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【Review Article】

Step by Step: Accumulated Knowledge and Future Directions of Step-defined Ambulatory Activity

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ABSTRACT Walking is one of the most common forms of human locomotion. The development of objective monitoring devices (e.g., pedometers or accelerometers) has afforded public health researchers a unique opportunity to measure ambulatory behavior, including walking, with minimal bias. Objective monitors have been used in a number of cross-sectional national- and state-representative studies to assess walking behavior. Data from these studies, and smaller investigations, have allowed researchers to assess the relationships between total daily ambulation (steps/day) and various health indicators. The growing body of investigations measuring ambulatory behavior has also prompted researchers to seek answers to related questions: "how many steps/day are too few?" and "how many steps/day are enough?" Moreover, recent epidemiological evidence has linked ambulatory speed (steps/min) to various health outcomes and has peaked researchers' interests in answering "how fast is enough?" This brief review: 1) summarizes current epidemiological literature examining objectively monitored ambulatory behavior, 2) answers public health relevant questions concerning insufficient and sufficient amounts of daily walking, 3) considers the relative importance of walking speed in relation to public health, and 4) identifies future research directions related to the assessment of walking behavior.

Key words: walking, public health, physical activity, sedentary lifestyle, epidemiology

Introduction

Numerous health benefits are associated with a physically active lifestyle.[1] Although there are a myriad of distinct types of physical activity an individual may engage in, walking is the most commonly reported leisure-time physical activity among adults.[2] Moreover, walking is an integral part of nearly all forms of daily locomotion and is a natural, simple, accessible, and effective mode of human movement. Considering the ubiquitous nature of walking, its current and future importance to international public health should not be overlooked.

Walking can be most precisely measured using objective monitoring devices (e.g., pedometers or accelerometers) that quantify movement in terms of steps. Step counts from such devices are often (but not always) provided in real-time (i.e., using a digital read out) and can be used to characterize ambulation at the individual or population level. To aid interpretation of habitual behavior, step counts are typically expressed as steps/day, which provides practitioners and members of the lay public with an easy to understand metric representing the total volume of ambulatory behavior (including walking) in a given day. Guidelines for physical activity from public health authorities have typically prescribed physical activity in terms of frequency, duration, and intensity; however, recent step-based physical activity recommendations have been made by various health groups, professional organizations, and government entities.[3-7]

The multiple purposes of this brief article include assembling the rapidly accumulating knowledge concerning the epidemiology of objectively monitored ambulatory activity, summarizing emerging answers to step-defined indices concerning insufficient and

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sufficient walking doses, pondering the role of walking speed relative to these questions, and identifying future research needs.

Epidemiology of objectively monitored ambulatory activity

The body of literature focused on step-defined physical activity has grown quickly over the last decade and a clearer understanding of its distribution and determinants is becoming more apparent. A number of national- and state-representative surveys have included objective monitoring of steps/day (by accelerometer or pedometer) and these are assembled in Figure 1,[8-15] juxtaposed against the highest average values collected to date in an Amish sample.[16] The representative surveys were conducted in Canada,[9] Japan,[11] Norway,[10] Switzerland,[13] Western Australia,[12] and in the United States (U.S.) as part of Colorado on the Move,[15] America on the Move,[8] and the National Health and Nutrition Examination Survey (NHANES).[14] Since Amish people choose to live their lives without modern technologies, including motorized transportation, their pedometer-determined data[16] provide a stark example of what life might have been like before such contemporary advances. Regardless of the choice of instrumentation (accelerometer or pedometer), it is apparent that daily step counts within the U.S. are the lowest population-level values collected to date.[8,14,15] The only country reporting trend data based on multi-year surveillance has been Japan;[17] between 1995 and 2007 there has been a population-level decline in objectively determined physical activity on the order of 529 and 857 steps/day for men and women, respectively, from a peak in 1998-2000. Significantly, the age-adjusted proportion of people taking < 4,000 steps/day has increased by 4.8% in men and 8.2% in women.

With few exceptions,[10] studies of step-defined physical activity indicate that men take more steps/day on average than women.[8,9,11-14,16] Steps/day is also inversely related with age[18] and BMI.[15,19-25] The number of daily accumulated steps also reflects day of the week, with weekend days being typically lower than weekdays,[26] month,[27] and season.[27,28] For example, Yasunaga et al.[29] and Mitsui et al.[30] have reported that steps/day are lower in winter months compared with summer months. Steps/day appears to also be impacted by weather changes and perceived neighborhood walkability.[31-33] In particular, having local and accessible destinations to walk to is associated with higher steps/day.[34,35] Engagement in

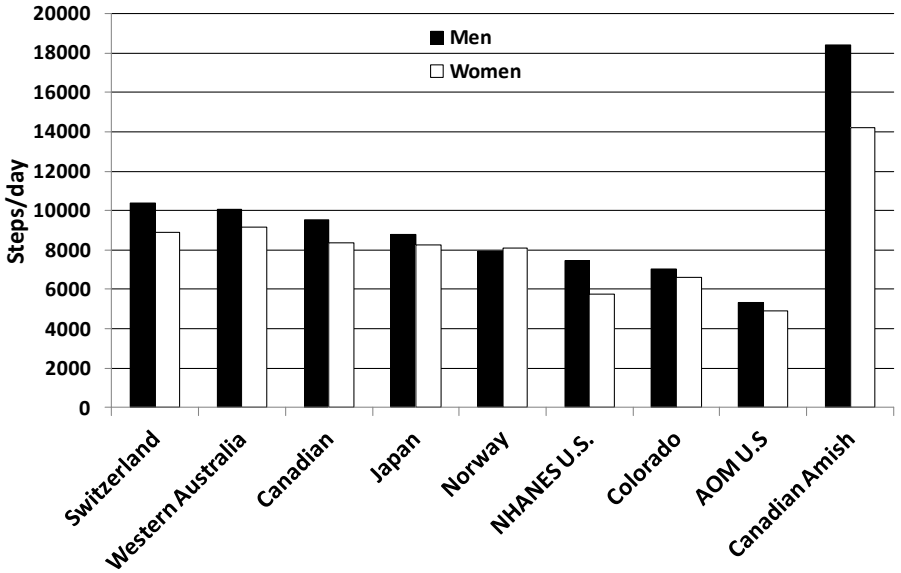

Figure 1 Mean steps/day among men and women by country, geographic region, or population sub-group.

NHANES = National Health and Nutrition Examination Survey; AOM = America on the Move.

exercise/sports is associated with increased steps/day as is active commuting behaviors.[26,36,37] For example, Wener and Evans reported that train commuters averaged 30% more steps/day than car commuters and they were also four times more likely to accumulate 10,000 steps/day.[37]

How many steps/day are too few?

Nationally representative assessments within the U.S. have revealed that many individuals perform little moderate-to-vigorous physical activity and spend inordinate amounts of time in sedentary pursuits.[38-40] These observations are alarming as high levels of sedentary behavior are associated with increased risks for a variety of negative health outcomes.[41-44] Such findings provide a basis for asking "how many steps/day are too few?"[45] That is, below what steps/day threshold are risks for various negative health outcomes significantly increased?

A minimum threshold of 5,000 steps/day was initially suggested by Tudor-Locke and colleagues after observing higher BMI values among adults accumulating < 5,000 steps/day in comparison to those taking > 5,000 steps/day.[22] The authors suggested that taking < 5,000 steps/day may be an indicator of a "sedentary lifestyle index." Tudor-Locke and Bassett later used 5,000 steps/day as the floor value of their proposed graduated step index.[46] Subsequently, the 5,000 steps/day threshold has been used by a number of researchers for population surveillance,[14,17,47-51] screening,[52,53] and intervention.[52,54]

In terms of health risks, a number of studies have reported that accumulating < 5,000 steps/day is associated with a higher waist circumference,[19,24] body fat percentage,[20,22-24] and BMI.[15,19,20,22-25,55] Recent investigations have also indicated that the prevalence of hypertension, dyslipidemia, and the metabolic syndrome is higher among individuals taking < 5,000 steps/day in comparison to those accumulating more steps/day.[56,57] Additionally, McKercher and colleagues reported that the prevalence of depression was 50% higher among those individuals taking < 5,000 steps/day in comparison to those taking ≥ 7,500 steps/day among women, and ≥ 12,500 steps/day among men.[58]

Despite the utility of using a straight-forward criterion of < 5,000 steps/day as a marker of ambulatory insufficiency, a certain degree of subjectivity was involved in its development and a range of other daily minimums have been proposed.[45] Step accumulations of < 6,000 and < 7,500 steps/day have been labeled "inactive" among middle-aged American women and Australian men and women, respectively.[59,60] These same thresholds have been labeled "sedentary" in other studies among postmenopausal women.[61,62] Another definition, "insufficiently active", has been defined as < 6,700 steps/day for men and < 5,900 steps/day for women,[31] while < 4,000 steps/day has been referred to as "sedentary" in several Japanese studies.[17,63,64]

Although there is potential usefulness in identifying a singular minimum steps/day for screening and tracking purposes, this approach is imperfect, as relatively lower step counts will likely be associated with increasingly negative outcomes and relatively higher step counts will be associated with better outcomes.[45] In this sense, there is an inevitable degree of subjectivity in identifying any minimum daily step recommendation in an attempt to answer "how many steps/day are too few?" However, validation studies with longitudinal step data and tracking of various health outcomes may shed light on an appropriate minimum step threshold. Until that time, and considering the substantial body of published literature which has already adopted this threshold, the consistent use of the "sedentary lifestyle index" (< 5,000 steps/day) would allow for comparisons between studies and population groups.[45]

How many steps/day are enough?

Numerous government and agency public health bodies have published guidelines and recommendations which highlight the importance of physical activity and its role in chronic disease prevention.[3,65-68] These guidelines have emphasized moderate-to-vigorous physical activity as a primary behavioral target.[68] In recent times, various step-based recommendations have been put forth.[3-7] Such recommendations should be thought of as a supplement to existing physical activity guidelines, not a

replacement or a source of additional confusion.[69] Still, it would be useful to identify, in terms of habitual activity levels, "how many steps/day are enough?" while also reflecting existing public health recommendations for frequency, duration, and intensity.

A previous review attempted to answer "how many steps/day are enough?" by computing a steps/day value based upon current physical activity guidelines.[70] The review referenced previous laboratory studies which identified a cadence of 100 steps/min as a proxy for moderate-to-vigorous physical activity.[71-75] Using this information, and further assuming that physical activity guidelines typically call for 30 to 60 minutes of moderate-to-vigorous intensity activity per day,[67,76,77] a range of 7,100-11,000 steps/day was identified as the daily volume of steps needed to be sufficiently active.[70] This range of values accounts for a basal minimum of 5,000 steps/day. In order to truly meet physical activity guidelines, a portion of the abovementioned range (3,000 steps/day or 15,000 steps/week) should be completed in bouts of at least 10 minutes and at an intensity of at least 100 steps/min.[70]

Results from a series of studies that reported steps/day translations for time spent in moderate-to-vigorous physical activity and energy expenditure present another option for addressing the "how many steps/days are enough?" question.[50,78-82] Findings from these studies were summarized by Tudor-Locke and colleagues who reported that a threshold of 7,000-8,000 steps/day is indicative of an individual meeting minimal physical activity or energy expenditure guidelines.[70] Interestingly, the minimum steps/day value computed using the previously described assumption-based methods (i.e., 7,100 steps/day) falls within the 7,000 to 8,000 steps/day range. The American College of Sports Medicine (ACSM) included achieving ≥ 7,000 steps/day in its list of evidence-based recommendations collated as part of its 2011 Position Stand providing guidance for prescribing exercise.[7]

The "how many steps/day are enough?" question can also be evaluated from a health risk perspective. Krumm and colleagues reported that post-menopausal women who took 5,000-7,500 steps/day had significantly lower BMI values than those accumulating < 5,000 steps/day. Moreover, women who took 7,500-9,999 steps/day had significantly lower BMI values than those accumulating 5,000-7,500 steps/day. Despite this evidence, the general lack of information relating steps/day to health outcomes makes it difficult to answer "how many steps/day are enough?"

How fast is enough?

A measure of steps/day is an indicator of total volume of ambulatory activity, regardless of the speed at which it is accumulated. A meta-analysis of prospective cohort studies indicated that self-reported walking pace (or speed) was a stronger independent predictor of all-cause mortality than self-reported walking volume (48 vs. 26% reductions in risk, respectively).[83] Recently, some researchers have begun to capture and interpret cadence (step/min) in an effort to provide more information about free-living walking speed beyond simply using a measure of steps/day.[84-88] Walking speed is determined chiefly by cadence and stride length; cadence is the primary strategy employed to increase walking speed, giving over to stride lengthening as an individual transitions from walking to jogging to running.[89]

A number of controlled studies[71-75] have demonstrated that cadence is strongly related to intensity (r = 0.93)[89] and have consistently concluded that, despite inevitable inter-individual variability, a cadence of 100 steps/min is a reasonable heuristic value indicative of moderate intensity (defined as 3 METs; metabolic equivalents; 1 MET = 3.6 ml of oxygen consumed per kg body weight per minute). Based on eight different covert observation studies[90-97] of adults walking in parks, shopping centers, and city streets around the world, the mean weighted observed cadence is 115.2 steps/min,[89] clearly showing that cadences of > 100 steps/min are easily attainable in natural settings. However, analyses of accelerometer data collected as part of the U.S. NHANES indicates that time accumulated over 100 steps/min is a seemingly rare phenomenon in daily life for the average U.S. citizen.[88] In fact, these data show that U.S. adults average < 7 min/day at such a cadence but they do spend > 383 min/day at a cadence of 1-19 steps/

min and > 289 min/day at zero cadence (indicative of non-movement).

Faced with the rarity of moderate intensity free-living ambulation, but needing to rank individuals for surveillance and empirical inquiry nonetheless, some researchers have begun to report peak cadence indicators, specifically peak 30-minute cadence, defined as the mean steps/min for the highest (not necessarily consecutive) minutes in a day using the output from time-stamped accelerometers.[86,87,98] Peak 30-minute cadence has been described as an indicator of "best natural effort."[87] U.S. men average a peak 30-minute cadence of 73.7 steps/min, and despite their generally shorter stature (and therefore relatively higher cadence measured during short distance gait tests[99]), U.S. women have a lower average peak 30-minute cadence of 69.6 steps/min.[87] Peak 30-minute cadence is also related to age, BMI, and steps/day.[87,98]

Conclusions/Future research needs

Walking is integral to daily mobility and is also a part of a healthy lifestyle. Although a number of national- and state-representative assessments of step-defined physical activity have been published, continued collection of data representing other regions will further inform distribution characteristics of this objectively determined indicator of mobility and health. In addition, continued secondary analysis of existing health-related data sets will illuminate important relationships between steps/day and various health indicators. Widespread adoption of systematic on-going surveillance of step-defined physical activity outside of Japan would provide more precise international tracking data.

The available cross-sectional literature suggests that ambulatory volume (steps/day) is inversely associated with waist circumference, body fat percentage, and BMI; however, more longitudinal and intervention studies are needed if dose-response issues (e.g., "how many steps/day are too few?" or "how many steps/day are enough?") are to be clarified. Such studies may elucidate the relationships between walking and various negative health outcomes (e.g., obesity, heart disease, diabetes, etc.), while evaluating the best approaches to favorably modify walking behavior. Factors which appear to influence steps/day include climatic forces and perceived neighborhood walkability, however, additional research is required to explore, manipulate, and evaluate other factors that may shape this critical health behavior. Using cadence to capture and study ambulatory intensity in free-living is a novel frontier and more investigations are needed to elucidate the relationships between habitual best cadence measures (e.g., peak 30-minute cadence) and various negative health outcomes. In addition, it has yet to be determined whether or not cadence provides any more useful information compared to only using a simple volume indicator of steps/day. Given the obvious worldwide interest in step-defined physical activity research, it would be beneficial to foment international collaborations in an effort to support and implement this next phase of research.

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