifestyles Digi-Walker SW-200; 7 days	Men: 2% Women: 7%
Mitsui (2008) Japan	62 men,117 women; 48 to 69 years of age; recruited during medical check-up at public health center	YAMASA EM-180; 7 days	Men: 30.6% Women: 28.2%
Payn (2008) USA	25 men, 60 women; 45-87 years of age; ambulatory community sample without cognitive impairment	Yamax Digi Walker SW-200; 7 days	29.4%
McKercher (2009) Australia	766 men, 869 women; 26 to 36 years of age; participating in a longitudinal study	Yamax Digiwalker SW-200; 7 days	Men: 8.2% Women: 6.7%
Schmidt (2009) Australia	887 men, 906 women; 26 to 36 years of age; participating in the Childhood Determinants of Health study (CDAHS) 489 men, 525 women; 50 to 80 years of age; participating in the Tasmanian Older Adult Cohort study (TOACS)	Yamax SW-200; 7 days (CDAHS) Omron HJ105; 7 days (TOACS)	Men: 7.8% Women: 6.2% (CDAHS) Men: 16.2% Women 14.5% (TOACS)

Cavanaugh (2010) USA	64 men, 93 women; 70+ years of age; Community-dwelling older adults recruited from Veterans Affairs Medical Center & Duke University Medical Centre, NC	StepWatch activity monitor (Ortho-Care Innovations, Mount Lake Terrace, WA); 14 days	Men: 23% Women: 11%
Cohen (2010) Canada	61 pregnant women; 32 ± 5 years of age; recruited from prenatal classes	New Lifestyles Digi-Walker SW-200; 7 days	34%
Cook (2010b) South Africa	267 men, 508 women;13.7-95.7 years of age; convenience sample recruited from rural households in Limpopo province, South Africa	New Lifestyles NL-2000 7 days	Men 3.3% Women: 10.9%
Kemper (2010) USA	24-32 students; approximately 21 years of age; recruited at a small southern rural Historically Black College (HBC)	Yamax Digiwalker SW-200 7 days	8.3% to 11.5% over a 5-week period

Zoellner (2010) USA	5 men, 78 women; 44 ± 13 years of age; African American participants in a community-based intervention in Hollandale, Mississippi	Yamax SW-701 Continuous recording for 6 months	41% at baseline
Hirvensalo (2011) Finland	791 men, 1060 women; 30 to 45 year of age; follow-up cohort from The Cardiovascular Risk in Young Finns study	Omron Walking Style One (HJ-152R-E) 7 days	Men: 26% Women: 16%
Ju (2011) USA	48 men, 48 women; approximately 55 years of age; Korean American couples who own dry cleaners in Chicago	New Lifestyles NL-800 3-6 days	Men: 10.4% Women: 20.8%
Sigmundova (2011) Czech Republic	273 men, 376 women; 18-69 years of age; randomly selected from across 8 regional towns	Yamax Digiwalker SW-700 7 days	4%
Hilgenkamp (2012) The Netherlands	133 men, 124 women; 50+ years of age; population-based sample of older adults with intellectual disabilities	New Lifestyles NL-1000 At least 4 days	38.5%

Jiang (2012) China	862 pregnant women; 20 - 35 years of age; participants in a pregnant women cohort	Omron HJ-005 4 days	2nd trimester: 18% 3rd trimester: 24.9% Last 2 trimesters: 17.3%
Sisson (2012) USA	1781 men, 1963 women; 20+ years of age; nationally representative adult sample of the U.S.	ActiGraph AM-7164; data adjusted to approximate pedometer scaling; 7 days	Men: 27.9% Women: 43.3%
Jennersjo (in press) Sweden	224 men,103 women; 54-66 years of age; with Type 2 diabetes	Yamax SW-200/KeepWalking LS2000 3 days	25.7%

* Inconsistencies in presentation of instrument brand/model details reflect underlying reporting inconsistencies in original articles.


High
Low
Average Daily Energy Expenditure
Physically Active Lifestyle
7,500+ steps/day
Meeting MVPA recommendations
Low Active Lifestyle
5,000-7,499 steps/day
Not meeting MVPA recommendations
Sedentary Lifestyle
< 5,000 steps/day
Non-exercise physical activity deficiency;
Lack of movement;
Higher accumulated time in sedentary behaviours
Physically Active
Physically Inactive

A Step-defined Sedentary Lifestyle Index:

< 5,000 Steps/day

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Abstract

Step counting (using pedometers or accelerometers) is widely accepted by researchers, practitioners, and the general public. Given mounting evidence of the link between low steps/day and time spent in sedentary behaviours, how few steps/day some populations actually perform and the growing interest in the potentially deleterious effects of excessive sedentary behaviours on health, an emerging question is: "how many steps/day are too few?" This review examines the utility, appropriateness, and limitations of using a re-occurring candidate for a step-defined sedentary lifestyle index: < 5,000 steps/day. Adults taking < 5,000 steps/day are more likely to have a lower household income, and be female, older, African American versus European American ethnicity, a current versus never smoker, and/or be living with chronic disease and/or disability. Little is known about how contextual factors (e.g., built environment) foster such low levels of step-defined physical activity. Unfavorable indicators of body composition and cardiometabolic risk have been consistently associated with taking < 5,000 steps/day. The acute transition (3-14 days) of healthy active young people from higher (>10,000) to lower daily step counts (<5,000 or as low as 1,500) induces reduced insulin sensitivity, glycemic control, increased adiposity and other negative changes in health parameters. Although few alternative values have been considered, the continued use of < 5,000 steps/day as a step-defined sedentary lifestyle index for adults is appropriate for researchers, practitioners, and communicating with the general public. There is little evidence to advocate any specific value indicative of a step-defined sedentary lifestyle index in children/adolescents.

Keywords: Physical activity, Physical Inactivity, Exercise, Walking, Ambulation, Sitting, Pedometer, Accelerometer

Introduction

Step counting (using pedometers or accelerometers) is widely accepted by researchers, practitioners, and the general public alike for assessing, tracking, and communicating physical activity doses. For example, researchers recently reported 5-year changes in body mass index (BMI), waist-to-hip-ratio, and insulin sensitivity related to 1,000 step incremental changes in step-defined physical activity (Dwyer et al. 2011); a practice-based journal published a unique collection of articles largely focused on step counting applications in a variety of special populations (Bassett Jr and John 2010; Bradley et al. 2010; Gardner et al. 2010; Jakicic et al. 2010; Lutes and Steinbaugh 2010; Motl and Sandroff 2010; Richardson 2010; Rogers 2010; Shephard and Aoyagi 2010; Temple 2010; Tully and Tudor-Locke 2010); and government/agency/professional organizations from around the world have published different step-based recommendations (Tudor-Locke et al. 2011h). This widespread adoption and practice of step counting provides a unique opportunity for bridging research to clinical practice and ultimately to real-world application since it allows a range of users to communicate using the same metric that captures an objective measure of ambulatory activity accumulated throughout the day. To further facilitate this communication, the purpose of this review is to present the rationale, utility, appropriateness, and limitations of a "step-defined sedentary lifestyle index." The content reflects our collective understanding of the ever increasing scope and nature of the step-based literature; specific articles are cited to support arguments and offer examples.

Why ambulatory activity?

Although there are other types of movements in the human behavioural repertoire, it is logical to focus on assessing and promoting ambulatory activity. Relatively few (or no) steps are accumulated during sedentary behaviours (Tudor-Locke et al. 2009a; Wong et al. 2011) and relatively more steps/min are accumulated during increasingly intense ambulatory activity (Abel et al. 2011; Beets et al. 2010b; Marshall et al. 2009; Rowe et al. 2011; Tudor-Locke et al. 2005), with the highest rates of accumulation occurring during performance of moderate-to-vigorous physical activity (MVPA) (Abel et al. 2011; Beets et al. 2010b; Marshall et al. 2009; Rowe et al. 2011; Tudor-Locke et al. 2005). The relationship between accelerometer-determined activity counts/day and steps/day is strong (r^2=0.87) (Tudor-Locke et al. 2011a). Steps/day explains approximately 62% (women) to 67% (men) of the daily variability in time spent in MVPA (Tudor-Locke et al. 2011a). Further, attaining approximately 7,000-8,000 steps/day is a reasonable approximation of also obtaining at least 30 minutes/day of MVPA (or at least 150 minutes/week) (Tudor-Locke et al. 2011d). Attainment of at least 7,000 steps/day is listed amongst the most recent evidence-based exercise recommendations issued by the American College of Sport Medicine (Garber et al. 2011).

Can steps/day be used to indirectly infer sedentary time?

Low step counts also imply that individuals have spent more time in sedentary behaviour. This approach to inferring time spent in sedentary behaviour from a relative lack of movement is the same concept used in accelerometry; a relatively low accelerometer activity count/min (e.g. < 100) is typically used to define time spent in sedentary behaviours (Matthews et al. 2008). On a daily basis, participants who took < 5,000 steps/day in the accelerometer monitoring component of the 2005-2006 National Health and Nutrition Examination Survey (NHANES) averaged 522 to 577 minutes/day in sedentary behaviours, compared to 348 to 412 minutes/day in those who took ≥ 10,000 steps/day, translating to a 2.75 to 2.9 hours/day difference in sedentary behaviours associated with these different categories of step-defined physical activity (Tudor-Locke et al. 2011a). Twenty-five percent of the variability in time (i.e., minutes) spent in daily sedentary behaviours as collected in these NHANES data is explained by a simple count of steps/day (Tudor-Locke et al. 2011a). Although this explanatory power might appear to be low in contrast to the stark differences in time estimates presented above, it is important to clarify that a single minute of "sedentary activity" (defined by Wong et al. (2011) as a minute where zero steps are taken, which they considered the "criterion measure" of this classification), is a missed opportunity to accumulate any number of steps taken between 1 and 120+ steps/minute (Tudor-Locke et al. 2011e).

It may be more meaningful to look beyond cross-sectional associations and examine the effects of changes in steps/day on time spent in sedentary behaviours. Gilson et al. (2009) did not show changes in self-reported sitting time at work with pedometer-enabled walking strategies, however, the intervention was confined only to working hours (which may have limited success) and the method of assessing time was not likely sensitive to potential real changes in behaviour. De Cocker et al. (2008) evaluated changes in self-reported sitting time by participants engaged in a pedometer-based community intervention focused on increasing steps/day. In 254 participants who increased their steps/day, an increase of 2,840 steps/day was associated with a self-reported decrease of 18 min/day in sitting time (both changes were statistically significant). De Greef et al. (2010) documented an increase of 2,502 steps/day in 20 individuals with Type 2 diabetes as a result of a pedometer-based intervention that also produced a > 1 hour decrease in accelerometer-determined sedentary behaviour (again, both changes were statistically significant). In another pedometer-based intervention study of 92 individuals with Type 2 diabetes, De Greef et al. (2011) reported significant increases of 2,744 steps/day and decreases in accelerometer-determined sedentary behaviour of 23 min/day. Finally, Mikus et al. (2012) recruited young adult volunteers who habitually took > 10,000 steps/day and instructed them to temporarily reduce their activity to < 5,000 steps/day based on self-monitored pedometer feedback. Concurrent accelerometer monitoring during this transition captured an average 2.5 hour increase in sitting time (from 593 minutes/day to 745 minutes/day). Although the difference was not statistically significant (the sample size of 12 participants was not powered to evaluate this specific outcome), few would suggest that a 2.5 hour/day increase in sitting time is an unremarkable change. Combining the results from the studies using objective monitoring, one would expect an increase of 2,500 steps/day to be associated with a 37-45 min/day reduction in sedentary behaviour.

How many steps/day are too few?

Recently a series of papers have explored the concept or question "how many steps are enough?" in terms of a step-based translation of current public health physical activity guidelines (Tudor-Locke et al. 2011f; Tudor-Locke et al. 2011g; Tudor-Locke et al. 2011h), which have historically focused on engagement in activities that are of at least moderate intensity. Although recent U.S public health guidelines continue to emphasize the benefits of time spent in MVPA, they also acknowledge that some activity is better than none (regardless of any intensity criterion), even while encouraging that more is better (Physical Activity Guidelines Advisory Committee 2008). Canadian Physical Activity Guidelines produced by the Canadian Society of Exercise Physiology (CSEP) (Tremblay et al. 2011b) focus on the health benefits of MVPA, however, they also state that for adults and older adults "who are physically inactive, doing amounts below the recommended levels can provide some health benefits." At the same time, interest continues to grow in the independent and potentially deleterious health effects of excessive time spent in sedentary behaviours (Katzmarzyk 2010; Katzmarzyk et al. 2009). CSEP's recent release of Sedentary Behaviour Guidelines for children and adolescents advocate sitting less (Tremblay et al. 2011a; Tremblay et al. 2012). The accompanying CSEP-endorsed press release clearly interpreted this as an opportunity to move more: "the majority of sedentary time can be replaced with light intensity activity and this can be done in a variety of ways" (CSEP 2011). Given that steps/day explains a large part of time spent in light and moderate intensity activities (Tudor-Locke et al. 2011a), and that there is an inverse relationship between accumulation of daily steps and time spent in sedentary behaviours, it has been suggested that asking "how many steps are too few?" may be a more relevant public health question, especially given mounting evidence of just how little physical activity some populations actually perform (Tudor-Locke et al. 2011h).

Tudor-Locke and colleagues (2001) first suggested that taking < 5,000 steps/day might be a useful metric indicative of a "sedentary lifestyle index." In that study they examined the distribution of BMI-defined weight status categories across step-defined physical activity in approximately 100 adults. They observed that individuals taking < 5,000 steps/day were more frequently classified as obese compared to all other BMI-defined weight status categories. Subsequently, Tudor-Locke and Bassett (2004) used 5,000 steps/day as the anchor for their proposed graduated step index that included < 5,000 (labeled "sedentary"), 5,000-7,499 ("low active"), 7,500-9,999 ("somewhat active"), 10,000-12,499 ("active"), and 12,500+ ("highly active") steps/day. Using < 5,000 steps/day as an "sedentary lifestyle" indicator was repeated again in 2008 (Tudor-Locke et al. 2008b). In 2009, Tudor-Locke et al. (2009a) suggested additional categories below this very broad category capped by 5,000 steps/day labeled as “basal activity” (<2,500 steps/day) and “limited activity” (2,500-4,999 steps/day).

Terminology

When the term “sedentary lifestyle index” was first proposed (Tudor-Locke et al. 2001), it was appropriate given where the state of knowledge was at that time. The sedentary behaviour research field has grown substantially and rapidly since then and the explosion of work focused on this low-end of the movement spectrum has inevitably led to debate around terminology. Specifically, recent calls for standardized use of terms “sedentary” and “sedentary behaviours” (Sedentary Behaviour Research Network 2012) have added complexity to the idea of using any number of steps/day to define a “sedentary lifestyle index.” What follows is the case to retain the original terminology applied to a step-based index.

Caspersen, Powell, and Christenson (1985) first clarified the terms “physical activity” (“any bodily movement produced by the skeletal muscles that results in energy expenditure”) and “exercise” (“a subset of physical activity that is planned, structured, and repetitive and has as a final or intermediate objective the improvement or maintenance of physical fitness”). In 2000, Owen et al. called for a shift in traditional approaches to studying exercise and sport and introduced the concept of studying sedentary behaviour as distinct from physical activity. They defined sedentary behaviours in terms of “low levels of energy expenditure,” specifically those activities that expend energy at 1.0 to 1.5 metabolic equivalent units (METs); one MET being the energy cost of resting quietly, or 3.5 mL of oxygen uptake per kg body weight per minute. Pate, O’Neill, and Lobelo echoed this MET-based definition of sedentary behaviour in 2008. Hamilton, Hamilton, and Zderic (2007) pushed to recognize that the study of “acute and chronic physiological effects of sedentary behaviors" included the study of "*nonexercise activity deficiency*". Thus, these pioneering researchers recognized that the effects of sedentary behaviour might extend beyond its impact only on energy expenditure, and included in their definition a focus on relative lack of movement (which they termed "nonexercise activity" or, elsewhere in the manuscript, as "nonexercise physical activity.")

Tremblay et al. assembled terms they believed important to describing and measuring sedentary behaviour in their 2010 publication. They defined "sedentary" as "*characterized by little physical movement and low energy expenditure."* Further, "sedentarism" was defined as "extended engagement in behaviours *characterized by minimal movement, low energy expenditure,* and rest." To be clear, both definitions recognized the *relative lack of physical movement* associated with sedentary behaviours. In contrast with the broader definition of "physical activity" advocated by Caspersen, Powell, and Christenson (1985), Tremblay et al. (2010) specifically defined "physical activity" as "activities of at least moderate intensity." In addition, these authors defined "physically active" as "meeting established guidelines for physical activity (usually reflected in achieving a threshold number of minutes of moderate to vigorous physical activity per day)." They also clarified "physical inactivity" as "the absence of physical activity: usually reflected as the amount or proportion of time not engaged in physical activity of some predetermined intensity." Since they had defined "physically active" in terms of MVPA attainment, it follows that the subsequently listed definition of "physical inactivity" also referred to this specific intensity. The authors specifically argued against using the term sedentary to confer "the absence of MVPA." Owen et al. (2010) also stated: "it is our contention that sedentary behaviour is not simply the absence of moderate-to-vigorous physical activity."

They also summarized objectively-assessed sedentary behaviour from the AusDiab findings (Healy et al. 2007; Healy et al. 2008) and concluded:

> "As logically would be expected, sedentary time and light-intensity activity time were highly negatively correlated (r = -0.96): more time spent in light-intensity activity is associated with less time spent sedentary. This suggests that it may be a feasible approach to promote light intensity activities as a way of ameliorating the deleterious health consequences of sedentary time. Our evidence suggests that having a positive light intensity/sedentary time balance (that is; spending more time in light-intensity than sedentary time) is desirable, since light-intensity activity has an inverse linear relationship with a number of cardio-metabolic biomarkers."

Although the term "sedentary time" has been used interchangeably with "sitting" (Healy et al. 2011), examples of postures that expend < 1.5 METs include lying down/reclining and standing still (e.g., standing quietly, standing in line, Compendium Code 07040) in addition to seated postures (Ainsworth et al. 2011). There are a number of original references catalogued in the 2011 Compendium on-line resources (located at https://sites.google.com/site/compendiumofphysicalactivities/) reporting that standing behaviours expend < 1.5 METs; two recent examples include Levine, Schleusner, and Jensen (2000) (average 1.1 METs) and Crouter, Clowers, and Bassett (2006) (average 1.19 METs). More recently, however, Owen et al. (2011) explicitly defined sedentary behaviours as "sitting without being otherwise active." Researchers expressly interested in sitting behaviours are able to more precisely assess such postures using inclinometers (Kozey-Keadle et al. 2011).

Sedentary behaviour has also been defined by relatively low accumulation of accelerometer-determined activity counts/min. Specifically, Matthews et al. (2008) wrote about defining sedentary behaviour in their well-known U.S.-based descriptive epidemiology paper: "Activity counts recorded while sitting and working at a desk are very low (≤ 50 counts/minute), and counts recorded while driving an automobile are typically below 100 counts/min (unpublished observations)." Since that time 100 counts/min has been routinely used to define sedentary behaviours from accelerometer data (Tudor-Locke et al. 2012). Crouter, Clowers, and Bassett (2006) reported that standing averaged 13.4 activity counts/min and filing averaged 59.8 activity counts/min, so it is apparent that these types of activities would also be classified as "sedentary behaviours" by this activity count/min definition. Regardless, the use of the terms "sedentary behaviours" and "sedentary time" attempt to capture time allocation to specific types of behaviours (at any particular point in time or accumulated over a specified period of time), and defined by relatively low rates of energy expenditure, posture, or relatively low accumulated activity counts/min.

Since time spent in such behaviours appears to be ubiquitously high in population-level data (Matthews et al. 2008), an index is needed to help classify what is potentially excessive in terms of habitual daily behaviour (i.e., an index of lifestyle in contrast to a measured behaviour captured at any particular point in time or accumulated duration of time). For example, a joint report (2001) of the Food and Agriculture Organization of the United Nations (FAO), the World Health Organization (WHO), and the United Nations University (UNU) uses the ratio of total energy expenditure to basal metabolic rate to estimate "physical activity level" or PAL, and then defines "sedentary or light activity lifestyle" as a PAL of 1.40-1.69 (the lower end of the range implies a sedentary lifestyle and the upper end implies a light activity lifestyle). Since direct measures of energy expenditure are less accessible to many practitioners and the general public, it is rational to attempt to provide a reasonable lifestyle index using more available instrumentation, for example, step counting devices. Specifically, objectively determined PAL (using multisensory armband accelerometer technology) is the strongest individual level predictor of all-cause mortality in patients with chronic obstructive pulmonary disease (COPD) (Waschki et al. 2011), and < 4,580 steps/day has been identified as the best cut-point for predicting a "sedentary" PAL of < 1.40 in this population (DePew et al. in press). Just as METs is to PAL (i.e., metabolic cost of behaviours captured at any particular point in time vs. lifestyle indicators of energy expenditure), steps/min is to steps/day. A cadence of 100 steps/min has been consistently associated with an absolutely definition of moderate intensity (i.e., 3 METs) (Abel et al. 2011; Beets et al. 2010b; Marshall et al. 2009; Rowe et al. 2011; Tudor-Locke et al. 2005) and zero steps/min is considered to be the "criterion measure" of "sedentary activity" (Wong et al. 2011). A low level of PAL is indicative of a sedentary lifestyle (FAO/WHO/UNU 2001), and a low level of steps/day should likewise be interpreted as a sedentary lifestyle if some degree of consistency is to be maintained. Although we considered alternative terminology, the continued use of "sedentary lifestyle index" applied to a low level step-defined threshold is harmonious with the use of the term "sedentary lifestyle" defined by relatively low levels of daily energy expenditure as previously established by the FAO, WHO, and UNU. Further, as will be presented in the following sections, it has already been consistently applied in a growing number of studies and to re-label it now would only add to the confusion.

To ease communication, we offer a simple schematic (Figure 1) to graphically present the combined application of these various definitions in defense of a "step-defined sedentary lifestyle index." Since we have demonstrated that NHANES participants who accumulate 7,000 to 8,000 steps/day meet MVPA guidelines (Tudor-Locke et al. 2011d), we have set the "physically active lifestyle" threshold at 7,500 steps/day. This is also congruent with an international review of steps/day values associated with attainment of public health recommendations of time in MVPA (Tudor-Locke et al. 2011h). Since the FAO, WHO, and UNU (2001) consider a "light activity lifestyle" to be relatively more active than a "sedentary lifestyle," and others have persuasively argued that the term "inactive" should be specifically reserved for non-attainment of MVPA recommendations (Owen et al. 2010; Tremblay et al. 2010) (indeed, a letter has been written urging journal editors and reviewers to oversee this appropriate use (Sedentary Behaviour Research Network 2012)), we therefore consider "physical inactivity" to refer to the spectrum of behaviour below the MVPA recommendation and have assigned the term "low active lifestyle" (terminology selected in keeping with previous recommendations (Tudor-Locke and Bassett 2004; Tudor-Locke et al. 2008b)) to fall immediately below this MVPA-associated threshold (i.e., 5,000 to 7,499 steps/day), but above the "sedentary lifestyle" (i.e., < 5,000 steps/day). Finally, since preceding and esteemed researchers have 1) recognized that the study of sedentary behaviours includes "nonexercise activity deficiency" (Hamilton et al. 2007), 2) acknowledged that more time in "light-intensity activity" is strongly associated with less time in sedentary behaviours,(Healy et al. 2007; Healy et al. 2008; Owen et al. 2010) and, 3) characterized "sedentarism" (Tremblay et al. 2010) by minimal movement and low energy expenditure, we remain resolute in identifying a steps/day value that could be used as a "sedentary lifestyle index." An "index" is considered to be a guide, an indicator, a sign, or a pointer. We wish to emphasize that this is a "*step-defined* sedentary lifestyle index." In much the same way, others have offered a "PAL-defined sedentary lifestyle index" (FAO/WHO/UNU 2001). In the future, still others may offer a "posture-defined sedentary lifestyle index," etc. Finally, we believe that the use of "sedentary lifestyle" does not detract from the continued use of "sedentary behaviour" to define behaviours captured at any particular point in time (or the accumulation of time spent in such behaviours), and defined by a relative lack of energy expenditure, a seated posture, or relatively low accumulated activity counts/min.

Utility, appropriateness, and limitations of < 5,000 steps/day

Semantics aside, the purpose of this review is not only to present the rationale, but to also examine and update the utility, appropriateness, and limitations of using the originally proposed cut-point of < 5,000 steps/day as a step-defined sedentary lifestyle index. The need for this selective focus is evident from the simple fact that there are few other contenders at this time, as will be presented in more detail below. The remainder of the article is organized into the following sections, categorized according to emergent themes identified in the step-based literature: 1) studies reporting sample proportions taking < 5,000 steps/day; 2) characteristics of people taking < 5,000 steps/day; 3) contextual factors that can limit accumulation of step-defined physical activity to values of < 5,000 steps/day; 4) health risks associated with taking < 5,000 steps/day; 5) health effects of increasing physical activity levels from < 5,000 steps/day to > 5,000 steps/day; 6) health effects of reducing physical activity levels to < 5,000 steps/day; 7) alternative step-based definitions for a sedentary lifestyle index, 8) relevance for children/adolescents, and 9) limitations to this approach. Throughout, we distinguish terminology used in original research studies in quotations (e.g., "sedentary").

Prevalence of taking < 5,000 steps/day

The descriptive epidemiology of various steps/day cut-points has been previously compiled (Tudor-Locke et al. 2011h), but is re-assembled, updated, and extended here to focus on 25 studies that included a specific report of the proportion of the study sample taking < 5,000 steps/day (Table 1). Only one (with the largest most inclusive sample reported) of the related Cook and colleagues' papers (Cook et al. 2010a; Cook et al. 2011; Cook et al. 2010b) of rural Black South Africans taking < 5,000 steps/day is presented in the table. Proportions classified by this step-defined sedentary lifestyle index ranged from 2% in a small sample of male university students in the U.S. (Mestek et al. 2008) and < 5% in a male South African sample (Cook et al. 2010b) and also in a Czech Republic sample (Sigmundova et al. 2011) to 56% in a U.S. sample of multi-ethnic low-income housing residents 18 to 70+ years of age (Bennett et al. 2006)), 71% in a small sample of African American Medicaid recipients aged 31-63 years (Panton et al. 2007), and 76% in overweight/obese individuals recruited to a physical activity intervention to promote weight maintenance following a behavioural and weight loss program (Villanova et al. 2006). Since at least eight analyses of the 2005-2006 National Health and Nutrition Examination Survey (NHANES) accelerometer step data (adjusted to come more in line with a pedometer scaling) have also focused on < 5,000 steps/day as at least one studied step-based cut-point (Sisson et al. 2012; Sisson et al. 2010; Tudor-Locke et al. 2009a; Tudor-Locke et al. 2011a; Tudor-Locke et al. 2011b; Tudor-Locke et al. 2010b; Tudor-Locke et al. 2011d; Yang et al. 2011), the table only includes the study with the most inclusive (i.e., largest) sample from the original data source that also specifically reported the weighted proportion classified as taking < 5,000 steps/day (Sisson et al. 2012). Accordingly, this nationally representative adult sample indicated that 36.1 % of U.S. adults took <5,000 steps/day. In a separate analysis of these

NHANES data, it appears that approximately 17% of the U.S. population takes < 2,500 steps/day (considered indicative of "basal activity") (Tudor-Locke et al. 2009a).

Not included in this table are two studies that reported number of days < 5,000 steps/day in monitored samples. Analyses performed on 8,197 person-days of data collected over a year-long study of 23 participants from two southern U.S. universities (Tudor-Locke et al. 2004d). indicated that 15.9% of all person-days were < 5,000 steps/day while the sample mean was 10,082 ± 3,319 steps/day. Only a single individual's values from this small and ostensibly healthy sample averaged < 5,000 steps/day over the course of the year. Finally, Barreira et al. (in press-b) collected 93 person-days of pedometer-determined data from 23 overweight/obese individuals. The sample average was 8,025 ± 3,967 steps/day and 25% of all person-days were <5,000 steps/day.

Characteristics of people taking < 5,000 steps/day

Sisson et al. (2012) reported that U.S. adults taking < 5,000 steps/day were more likely to have a relatively lower household income and be female, older, African American versus European American ethnicity, and a current versus never smoker. Hornbuckle et al. (2005) also reported significant age differences between those taking < 5,000 steps/day (relatively older) and those taking ≥ 7,500 steps/day (relatively younger). The lowest reported mean pedometer-determined physical activity reported in a review of expected values for older adults was 2,015 steps/day in a sample of 85+ year olds (Croteau and Richeson 2005). More recently, a value of 12,727 ± 9387 steps/week (translating to 1,818 steps/day) was reported for a sample of older African American women (73.3 ± 9.6 years) engaged in a faith-based intervention (Duru et al. 2010). A review of cross-sectional studies of individuals living with heart and vascular diseases, chronic obstructive pulmonary disease (COPD), dialysis, arthritis, joint replacement, fibromyalgia, and physical disability indicate that all average < 5,000 steps/day (Tudor-Locke et al. 2009b). Recent additions to this body of research indicate that patients with COPD average 3,826 (DePew et al. in press) to 5,680 steps/day (Moy et al. in press), those with diabetes (without mobility limitations) average 6,429 steps/day (van Sloten et al. 2011), and those undergoing total joint arthroplasty average 6,721 steps/day (Naal and Impellizzeri 2010). Even in these samples showing average values somewhat greater than 5,000 steps/day, lower values were associated with compromised health-related outcomes (Moy et al. in press; van Sloten et al. 2011).

In a recent review of pedometer-based physical activity interventions for older adults (age 65+) (Tudor-Locke et al. 2011g), 10/12 studies identified reported baseline values < 5,000 steps/day, and only 3 of those studies with samples averaging < 5,000 steps/day at baseline were able to elicit a level of increase that put the average over 5,000 steps/day post-intervention. Pedometer-based intervention studies conducted with special populations were included in the same review (Tudor-Locke et al. 2011g). Baseline values were < 5,000 steps/day for 2/9 cancer/cancer survivor studies identified, 1/3 COPD studies, 0/2 coronary heart disease and related disorder studies, 4/15 diabetes and related disorder studies, and 3/3 joint and muscle disorder studies. It appears that not all of these interventions were focused on recruiting physically inactive individuals, at least as defined by taking < 5,000 steps/day at baseline.

Finally, morbidly obese individuals have been shown to take, on average, < 5,000 steps/day (Damschroder et al. 2010; Duru et al. 2010; Maraki et al. 2011). For instance, Vanhecke et al. (2008) reported that 10 morbidly obese (BMI = 53.6 ±11.7) individuals averaged 3,763 ± 2,223 steps/day.

Contextual factors related to < 5,000 steps/day

Contextual factors that shape sedentary behaviour and physical inactivity include social, natural, or built environments, and organizational or situational factors (Spence and Lee 2003). The built environment is associated with sedentary behaviour in both children (Timperio et al. 2012) and adults (Kozo et al. in press; Sugiyama et al. 2007). Lower steps/day are also associated with inaccessible and/or a lack of destinations in children (McCormack et al. 2011a), adults (Kondo et al. 2009) and older adults (King et al. 2003). A negative perception of neighbourhood environment is associated with lower steps/day in older adults (Oka and Shibata 2012). Further, mode of transport influences steps/day: Wener and Evans (2007) reported that car commuters took 30% fewer steps/day than those who commuted by train. Van Dyck et al. (2009) showed that residents of low walkable neighbourhoods took fewer steps/day and also walked less frequently for transportation in their neighbourhood. As well, Bennett et al. (2007) reported that steps/day were positively associated with perceived night-time safety; thus, those with the greatest safety concerns also took the lowest steps/day. Despite these accumulating reports, few studies have directly examined the effects of these contextual factors on taking < 5,000 steps/day. Perhaps most illuminating, however, is a study examining differences in pedometer-determined physical activity of a submarine crew when free-living and stationed on land vs. deployed to sea and engaged in structured tasks conducted in a confined and crowded space; 109 crew members from two submarines averaged approximately 7,000 steps/day while stationed on land and this was reduced to approximately 2,000 steps/day when deployed (Choi et al. 2010).

The weather (e.g., ambient temperature, rainfall) is another contextual factor related to pedometer-determined physical activity (Chan et al. 2006; Duncan et al. 2008). Specifically, Dasgupta et al. (2010) demonstrated that average step-defined physical activity dips to < 5,000 steps/day in fall/winter in individuals with Type 2 diabetes living in Montreal, Canada. Similarly, daily steps in a sample of older adults (aged 75-83 years) decreased below 5,000 steps/day during the winter months of December and January in Japan (Yasunaga et al. 2008). In another study, male office workers in rural Japan walked fewer steps/day in the winter compared with the summer, and this dropped below 5,000 steps/day on non-working days (Mitsui et al. 2010).

Health risks associated with taking < 5,000 steps/day

As indicated previously, Tudor-Locke and colleagues (2001) first reported that U.S. individuals taking less than approximately 5,000 steps/day (representing the 25th percentile for distribution of steps/day in that particular sample) had a significantly higher BMI than those categorized into two higher step-defined physical activity categories (between 25th and 75th percentiles and above 75th percentile). Cook et al. (2008) also reported the increased risk of BMI-defined obesity for South African individuals taking < 5,000 steps/day compared to all other levels of step-defined physical activity. Higher BMIs in those taking < 5,000 steps/day have also been reported by Mitsui et al. (2008) studying a Japanese sample, Wyatt et al. (2005) in a Colorado-based sample, Hornbuckle et al. (2005) in African American women, and Krumm et al. (2006) in a post-menopausal sample. Similarly, the odds of experiencing excessive gestational weight gain were higher in pregnant Chinese women taking < 5,000 steps/day (defined as "sedentary") than active women (> 10,000 steps/day) in the 2nd trimester and "somewhat active" women (7,500-10,000 steps/day) in the 3rd trimester (Jiang et al. 2012). Similar findings have been reported for percent body fat (Hornbuckle et al. 2005; Tudor-Locke et al. 2001) and waist circumference (Dwyer et al. 2007; Hornbuckle et al. 2005).

Schmidt et al. (2009) reported that, with the exception of younger men, individuals taking < 5,000 steps/day had a substantially higher prevalence of cardiometabolic risk factors (including metabolic syndrome and 3+ elevated risk factors such as waist circumference, systolic blood pressure, and fasting glucose, triglyceride, and HDL cholesterol values) than those taking higher steps/day. Sisson et al. (2010) also showed that each higher category of step-defined physical activity showed lower odds of having metabolic syndrome compared to the category defined by taking < 5,000 steps/day. For example, the odds were 40% lower for individuals taking 5,000-9,999 steps/day and 72% lower for those taking ≥ 10,000 steps/day compared to those taking < 5,000 steps/day. Recently, Jennersjo et al. (in press) reported that individuals with Type 2 diabetes who took < 5,000 steps/day had higher BMI, waist circumference, C-reactive protein, interleukin-6, and pulse wave velocity than those who took ≥ 10,000 steps/day.

Finally, McKercher et al. (2009) reported a 50% higher prevalence of depression associated with taking < 5,000 steps/day compared to taking ≥ 7,500 steps/day in women, and taking ≥ 12,500 steps/day in men.

Effects of increasing from < 5,000 steps/day to > 5,000 steps/day

Interventions designed to move people from taking < 5,000 steps/day to relatively higher values have demonstrated positive health outcomes. Swartz et al. (2003) reported improved glucose tolerance with an 8 week pedometer-based walking program in 18 postmenopausal women who averaged 4,491 ± 2,269 steps/day at baseline and ended up averaging 9,213 ± 362 steps/day. Participants in a 12-week worksite pedometer program who increased their daily steps from 4,244 ± 899 to 9,889 ± 1609 experienced significant decreases in body weight, BMI, and resting heart rate relative to a no-change comparison group (Musto et al. 2010). A non-significant increase from 4,471 ± 2,315 steps/day to 5,257 ± 2,355 steps/day among 14 obese middle-aged veterans was associated with a significant weight loss (-3.8 ± 3.6 kg) in a lifestyle coaching intervention that included nutritional goals, so the relative contribution of the change in steps/day to the weight change is unknown (Damschroder et al. 2010). Villanova et al. (2006) reported that 76% of 200 overweight/obese participants in a 9-month behaviour program took < 5,000 steps/day at baseline and only 16% were below this value at the end of the program; the probability of increased amount of weight loss was enhanced with increased steps/day. As far as we are aware, no other interventions have expressly recruited participants who take < 5,000 steps/day at baseline and studied the effects of attaining at least this cut-point or beyond.

Bell and colleagues (2010) compared the effectiveness of a walking program with a fitness training group and control group among “sedentary” (< 5,500 steps/day) individuals ranging in age from 20 to 65 years. At the end of a 6-month period, the walking group had achieved 9,221 ± 1,429 steps/day with the ultimate goal of averaging 10,000 steps/day. Though changes were observed in several health-related variables for all groups (even the control group) at the end of the intervention, the authors concluded the greatest reductions in body mass, waist circumference, and waist-to-hip ratio occurred in the two activity groups.

Finally, achieving a steps/day value > 5,000 steps/day may not be completely necessary to reap at least some health benefits in those who take < 2,500 steps/day (considered indicative of “basal activity”(Tudor-Locke et al. 2009a)). Duru et al. (2010) studied obese African American women who increased their physical activity by 1,411 steps/day from a baseline value of 1,818 steps/day as a result of a multicomponent faith-based intervention (a pedometer was used for measurement and as part of weekly pedometer competitions during the intervention, but pedometer readings were never revealed to participants). This modest improvement over seemingly very low initial baseline values was associated with a significant decrease in systolic blood pressure but no changes in body weight or diastolic blood pressure compared to a control group.

Effects of reducing to < 5,000 steps/day

Thyfault and Krogh-Madsen (2011) reviewed a number of recent studies that examined the health effects of recruiting relatively healthy and active subjects and temporarily transitioning them to very low values of steps/day. These and a few recent additions are described briefly here.

Seminal animal studies from Dr. Frank Booth's laboratory showed that transitioning rodents from naturally high daily activity (access to running wheels) to low activity (locking running wheels) induced fast and dramatic changes in body composition, insulin sensitivity, and tissue metabolism, suggesting that the conversion to inactivity brought about by an abrupt removal of opportunity for activity triggers potentially harmful metabolic changes in a short period of time (Kump and Booth 2005a; Kump and Booth 2005b; Kump et al. 2006; Laye et al. 2007). These rodent studies prompted another group led by Dr. Bente Pedersen to determine if transitioning young, active, but non-exercising men to a lower daily ambulatory activity would result in similar results. In the first study, Olsen et al. (2008) examined metabolic responses in 8 young men whose step-defined physical activity was reduced from a mean value of 6,203 steps/day to 1,394 steps/day for 22 days. Plasma insulin area under the curve (AUC), assessed by oral glucose tolerance test, increased significantly from 757 pmol/L/3h to 1,352 pmol/L/3h after 3 weeks of reduced step activity. Olsen et al. (2008) also reported a second study conducted with 10 healthy young men transitioned from a mean activity level of 10,501±808 steps/day to

1,344±33 steps/day for two weeks. Plasma insulin AUC increased significantly from 599 pmol/L/3h to 942 pmol/L/3h. In addition, plasma C-peptide AUC increased significantly from 4,310 pmol/L/3h to 5,795 pmol/L/3h. These results suggested that it took a greater insulin response to dispose of blood glucose during postprandial conditions, due to reduced insulin sensitivity in skeletal muscle. The 2-week intervention was also associated with a 7% increase in intra-abdominal fat mass with no change in total fat mass, and a decrease in both total fat-free mass and BMI. Krogh-Madsen et al. (2010) analysed additional data collected from this same sample of 10 men and confirmed that there was indeed reduced insulin sensitivity in skeletal muscle (17% reduction in glucose infusion rate during a hyperinsulinemic-euglycemic clamp) and reduced activation of insulin signalling in biopsied skeletal muscle samples. Moreover, they reported a 7% decline in VO_2 max, and a 0.5 kg decrease in leg lean mass following a 2-week decrease of about 9,000-10,000 steps/day. Although the decrease to < 1,500 steps/day is much lower than 5,000 steps/day, this study shows that reducing daily ambulatory activity to such very low levels causes dramatic changes in health indices known to powerfully influence risk for morbidity and mortality.

The same research group has performed follow-up studies to determine if reducing daily steps from >10,000 to <1,500 combined with a higher calorie diet (+50% kcal) would induce greater changes in insulin sensitivity and body composition (Knudsen et al. in press). They also performed OGTTs and measured body fat, visceral adiposity, and body mass at baseline and 3, 7 and 14 days after the transition to reduced steps/day to determine if a change in insulin sensitivity occurred before or after significant changes in adiposity and body weight. Insulin sensitivity, derived from an index of the glucose and insulin responses to the OGTT, was significantly reduced by 37% after only 3 days of inactivity, and occurred prior to significant increases in body mass and adiposity (both whole body and visceral) that trended up at days 3 and 7 but were not significantly greater than baseline until day 14, at which time visceral adiposity had increased by 49% above baseline. Importantly, this study confirmed earlier findings that an acute transition to very low daily steps induces significant changes in insulin sensitivity and adiposity. Another interesting outcome of this study was that measures were again collected 16 days after the two weeks of inactivity to determine if a return to the subject's normal daily step count returned measured variables to baseline levels. Interestingly, despite insulin sensitivity returning to normal, both body mass and body fat were still elevated (visceral adiposity was not assessed) suggesting that acute periods of inactivity may lead to an incremental increase in adiposity and body mass over time.

Reduced skeletal muscle insulin sensitivity plays a fundamental role in impaired postprandial glycemic control. An increased postprandial glucose response is both a risk factor for the development of Type 2 diabetes and an independent risk factor for cardiovascular disease in people with and without Type 2 diabetes. A study conducted by Mikus et al. (2012) transitioned healthy, active individuals who were obtaining >10,000 steps/day to <5,000 steps/day for only 3 days to determine if this abrupt and temporary change in daily physical activity would modify postprandial and overall glycemic control as measured by continuous glucose monitors, devices that measure blood glucose minute-by-minute during free-living conditions. The study found that only 3 days of reduced activity led to significant increases in average glucose excursions following meals. Moreover, daily measures of glucose control including maximal and minimal glucose levels, and the duration of time above a high threshold of euglycemia were also significantly altered. In summary, these findings suggest that taking even temporary transitions to < 5,000 steps/day dramatically alters glycemic control and may play a fundamental role in the increased risk for diabetes and other metabolic diseases witnessed in people who chronically take < 5,000 steps/day.

Another research group has recently examined the combined effects of inactivity and overeating on body composition and mental health. Ernersson et al. (2010a; 2010b; 2010c) reported that young healthy individuals who adopted obesity-provoking behaviours for 4 weeks that included doubled energy intake (primarily from fast food) and taking < 5,000 steps/day increased their body weight (Ernersson et al. 2010a; Ernersson et al. 2010c), increased both fat free mass and fat mass (Ernersson et al. 2010a), decreased their health-related quality of life (Ernersson et al. 2010c), and reported developing a lack of energy (related to emotional life, relations and life habits) (Ernersson et al. 2010b). One year after this brief intervention, the body weight increase remained higher relative to a control group (Ernersson et al. 2010a). In addition, fat free mass was unchanged relative to baseline, but the increase in fat mass remained (Ernersson et al. 2010a). This study again suggests that acute periods of inactivity and dietary excess may lead to an incremental increase in body mass that is then sustained over time. The relative contribution of the decreases in step-defined physical activity compared to the energy intake hyper-alimentation was not determined.

Alternative definitions

Thompson et al. (2004) defined “inactive” as < 6,000 steps/day in a study of middle-aged American women. Others have used this cut-point too (Graff et al. 2012; Lara et al. 2010) with Lara and colleagues (2010) labelling it as “sedentary.” Tudor-Locke et al. (2008a) defined < 7,500 steps/day as “inactive” in an Australian sample with a relatively high mean steps/day. This same steps/day cut-point has been labelled “sedentary” (Barbat-Artigas et al. 2012) and also "sedentary to low active" (Inoue et al. 2011b). In an intervention study conducted in a Canadian sample with Type 2 diabetes, Tudor-Locke et al. (2004b) defined "insufficiently active" as < 8,800 steps/day for recruitment purposes based on a previous cross-sectional study of individuals with Type 2 diabetes where this level approximated the 75^{th} percentile of distribution (Tudor-Locke et al. 2002). Oka et al. (2012) defined "insufficiently active" as < 6,700 steps/day (men) and < 5,900 steps/day (women) based on not attaining a Japanese national physical activity objective applied specifically to older adults ≥ 70 years of age. Finally, a number of other Japanese researchers have defined "sedentary" as < 4,000 steps/day (Inoue et al. 2011a; Ishikawa-Takata et al. 2010; Park et al. 2007). Differences in exact steps/day values used and associated terminology reflect earlier thinking and/or a need to accommodate study specific and unique sample distribution parameters. The variation in terminology between original research studies and review articles relating to what relatively low daily step values mean lends support as to why the present review is so important.

There are weaknesses to using < 5,000 steps/day as a step-defined sedentary lifestyle index. First and foremost, the evidence supporting it use has largely been derived as a result of a "self-fulfilling prophecy." For example, the demographic results reported by Sisson et al. (2012) would not likely have changed if alternative cut-points of 4,000 or 6,000 steps/day had been considered. Further, the detrimental effects of taking even fewer steps/day (e.g., < 1,500 steps/day) are emerging (Knudsen et al. in press; Krogh-Madsen et al. 2010; Olsen et al. 2008). Since < 5,000 steps/day has been the most common candidate for a step-defined sedentary lifestyle index presented to date, however, it gets reinforced simply by repetition. Widespread use and repetition are not evidence of veracity. Alternative thresholds might be more valid, but have not been used extensively, and are therefore lacking confirmation. A creative analysis would attempt to identify a specific steps/day value associated with select disease conditions or specific health parameters. This is a challenging pursuit however, since, hypothetically, relatively (and incrementally) lower values will always be associated with increasingly negative results and relatively (and incrementally) higher values will be associated with increasingly positive results. Moreover, related changes in some health parameters may mediate or modify changes in other health parameters (i.e., waist circumference and insulin sensitivity or blood lipids). Where the line is drawn becomes somewhat subjective against this indistinct background; there are likely to be samples with even lower steps/day values than any identified cut-point. On the other hand, the usefulness of any index is compromised if it is too low; if it is so low that few people are affected by it, then its public health relevance is limited. For example, U.S. data suggest that approximately only 17% of the population take < 2,500 steps/day (Tudor-Locke et al. 2009a), and we could only assume this percentage would be much lower in other, more active populations. Ultimately, validation with longitudinal data with various health outcome measures is warranted. While it may continue to be debated, and despite its simplistic origins, the consistent use of a standardized definition of a sedentary lifestyle index as < 5,000 steps/day would facilitate comparisons between studies and population groups.

Relevance for children/adolescents

NHANES accelerometer data indicate that, during the monitored day, U.S. children and adolescents (6-19 years of age) spend on average approximately 4 hours at zero steps/min (non-movement), 8.9 hours/day between 1-59 steps/min, 22 min/day at 60-79 steps/min, 13 min/day at 80-99 steps/min, 9 min/day at 100-119 steps/min, and 3 min/day at cadences ≥ 120 steps/min (Barreira et al. in press-a). However, unlike the growing evidence to support an adult step-defined sedentary lifestyle index, there are relatively few pertinent studies to inform a similar index for children and/or adolescents. Though the step-based pediatric literature is quite consistent with regard to:1) boys accruing more steps/day than girls (Craig et al. 2010; Tudor-Locke et al. 2009c), 2) steps/day declining from childhood to adolescence (Beets et al. 2010a; Craig et al. 2010), and 3) the inverse relationship between steps/day and body composition (Duncan et al. 2010; McCormack et al. 2011b; Tudor-Locke et al. 2011c; Tudor-Locke et al. 2004c), and between steps/day and aerobic fitness (Le Masurier and Corbin 2006; Lubans et al. 2008) in children and adolescents, the majority of the general pediatric physical activity literature is concerned with assessment of compliance with intensity-based guidelines or meeting specific physical activity targets other than any number of steps/day. However, the focus on "how many steps/day are enough?" in children/adolescents (Tudor-Locke et al. 2011f) has recently driven the pursuit of a steps/day translation of accumulating at least 60 minutes of daily MVPA, an accepted time-and-intensity based public health recommendation (Janssen and Leblanc 2010).

Using accelerometer data from the Canadian Health Measures Survey, Colley et al. (2012) recently proposed that 12,000 steps/day be used as this target for children and adolescents. Since the Sedentary Behaviour Research Network (2012) has recommended that journal editors and reviewers require that "authors use the term "inactive" to describe those who are performing insufficient amounts of MVPA (i.e. not meeting specified physical activity guidelines)", the implication of the research conducted by Colley et al. (2012) is that children and adolescents who take < 12,000 steps/day are physically inactive. This is only a single example, and whether or not it was these authors' intent, we believe it more prudent to move beyond a simple dichotomous classification of active vs. inactive. We suggest instead that there is a lower value (similar to that presented in Figure 1 but more relevant to a child/adolescent population), perhaps based on a low-level percentile of distribution, or tied to a deleterious health parameter, or a combination of these, that would be more useful for identifying those who are most likely to be putting their health at risk as a result of their behaviour.

Emerging research on the population distribution of steps/day among children and adolescents could inform a percentile-based definition of the index. Without question, the largest population study is the ongoing nationally representative Canadian Physical Activity Levels among Children and Youth study (CANPLAY) (Craig et al. in press; Craig et al. 2010), which has been collecting pedometer data on about 6,000 children annually since 2005-2006. Based on the criterion of a steps/day cut-point at the lowest 15th percentile of the distribution (equivalent to a mean values minus one standard deviation) derived from 17,314 boys and 16,913 girls (Craig et al. in press), "taking too few steps" may be defined as taking < 8,448 steps/day among boys 5-13 years, < 6,336 steps/day among boys 14-19 years, < 7,761 steps/day among girls 5-13 years, and < 5,867 steps/day among girls 14-19 years. Applying this distribution-based criterion to published data from a smaller national U.S. study (Tudor-Locke et al. 2010a), associated pedometer-equivalent step-based values are < 6,040 and 3,695 steps/day among boys 6-13 and 14-19 years, respectively, and < 4,855 and 2,850 steps/day among girls 6-13 and 14-19 years, respectively. Such distribution-based cut-points derived from population level data reflect current physical activity patterns of the specified population, which may also be associated with lower than ideal health measures within that population. For example, we know that physical fitness of children and youth has declined overtime in Canada (Craig et al. 2012) while obesity levels have increased (Janssen et al. 2011; Janssen et al. 2012). A step-defined sedentary lifestyle index derived from normative distributions of other populations engaging in more traditional lifestyles reflective of lower rates of obesity (such as the North American Amish (Bassett Jr et al. 2007)) would provide substantially different values. The above cut-points defined on national population data (both Canada and the U.S.) would identify outliers applied to an Amish population (mean minus *three* standard deviations = 6,385 and 5,450 steps/day for boys 6-12 and 13-18 years respectively and 7,250 and 3,155 steps/day for girls 6-18 years) whereas the mean minus one standard deviation criterion for establishing an Amish step-defined sedentary lifestyle index (<13,410 and 13,770 steps/day for boys 12 and 13-18 years and <11,840 and 9,165 steps/day for girls 6-12 and 13-18 years) exceeds the average daily steps of North American children. The variation among populations illuminates the problem with distribution-based thresholds and underscores the need to define a standardized index based on health-related outcomes.

An early suggestion (Tudor-Locke et al. 2008b) that values of < 10,000 and < 7,000 steps/day could be used to identify sedentary lifestyle for school-aged boys and girls (6-12 years) respectively, was loosely based on BMI-referenced anchors (Tudor-Locke et al. 2004c) and modeled after a proposed adult graduated step index (Tudor-Locke and Bassett 2004). This is consistent with a more recent finding from CANPLAY where the odds of obesity decreased for every 3,000 step increase in steps/day so that boys (5-13 years) taking roughly 10,000 steps/day and girls taking about 8,000 steps/day were 19% more likely to be obese than the average boy (mean = 12,813 steps/day for 5-9 year olds and 12,845 steps/day for 10-13 year olds) and girl (mean = 11738 steps/day for 5-9 year olds and 11,265 for 10-13 year olds), controlling for television viewing time (Tudor-Locke et al. 2011c).

Applying these sex-specific cut-points (i.e., < 10,000 and < 7,000 for boys and girls respectively) to 2,610 children's and adolescents' data collected as part of NHANES accelerometer monitoring, Tudor-Locke et al. (2010a) reported that as many as 42% of U.S. boys and almost 21% of girls may be considered "sedentary" when the accelerometer data were adjusted to come more in line with expected step values from pedometry. The appropriateness of a sex-specific definition may be debated. When both boys and girls were evaluated relative to a standard cut–point of 7,000 steps/day in the Canadian CANPLAY pedometer surveillance data of 19,789 children and adolescents, Craig et al. (2010) reported that approximately 25% of boys and 33% of girls were considered "low active" and 6% of both boys and girls took < 5,000 steps/day and were considered "sedentary." Although not specifically looking to examine the usefulness of these potential markers of a physically inactive lifestyle, Kambas et al. (2012) did demonstrate that preschool-aged children who accumulated approximately < 7,000 steps/day (discerned from a figure) were also categorized within the lowest quartile of motor proficiency. Although <7,000 steps/day has been more frequently repeated in the pediatric literature at this time as a potential low end candidate, unlike the adult data, the paucity of the additional evidence on this topic does not allow us to conclusively identify a minimum value of steps/day to inform a clear evidence-based child/adolescent-specific step-defined sedentary lifestyle index at this time. We anticipate that this will improve as this gap is recognized and the research process inevitably unfolds.

Limitations

There are a number of limitations to this approach of using a step-based definition as a sedentary lifestyle index that must be acknowledged. First, a variety of step-counting devices are available for use among researchers, practitioners, and the general public. Each one of these user groups has different but overlapping needs and it would be best if any unit of measurement could be simply translated at all levels. However, it has become increasingly apparent that there are differences in how these various objective monitors detect and present a "step" (Crouter et al. 2003; Feito et al. 2012; Le Masurier and Tudor-Locke 2003; Le Masurier et al. 2004). This is not limited just to step counting; estimates of time spent in sedentary behaviours and at any intensity of physical activity are also variable between different types of instrumentation that attempt to capture such data (Tudor-Locke 2010). Perhaps even more concerning, there is evidence that different generations of instrumentation are inconsistently sensitive (Rothney et al. 2008). As with all measures, a trade-off exists between sensitivity and specificity; increasing sensitivity to capture very low force movements in an attempt to be maximally inclusive leads to increased capture of “erroneous steps” (Le Masurier and Tudor-Locke 2003) and vice versa.

To be clear, the original graduated step index was presented in an article that specifically stated in the title: “Preliminary *pedometer* indices for public health” (Tudor-Locke and Bassett 2004). That article included the proposed values for (what was known at the time as) a “sedentary lifestyle index,” which itself was originally formulated based on *pedometer* measures (Tudor-Locke et al. 2001). Most of the research (23 out of 25 studies) presented in Table 1 has been collected with *pedometers*. Further, 1 of the 2 remaining studies represented in the table that used accelerometers to collect the step data actually adjusted the output to be more translatable in terms of what might be expected using *pedometry* before applying the pedometer-based index to the data (Sisson et al. 2012). Since pedometers are less expensive, and therefore more accessible and feasible for use in practical applications, including widespread adoption by the general public, it is reasonable to provide index values to guide their use at this level. Physical activity recommendations expressed in terms of steps/day produced by various governmental and health organizations around the world (Tudor-Locke et al. 2011h) are ultimately intended for public consumption, and therefore have been logically designed for users of such low-cost and accessible technologies. Producing cut-points and other indices that are only to be used by other researchers with access to enhanced technological precision may be necessary to address specific research questions, but may ultimately have little application to the real-world condition outside of the laboratory.

Although many accelerometers have evolved to include step-based outputs in addition to their more traditional activity count outputs, we acknowledge that these similarly named outputs are not likely to be on the exact same scale as that captured by lower technology pedometers. Therefore, researchers should cautiously compare and interpret any steps/day value or apply any index to data collected using different types of instrumentation. This specifically means it may be just as debatable to cast an accelerometer-generated steps/day estimate as an un-adjusted index for pedometer users, as it is to interpret accelerometer-determined steps/day using an index originally intended to interpret pedometer data. For example, one of the studies listed in Table 1 used an ankle-worn StepWatch Activity Monitor to monitor steps/day in an older adult sample (mean age approximately 80 years) (Cavanaugh et al. 2010). This instrument is known to be highly sensitive to low force accelerations and detects 11-15% more daily steps in free-living than commonly used pedometers (Karabulut et al. 2005). Perhaps unaware of the implications of this difference in instrument sensitivity, Cavanaugh et al. (2010) applied the pedometer-based graduated step index (Tudor-Locke and Bassett 2004) to interpret their data without any form of adjustment. As a result, they concluded that only 26% of this aged sample took < 5,000 steps/day, and at least 29% were "highly active," that is, accumulating over 10,000 steps/day. Directly (and inappropriately) compared to U.S. national estimates (where average values were closer to 6,500 steps/day and comparable categories were 36% and 16%, respectively) collected with an accelerometer but adjusted to be more in line with a pedometer-based scale (Sisson et al. 2012), this smaller sample could be described as uniquely active for their age. However, it is more likely that differences in instrumentation explain the remarkable finding.

It is worth repeating that step counting devices are now widely available in a number of different commercially available formats including those worn at the waist, on the arm, at the wrist, on the ankle, in a pocket, as a piece of jewelry, as an ear piece, in cell phones, etc. Their measurement mechanisms are patent-protected, they change and become obsolete, and it has become clear that similarly named outputs do not necessarily capture the same behaviour between instruments (Tudor-Locke 2010). Industry standards have helped to make ambulatory monitoring more uniform in Japan (Crouter et al. 2003), however this is not the case elsewhere. Although it is lamentable, it may be that instrument-specific index values will be necessary. This is already known to be the case for application of accelerometer activity count cut-points. Methods of adjustment are sorely needed to aid translation and comparison between instruments. Despite these inconvenient truths, we must be careful not to "throw the baby out with the bathwater." Still, any value offered as a generic step-defined sedentary lifestyle index must be treated as a "heuristic" (i.e., guiding) value that must also be thoughtfully applied and communicated, keeping in mind the end user.

Another limitation also related to instrumentation and measurement is the concern for optimal amounts of wearing time. Instruments with time-stamping technology (typically accelerometer-type devices) provide researchers with additional information that can be processed and used to determine wear time and limit data queries to the best quality data using user-defined criteria. However, a number of researchers (Choi et al. 2011; Masse et al. 2005; Tudor-Locke et al. 2011b) have shown that it is the estimate of time spent in sedentary behaviour that is most affected by premature removal of accelerometers; the impact on detected movement, for example, steps/day is less profound (Schmidt et al. 2007; Tudor-Locke et al. 2011b). Nevertheless, researchers remain very cognizant of this potential threat to validity and addressing it is often a foremost consideration. From the practitioner's point of view, however, and especially from that of the general public, the potential impact of wear time on an estimate of steps/day is not likely to be as much of a concern; Schmidt et al. (2007) have demonstrated that adjustments for wear time did not alter correlations between pedometer steps/day and cardiovascular risk factors. Further, a wealth of health-related step data has been accumulated to date primarily using pedometers that have not had time-stamping technology, and the consistency and robustness of the findings have been clear (Tudor-Locke et al. 2011f; Tudor-Locke et al. 2011g; Tudor-Locke et al. 2011h). Perhaps most compelling, meta-analyses (Bravata et al. 2007; Kang et al. 2009; Richardson et al. 2008) of pedometer-based behaviour interventions demonstrate consistent statistically and clinically significant changes (i.e., approximately 2,000 to 2,500 steps/day) in ambulatory activity and related improvement in health outcomes using this simple technology, without any consideration of wearing time.

Finally, and as mentioned earlier, not all human movement is represented by a measure of daily steps taken. Step-counting devices do not characterize non-ambulatory activities (e.g., weight training, bicycling, swimming, skateboarding, roller blading, hockey, kite surfing) well (Miller et al. 2006). However, it is clear that ambulatory behaviours, and specifically walking, are fundamental to basic human mobility across all domains of daily life, including exercise, recreation, work, chores, shopping, social interactions, and cultural exchanges (Ainsworth et al. 2011; Tudor-Locke and Ham 2008). Further, although steps/day explains 61-67% of the variability in MVPA (Tudor-Locke et al. 2011a), and taking 5,000 steps/day is associated with approximately 10 minutes (not necessarily consecutive) of MVPA (Tudor-Locke et al. 2011a), a measure of total steps taken in a day is not a direct indication of physical activity intensity, a dominant precept of public health guidelines (Physical Activity Guidelines Advisory Committee

2008; Tremblay et al. 2011b). Nonetheless, step-counting devices, especially those accessible to the general public, are important health behaviour tools (Tudor-Locke and Lutes 2009). Their utility is limited, however, without provision of evidence-based, applicable, and reasonable index values to help guide and interpret their output.

Conclusions

A growing number of studies have used the < 5,000 steps/day cut-point to categorize individuals as "sedentary"(McKercher et al. 2009; Schmidt et al. 2009) or "inactive"(Cavanaugh et al. 2010; Hirvensalo et al. 2011) since it was first proposed (Tudor-Locke et al. 2001) and subsequently included in a more fully expanded graduated step index (Tudor-Locke and Bassett 2004; Tudor-Locke et al. 2008b). The profile of individuals more likely to be taking < 5,000 steps/day includes having a relatively lower household income and being female, older, African American versus European American ethnicity, a current versus never smoker and/or living with chronic disease and/or disability (including morbid obesity). Although the fall/winter season in the Northern hemisphere appears to discourage taking > 5,000 steps/day, little else is known about how other contextual factors foster such low levels of step-defined physical activity. Adverse measures of body composition have been consistently associated with taking < 5,000 steps/day in a range of population samples. Indicators of cardiometabolic risk, and specifically metabolic syndrome, have also been associated with taking < 5,000 steps/day. Using < 5,000 steps/day to identify and recruit physically inactive and/or sedentary individuals to interventions focused on increasing physical activity and/or reducing sedentary behaviours seems to be a prudent approach to maximizing potential for effect in a population most at need, but this approach has not yet been systematically adopted. Interventions have typically focused on attaining a singular and lofty goal (e.g., 10,000 steps/day) (Bravata et al. 2007) and not necessarily on shifting individuals who take relatively few steps/day to the next immediately higher categories (e.g., “low active” defined as 5,000-7,500 steps/day or “somewhat active” defined as 7,500-9,999 steps/day (Tudor-Locke and Bassett 2004; Tudor-Locke et al. 2008b)). Short term interventions to reduce step-defined physical activity to values < 5,000 steps/day conducted with small samples of young, healthy, and active individuals have shown dramatic adverse effects on a number of health parameters. Consistent implementation of a standardized steps/day definition for a sedentary lifestyle index would facilitate comparisons between studies and groups; however, unique sample distributions (i.e., generally active, or generally low active) may require tolerance for a degree of flexibility, including segmenting the < 5,000 steps/day category into “basal activity” (<2,500 steps/day) and “limited activity” (2,500- 4,999 steps/day) (Tudor-Locke et al. 2009a). A standardized definition would be useful for screening, recruiting, and tracking purposes as well. Although additional research is needed to further illuminate the appropriateness of using < 5,000 steps/day as a step-defined sedentary lifestyle index, especially its application across different types of objective monitoring technologies, it clearly demonstrates multiform utility for researchers, practitioners, and perhaps most importantly, communicating with the general public at this time. There is currently little evidence to advocate any specific value indicative of a step-defined sedentary lifestyle index in children or adolescents.

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Figure Captions:

Figure 1: Step-Defined Sedentary Lifestyle Index for Adults