Table 2 Studies of free-living behaviour reporting percent of participants meeting select step-defined cut points in adults *(Continued)*

McKercher [59] Australia 2009	766 men, 869 women; young adults participating in a longitudinal study; 26 to 36 years	Yamax Digiwalker SW-200	7 days	Adult Graduated Step Index	Men 8.2% < 5,000 29.6% 5,000-7,499 27.7% 7,500-9,999 19.7% 10,000-12,499 14.8% 12,500+ Women 6.7% < 5,000 28.2% 5,000-7,499 33.5% 7,500-9,999 21.1% 10,000-12,499 10.6% 12,500+
Schmidt [30] Australia 2009	887 men, 906 women; 26 to 36 years	Yamax SW-200	7 days	Adult Graduated Step Index	Men 7.8% 0-4,999 27.9% 5,000-7,499 27.3% 7,500-9,999 21.4% 10,000-12,999 15.7% 12,500+ Women 6.2% 0-4,999 27.9% 5,000-7,499 33.2% 7,500-9,999 21.3% 10,000-12,999 11.4% 12,500+
Tudor-Locke [83] USA 2011	1781 men, 1963 women; NHANES participants (nationally representative); 20 to 85+ years	ActiGraph AM-7164; censored data to approximate pedometer outputs	7 days	Adult Graduated Step Index with additional sedentary categories	Men 14.1% < 2,500 20.6% 2,500-4,999 24.2% 5,000-7,499 19.3% 7,500-9,999 10.9% 10,000-12,499 10.8% 12,500+ Women 14.1% < 2,500 20.6% 2,500-4,999 24.2% 5,000-7,499 19.3% 7,500-9,999 13.2% 10,000-12,499 10.8% 12,500+
Clemes [84] UK 2011	44 men 52 women; 18 to 65 years	SW-200 pedometer (New Lifestyles, Inc., Lees Summit, MO)	4 weeks in summer and again in winter	10,000 steps/day	Normal weight Summer 60% ≥ 10,000 Winter 35%≥ 10,000 Overweight Summer 43%≥ 10,000 Winter 35%≥ 10,000

Adult Graduated Step Index [11]: 1) < 5,000 steps/day ('sedentary'); 2) 5,000-7,499 steps/day ('low active'); 3) 7,500-9,999 steps/day ('somewhat active'); 4) ≥10,000-12,499 steps/day ('active'); and 5) ≥12,500 steps/day ('highly active'). These categories were reinforced in an updated review in 2008 [12] and in 2009 the original 'sedentary' level was segmented into two additional levels: < 2,500 steps/day ('basal activity') and 2,500 to 4,999 steps/day ('limited activity') [3].

adults, based on a cadence of 100 steps/minute [38-40,43,44]. To be considered a true translation of public health guidelines' focus on time in MVPA, however, these steps should be of at least moderate intensity (i.e., be ≥100 steps/minute), accumulated in at least 10 minute bouts, and should be taken *over and above* some baseline level of steps/day indicative of sedentarism. Since a value of ≤5,000 steps/day had been proposed as a 'sedentary lifestyle index' [11,12,48], summing this value and the supplemental steps/day considered minimally representative of recommended amounts of time in MVPA produces a floor value of approximately 8,000 steps/day. Some physical activity

Table 3 Controlled study designs that have informed "how many steps/day are enough?" in adults

Reference	Sample Characteristics	Step Counting Instrumentation	Protocol	Analysis strategy	Findings
Welk [41] 2000 USA	17 males, 14 females Cooper Aerobics Center employees 29.0 ± 8.0 years	Yamax Digi-Walker (Yamax Inc., Tokyo, Japan), observed tally	walk/jog a track and/or treadmill mile at 4, 6, and 7.5 miles/hr (6.4, 9.66, and 12.8 km/hr*)	steps taken for each pace extrapolated from 4mph pace steps in 30 minutes moderate intensity	3,800-4,000 steps would approximate 30 minutes of moderate intensity walking
Tudor-Locke [38] 2005 USA	25 males, 25 females university community 18 to 39 years	Yamax SW-200, Yamax Corp., Tokyo, observed tally	6-minute treadmill bouts at 4.8, 6.4, and 9.7 km/hr	VO_2 from expired gases Regression METs predicted from steps/minute	3,000-4,000 steps in 30 minutes of moderate intensity walking based on a threshold cadence of 100 steps/min
Marshall [39] 2009 USA	39 males, 58 females community sample of Latino adults 32.1 ± 10.6 years	Yamax SW-200, observed tally	6-minute treadmill bouts at 2.4, 3.0,3.5, 4.1 miles/hr (3.86, 4.83, 5.64, and 8.04 km/hr*)	VO_2 from expired gases; METs predicted from steps/minute multiple regression, mixed modelling, receiver operating curves	Inter-individual variation apparent however, minimally 3,000 steps in 30 minutes of moderate intensity walking based on a threshold cadence of 100 steps/min
MacPherson [42] 2009 New Zealand	12 males, 15 females university students 18 to 39 years	Observed tally	10,000 steps on treadmill at 3.2 and 6.4 km/hour	time to complete and PAEE kcal from Tritrac-R3D accelerometer	most participants could achieve at least 150 kcal in energy expenditure with 10,000 steps at the slow walk (median 255 kcal, range 148-401). Faster walking produced a higher energy expenditure (median 388 kcal, range 294-901).
Beets [44] 2010 USA	9 males, 11 females; healthy adults; 26.4 ± 4.5 years	Observed tally	6-minute hallway bouts at 1.8, 2.7, 3.6, 4.5, and 5.4 km/hr*	Random effects models to predict steps/min from METs and anthropometric measures	Inter-individual variation apparent however, minimally 3,000 steps in 30 minutes of moderate intensity walking based on a threshold cadence of 100 steps/min
Rowe [40] 2011 UK, USA	37 males, 38 females; university students, employees, and their families; 32.9 ± 12.4 years	Observed tally	6-minute treadmill bouts at randomly assigned sets of slow (mean 4.3 km/hr), medium (5.0 km/hr), fast (5.8 km/hr) speeds And Over-ground track walks (at least 4 minutes) at treadmill-determined cadences (cued by metronome)	Mixed model regression analysis to predict METs from cadence, anthropometric measures, stride length	Inter-individual variation apparent however, minimally 3,000 steps in 30 minutes of moderate intensity walking based on a threshold cadence of 100 steps/min
Abel [43] 2011 USA	9 males, 10 females; university population, frequent runners; 28.8 ± 6.8 years	Observed tally	10-minute treadmill bouts at walking (3.24, 4.8, and 6.42 km/hr*) and running speeds (8.04, 9.66, 11.28 km/hr*)	Linear and non-linear regression analysis to predict METs from cadence Mixed ANOVA: Between subjects (sex), within subject effect of speed for cadence, stride length, VO_2, and METs	Inter-individual variation apparent however, 100 steps/minute a reasonable estimate of moderate intensity walking

*reported speeds converted to km/hr.

guidelines recommend up to 60 minutes of activity that is of at least moderate intensity [6,9]. Multiplying 60 minutes by 100 steps/minute results in 6,000 steps, that when added to a 'sedentary' level of 5,000 steps/day produces a total value of 11,000 steps/day. Therefore, a simple arithmetical translation of free-living physical activity that also includes recommended amounts of time in MVPA is 8,000 to 11,000 steps/day for adults, applied with the caveats listed above, and if expressed as a daily recommendation.

It is important to emphasize that these calculations consider only activities that generate steps. There are, of course, a wide range of human activities that may or may not generate steps, for example, those that may include upper body movement. However, bipedal locomotor activity is a fundamental aspect of human movement. Additionally, it has been shown that wrist-worn accelerometers add little extra information to those worn at the waist (and therefore are also most sensitive to ambulatory

Table 4 Speed, MET levels, and cadence from track, treadmill, and hallway walking/running studies of adults

Reference	Speed (miles/hr)	Speed (km/hr)	MET	Cadence (spm)
Beets [44]	1.12[A]	1.8[A]	2.0[B]	64[C]
Beets [44]	1.68[A]	2.70[A]	2.4[B]	81[C]
MacPherson [42]	1.99[D]	3.2	2[E]	93
Abel [43]	2.01[F]	3.24[F]	3.1[B]	96[C]
Beets [44]	2.24[A]	3.6[A]	2.7[B]	96[C]
Marshall [39]	2.4	3.86[G]	3.09[H]	109[I]
Rowe [40]	2.7	4.3	2.94[J]	102
Beets [44]	2.8[A]	4.50[A]	3.2[B]	106[C]
Abel [43]	2.98[F]	4.80[F]	4.0[B]	114[C]
Tudor-Locke [38]	2.98[D]	4.8	3.60	108[C]
Marshall [39]	3	4.83[G]	3.73[H]	115[I]
Rowe [40]	3.1	5.0	3.46[J]	114
Beets [44]	3.36[A]	5.40[A]	3.9[B]	115[C]
Marshall [39]	3.5	5.64[G]	4.94[H]	124[I]
Rowe [40]	3.6	5.8	4.2[J]	125
Abel [43]	3.99[F]	6.42[F]	5.5[B]	127[C]
Tudor-Locke [38]	3.98[D]	6.4	5.25	127[C]
Welk [41]	4	6.44	5.25[K]	129[L]
MacPherson [42]	3.98[D]	6.4	5.25[K]	129
Marshall [39]	4.1	6.60[G]	6.85[H]	134[I]
Abel [43]*	5.0[F]	8.04[F]	9.18[B]	158[C]
Abel [43]*	6.0[F]	9.66[F]	10.93[B]	165[C]
Welk [41]*	6	9.66	10[M]	163[N]
Tudor-Locke [38]*	6.02[D]	9.7	10.00	161[C]
Abel [43]*	7.01[F]	11.28[F]	12.98[B]	170[C]
Welk [41]*	7.5	12.08	12.5[O]	165[P]

* Jogging/running.
Note: Superscripts denote values derived from information contained in original manuscript.
[A] Converted from reported meters/second.
[B] METs determined by weighted average METs reported for males and females.
[C] Cadence determined by weighted average spm reported for males and females.
[D] Converted from reported km/hr.
[E] Compendium code 1179: walking on job, less than 2.0 mph (in office or lab area), very slow.
[F] Converted from reported meters/minute.
[G] Converted from reported miles/hr.
[H] METs determined by weighted average METs for normal weight, overweight, obese.
[I] Cadence determined by weighted average hand-counted spm for normal weight, overweight, obese.
[J] Converted from reported VO_2.
[K] MET assumed to be the same as that for 6.4 km/hr pace in Tudor-Locke et al. [38].
[L] Cadence determined by dividing weighted mean steps for men and women (1936) by time taken to complete a mile (15 min).
[M] Compendium code 12050: running, 6 mph (10 minute mile).
[N] Cadence determined by dividing weighted mean steps for men and women (1631) by time taken to complete a mile (10 min).
[O] Compendium code 12080: running, 7.5 mph (8 minute mile).
[P] Cadence determined by dividing weighted mean steps for men and women (1317) by time taken to complete a mile (8 min).

activity detected while on the wrist) [49]. The calculation above focused on adding recommended amounts of MVPA to baseline physical activity levels and therefore presumes 30 minutes of MVPA in a day. Some public health guidelines now clearly promote 150 minutes/week as the minimal amount of health-related moderate intensity [1,7]. A computed translation of this expression is 15,000 steps/week, again based on the 100 steps/minute heuristic value described above. Considering 7 days at a baseline level of 5,000 steps/day (or 35,000 steps/week), adding these extra 15,000 steps/week (for a total of 50,000 steps/week), and averaging over 7 days, produces an average of approximately 7,100 steps/day. Adding an extra 30,000 steps/week (i.e., up to 300 minutes/week [1,7]), produces an overall estimate of approximately 9,300 steps/day averaged over a week.

In summary, a computed translation of daily free-living ambulatory physical activity for adults that includes allowance for recommended amounts of time in MVPA is 8,000 to 11,000 steps/day. Allowing for a more flexible accumulation pattern that may include some "off" days, and averaged across a week, the estimate is 7,100 to 9,300 step/day. Together these estimates span 7,100 to 11,000 steps/day. In both cases, it remains important to emphasize that at least a portion of these steps (3,000 for the daily accumulation and 15,000 of the weekly total accumulation) are minimally taken at an intensity of at least 100 steps/minute (i.e., moderate intensity, absolutely defined), and in bouts of at least 10 minutes.

Direct studies of step equivalents of physical activity guidelines

Six studies (Table 5) were identified that have attempted to provide steps/day translations of recommended amounts of either time spent in MVPA or energy expended (kcal) in healthy adults. Tudor-Locke et al. [48] reported that people who averaged 30 minutes/day of accelerometer-determined MVPA also accumulated 8,000 pedometer-determined steps/day when the two instruments were worn concurrently. Miller and Brown [50] reported that working adults who self-reported accumulating at least 150 minutes of MVPA in a week averaged 9,547 steps/day. Behrens et al. [51] reported that college students who accumulated at least 30 minutes of moderate intensity activity (vigorous intensity not considered) averaged 11,822 steps/day. In the latter two studies, mean values of the sample can be influenced by skewed data, and the process does not effectively capture a

Table 5 Studies that have attempted to set steps/day cut points in adults relative to time spent in MVPA or energy expended

First Author	Sample Characteristics	Instrument	Monitoring Frame	Analytical Strategy	Findings
Tudor-Locke [48] 2002 USA	27 men, 25 women university community 38.2 ± 12.0 years	Yamax SW-200, Yamax Corporation, Tokyo, Japan; CSA 7164 Version 2.2, Computer Science Applications, Inc., Shalimar, FL	7 days	Mean steps/day associated with the step/day quartile distribution in which participants accumulated an average of 30 min/day accelerometer-determined MVPA	8,000 steps/day corresponded with accumulating 30 minutes of MVPA people taking > 12,500 took more moderate and vigorous activity than any other group
Miller [50] 2004 Australia	74 men, 111 women workplace employees 18 to 75 years	Yamax SW 700; Active Australia questionnaire	7 days	Steps/day equivalent to 150+ minutes/week self-reported MVPA	Those who met guidelines averaged 9,547 ± 2,655 steps/day
Behrens [51] 2005 USA	18 men, 18 women college students 23.3 ± 3.1 years	Digi-walker (Model DW-200, Yamax, Tokyo, Japan) Actigraph 7164, Manufacturing Technology Incorporated, Fort Walton Beach, FL	7 days	Steps/day related to 30+ minutes of accelerometer-determined moderate physical activity	11,822 steps/day
Jordan [52] 2005 USA	111 postmenopausal women intervention participants 45-75 years	Accusplit Eagle 120 (AE 120)	7 days	Steps/day associated with attaining prescribed and verified exercise equivalent to 120-150 min/week or 8kcal/kg/week EE	3-4 days of 10,000 steps/day met energy expenditure guidelines for the week or approximately 7300 steps/day (imputed from reported data)
Macfarlane [53] 2008 China	30 men, 19 women apparently healthy 15 to 55 years	SW-700, Yamax Corporation., Tokyo, Japan MTI 7164, MTI Actigraph, Fort Walton Beach, FL Tritrac RT3, Stayhealthy INC., Monrovia, CA Heart rate monitor, Team system, Polar OY, Finland	7 days	Selected 25th percentile of steps/day distribution; examined sensitivity/specificity of achieving 30 minutes MVPA measured by various instruments	8,000 steps/day
Tudor-Locke [83] 2011 USA	1781 men, 1963 women; NHANES participants (nationally representative); 20 to 85+ years	ActiGraph AM-7164; censored data to approximate pedometer outputs	7 days	Step-defined activity category where at least 30 minutes of MVPA was accumulated	Men who took 7,500-9,999 steps/day accumulated 38 minutes MVPA; women who achieved 10,000-12,499 steps/day accumulated 36 minutes of MVPA (women who achieved 7,500-9,999 steps/day accumulated 25 minutes of MVPA

threshold value necessarily associated with achieving public health guidelines.

Jordan et al. [52] described total steps/day associated with attaining prescribed and verified exercise equivalent to 120-150 minutes/week or 8 kcal/kg/week of energy expenditure in a sample of post-menopausal women participating in an intervention study. They found that 3-4 days of 10,000 steps/day met energy expenditure guidelines for the week, and when considered along with data collected beyond the formal exercise setting, that is, in the course of daily living outside of exercise sessions and on non-exercise days, was equivalent to approximately 7,300 steps/day (imputed from data reported in the original article). MacFarlane et al. [53] selected the 25th percentile of steps/day distribution in 49 Hong Kong Chinese people aged 15-55 years, examined sensitivity/specificity of achieving 30 minutes MVPA measured by various instruments across quartiles of steps/day distribution, and reported that the 25th percentile value of 8,000 steps/day provided the best overall accuracy, sensitivity and specificity compared with higher quartile splits.

Finally, Tudor-Locke et al. [54] adjusted the 2005-2006 NHANES accelerometer data to more closely represent pedometer-based scaling and considered concurrently detected minute-by-minute step and activity count data from over 3,500 individuals with at least one valid day of wear time defined as 10/24 hours/day. Considering any minute spent in MVPA, they reported that 30 minutes/day was associated with approximately 8,000 steps/day for both men and women. A focused analysis on a sub-sample of participants with 7 valid days indicated that 150 minutes/week of MVPA was associated with approximately 7,000 steps/day (or 49,000 steps/week). The authors concluded that 7,000 to 8,000 steps/day, acknowledging that more is better, is a reasonably simple message that is also congruent with public health recommendations focused on minimal amounts of MVPA. A caveat is that these data considered any minute above MVPA, and therefore do not reflect an exact translation of public health guidelines that include a directive for minimal bout lengths. However, the chasm between these guidelines that have been traditionally based on self-reported activity and objectively monitored activity has been pointed out previously by users of these NHANES data [55].

In summary, directly studied estimates of free-living behaviour suggest that a total daily volume of ambulatory physical activity associated with meeting minimal amounts of MVPA is at least 7,000-8,000 steps/day. This range is similar to the threshold produced from the assumption-based computations above (i.e., 7,100 steps/day). Collectively, the results suggest that the designation of 'active' originally reserved for achieving at least 10,000 steps/day [11,12], actually encompasses a range that begins as low as 7,000 steps/day if 'active' is intended to indicate likelihood of achieving recommended amounts of weekly MVPA. Spread out over a week, more modest increases of ≅ 2,800 steps on three days/week, in line with just 50% of public health guidelines, and relative to a sedentary baseline (i.e., ≅ 4,700 steps/day) have produced important improvements in a number of health outcomes [52,56-58]. This is in keeping with the recent physical activity guidelines [1] that acknowledge that, especially for inactive adults, "some physical activity is better than none."

Steps/day associated with various health outcomes

Although this section does not deal directly with a step-based translation of existing physical activity guidelines, five cross-sectional studies were identified that have attempted to set steps/day cut points relative to any health-related outcome, and these fit under the general purpose of this review to consider "how many steps/day are enough?" McKercher et al. [59] reported that women who achieved ≥ 7,500 steps/day had a 50% lower prevalence of depression than women taking < 5,000 steps/day. No additional benefit for depression was observed from attaining higher step-defined physical activity levels. Men who achieved ≥ 12,500 steps/day also had a 50% reduction in prevalence of depression compared with those taking < 5,000 steps/day. Only the women's results were statistically significant.

Krumm et al. [29] examined the relationship between pedometer-determined steps/day and body composition variables in 93 post-menopausal women. In relation to BMI, a linear relationship was observed such that women who took 5,000-7,500 steps/day had a significantly lower BMI than those who took < 5,000 steps/day. Further, women who took 7,500-9,999 steps/day had a significantly lower BMI than those who took 5,000-7,500 steps/day. There was no significant difference in BMI between women who took 7,500-9,999 steps/day and those who took > 10,000 steps/day.

Although Dwyer et al. [60] did not expressly set any specific steps/day cut point, they did document an inverse cross-sectional relationship between steps/day and markers of obesity in a population-based adult sample. Further, the logarithmic nature of the relationship was such that greater relative differences in waist circumference and BMI were observed for those taking habitually lower steps/day. Specifically, an extra 2,000 steps/day for someone habitually taking only 2,000 steps/day was associated with a 2.8 cm lower waist circumference in men compared with 0.7 cm lower for men already walking 10,000 steps/day. The corresponding values for potential reductions in waist circumference for women were 2.2 and 0.6 cm, respectively, for a 2,000 step addition to the two habitual walking level examples. Not surprisingly, there were larger differences in both waist circumference and BMI between those reporting 2,000 steps/day and those reporting higher counts of 10,000, 15,000 or 20,000 steps/day, but the relative benefits of small differences at lower habitual levels were still notable.

Tudor-Locke et al. [61] applied a contrasting groups method to identify optimal steps/day related to BMI-defined normal weight vs. overweight/obese in an amalgamated data base featuring pedometer and BMI data that were independently collected but using similar protocols and the same type of pedometer from Australia, Canada, France, Sweden, and the USA. Despite data limitations (e.g., fewer data available for men than women), the researchers suggested that a total number of steps/day related to a normal BMI in adults would range from 11,000 to 12,000 in men and from 8,000 to 12,000 in women, and that values were consistently lower in older age groups than in younger age groups. Spring-levered pedometers are known to undercount steps related to obesity, so the values in this data base reflect that potential threat to validity [62]. However, their use does not completely misrepresent the general findings that steps/day differ significantly across BMI-defined obesity categories, even when measured by more sensitive accelerometers [63]. Once again, however, since pedometers are more likely to be used in clinical and public health applications, the presentation of pedometer-determined steps/day as detected in free-living populations, that include obese individuals, is relevant and therefore defensible.

It is important to consider whether we are asking the wrong question (at least for some health parameters): "How many steps/day are enough?" The question itself promotes a single-minded pursuit of threshold values, a presumed phenomenon that may not accurately characterize the true shape of a specific dose-response curve. Further, if such a threshold exists, it might only be readily achieved by a small and possibly already active subsample of any population. Recently, there has been growing interest in the study of sedentary behaviour and its potentially deleterious effects on health [64,65]. Considering this, it may be that the more appropriate question to ask in terms of pedometer-determined physical activity cut points is "How many steps/day are too few?" In support of this notion, many of the studies herein could be re-interpreted to conclude what levels of step-defined physical activity were associated with compromised health outcomes. For example, Schmidt et al. [30] reported that individuals taking < 5,000 steps/day had a substantially higher prevalence of a number of adverse cardiometabolic risk factors than those taking higher steps/day. From a public health practice point of view it is both rational and appealing to focus on motivating behaviour change in the larger portions of the population with low to very low physical activity levels rather than to focus solely on tailoring messages that may very well only appeal to subsamples that are already comparatively active. The adoption and use of a fully expanded steps/day scale that incorporates step-based translations of recommended amounts of MVPA would facilitate efforts designed to communicate both "How many steps/day are enough?" and also "How many steps/day are too few?"

In summary, it may be that specific thresholds of step-defined physical activity are associated in different ways with specific health outcomes. For example, relatively greater benefits in body composition parameters may be realized with small increments (e.g., adding 2,000 steps/day) over low levels of habitual activity in individuals who already have excess body fat, but "normalization" (with no further needed improvements) may require optimally higher physical activity levels (e.g., 11,000 to 12,000 steps/day in men, 8,000 to 12,000 step/day in women) and be relatively more difficult to achieve. Other health parameters may exhibit a more classic threshold effect, for example, positive effects on depression at ≥ 7,500 steps/day [59]. The concept of distinctly different dose-response curves related to physical activity is in keeping with the findings presented at the historic dose-response symposium in 2001 [66].

Discussion

Human movement is not limited to bipedal locomotion, however, such locomotion is a fundamental part of daily life and is a prominent focus of public health physical activity guidelines. Steps can be accumulated throughout the day during chores, occupational requirements, child care, errands, and transportation. Walking for exercise remains the most frequently reported leisure-time activity [67]. Other types of sport and exercise can also be viewed as strategies to increase steps/day [68], but some activities, for example, swimming, and bicycling, are alternative healthy physical activities that do not easily lend themselves to tracking with pedometers [69]. We acknowledge that step-based recommendations for physical activity might be more appropriate and better received by the large segment of the population who do not regularly engage in any sport or other exercise apart from walking. Incorporating at least 30 minutes, or approximately 3,000-4,000 steps, of brisk walking should be emphasized with the promotion of any step-based recommendation, in line with public health guidelines' focus on time in MVPA. The additional benefits of engaging in even more vigorous intensity activities, and activities that do not necessarily focus exclusively on bipedal locomotion, should also be acknowledged [1].

Current public health physical activity guidelines are derived from accumulated knowledge gained over the past several decades primarily from epidemiological and intervention studies of self-reported physical activity. To be clear, messages to perform at least 30 minutes of moderate intensity activity on most, preferably all days of the week [70] (or more recently, at least 150 minutes/week in moderate intensity, 75 minutes/week in vigorous intensity physical activity, or a combination of both [1,7]) can be, for the most part, traced back to research participants' subjective descriptions of this duration, intensity, and frequency of leisure-time physical activity behaviour. The well-designed dose-response to exercise in women (DREW) study clearly demonstrated that previously sedentary women who performed even 50% of physical activity guidelines, expressed in terms of energy expenditure and objectively verified, reaped benefits in terms of significant improvements in measured cardiorespiratory fitness [56], for example. However, with the advent of body worn objective monitoring technologies there has been a keen interest in providing an objectively determined translation of the physical activity guidelines as stated, particularly with reference to time in MVPA. It is quite easy to ask someone to walk on a treadmill for 30 minutes at moderate intensity and produce a precise estimate of directly observed steps taken, for example. However, it is important to emphasize that the rich collection of research that has informed public health guidelines to date is based, for the most part, on self-reported behavior, that is, people's unique perceptions and accounts of their own behaviour. We have come to accept that, although there is a correlation [2], there is a disconnect between self-reported and objectively monitored physical activity; agreement between cross-tabulated NHANES accelerometer and self-reported physical activity data was only 18.3% (men, 20-59 y) to 32.7% (women, 60+ y) [55]. Further, those with absolutely no accelerometer-determined time spent in MVPA self-reported accumulating 43.1 to 65.2 minutes/day in MVPA [55]. To be very clear, it remains possible that self-reported frequency and time spent in absolutely defined MVPA actually equates to a lesser amount of objectively monitored behaviour than a direct and objective measurement of free-living activity, that includes the same amount of MVPA, would suggest. Alternatively, it is plausible that people have been systematically over-reporting absolute intensity of activity, as evident from the observed discrepancy between concurrent estimates of self-reported and objectively measured activity [55].

Any time a cut point of any type is set, there is an inevitable trade-off between sensitivity and specificity. Sensitivity is the proportion of true positives (values that are classified correctly as positive) relative to the sum of both true positives and false negatives and specificity is the proportion of true negatives (values that are classified correctly as negative) relative to the sum of both true negatives and false positives. For example, and hypothetically, if we set 10,000 steps/day as a cut point indicative of attaining public health guidelines that includes meeting minimal requirements for MVPA, we would anticipate that there will be some people who take 10,000 steps/day and do not accumulate 30 minutes of MVPA in at least 10-minute bouts (false positives) and also people who take less than 10,000 steps/day and still manage to accumulate 30 minutes of MPVA in at least 10-minute bouts (false negatives). This phenomenon is known [41,71-74]. If we raise the cut point to say, 12,500 steps/day, we can increase specificity and reduce the number of false positives. The trade-off is decreased sensitivity: we misclassify those who achieve sufficient MVPA at lower steps/day values. A higher cut point is desirable in research if we really want to save resources, and are willing to 'let some slip by' in a focused effort to locate those for our research studies who are most likely to be accumulating appropriate amounts of time spent in MVPA. Alternatively, if we lower the cut point to say, 7,500 steps/day, sensitivity is increased (i.e., more people meeting MVPA guidelines will be correctly classified) at the expense of decreased specificity (i.e., more people who do not meet MVPA guidelines will be incorrectly classified as if they have met them). This latter scenario is likely to be more acceptable in terms of public health strategies to communicate healthful levels of physical activity, especially if they are communicated as minimal cut points, above which additional benefits may be reaped. Regardless, it is important to realize that, whatever threshold is selected, there will be "exceptions to the rule" and these must be tolerated, otherwise confidence in any guideline can deteriorate.

Using a graduated step index as originally developed [11] to categorize escalating levels of pedometer-determined physical activity represents an important evolution beyond single value estimates of "How many steps/day are enough?" (e.g., 10,000 steps/day). Any single value, although attractive in terms of simplistic messaging, is vulnerable to "exceptions to the rule" and must be repeatedly declared with several caveats. Further, it can undermine credibility in communicating the importance of a physically active lifestyle to health at any age when it is perceived that disagreement and confusion exist. In contrast, a graduated step index has the potential to bridge research and practice because it has utility in research (e.g., reporting health outcomes across step-defined physical activity levels, tracking population levels of achievement, etc.), clinical practice (screening, prescription, compliance, etc.), behaviour change (goal-setting, self-monitoring, feedback, etc.), and public health practice (surveillance, evaluation, communication, etc.). Increased physical activity can be captured individually or on a population level by attainment of relatively higher levels within the graduated step index. The graduated levels are congruent with the now accepted concept that some activity is better than none, that increased levels of activity should be approached progressively, and that health may be optimized at higher levels, although some relatively important health benefits may be realized even with improvements over the lowest levels [1].

A further improvement to the original graduated step index would be to offer a more fully expanded steps/day scale with additional "rungs on the ladder," which may be very important when applied to low active individuals and populations. Such a scale would incorporate step-based translations of public health recommendations for MVPA (e.g., superimposed on the scale), but also provide additional incremental "rungs" corresponding with roughly 10-minute bouts of activity, beginning at zero and continuing to 18,000+ steps/day, the highest mean value reported for a sample at this time: Amish men [18]. This concept is shown in Figure 1. The arrows, which suggest that more is even better, are superimposed over the fully expanded scale in Figure 1 and summarize steps/day ranges congruent with recommendations for time in MVPA across the lifespan. The base of the arrow indicates a minimal amount of recommended steps for a subgroup. For example, the range for adults is 7,000-8,000 steps/day, at least 3,000 of which should be accumulated at a brisk pace. To emphasize, this is only a threshold and the arrow indicates that more is even better. Individual and

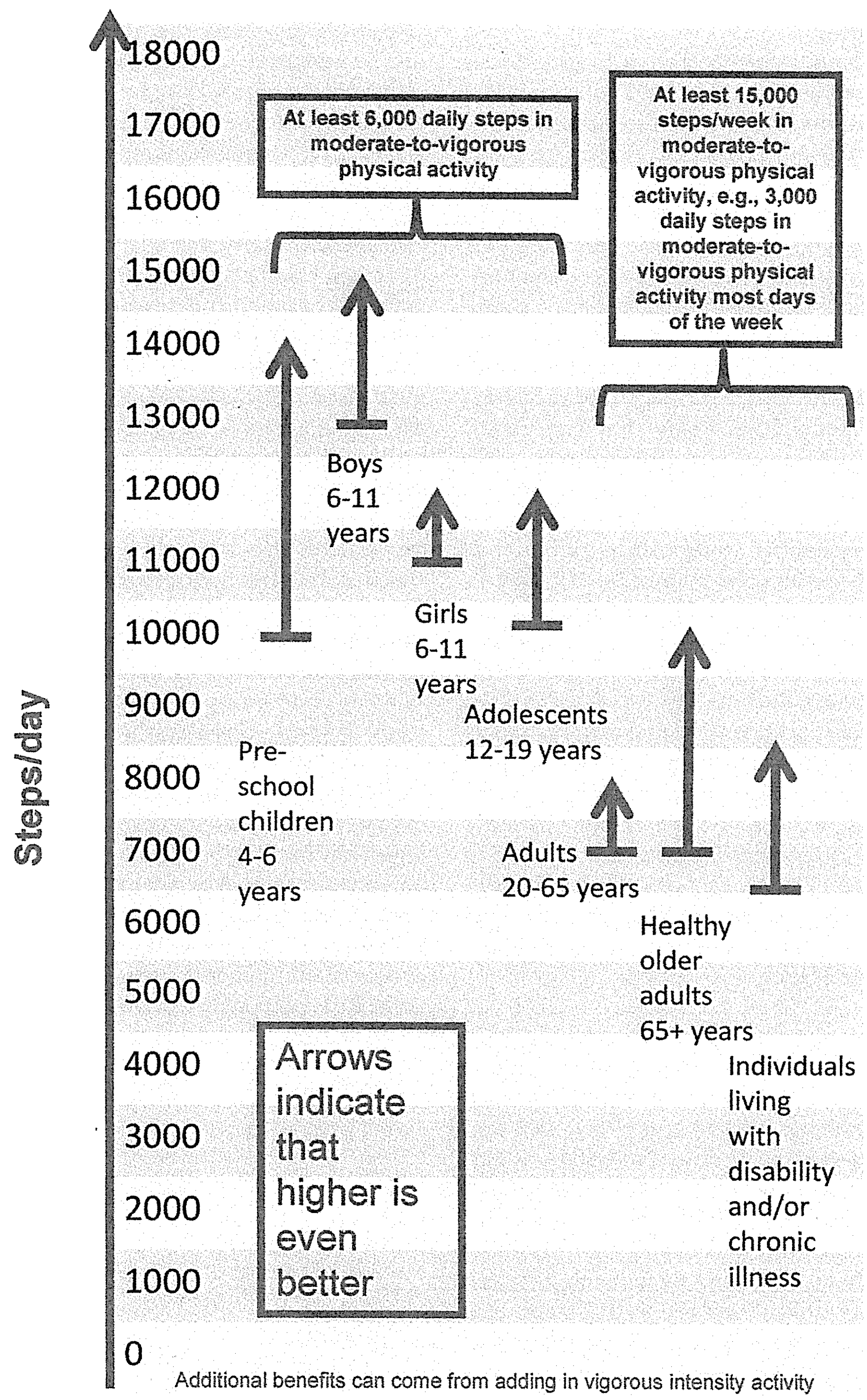

Figure 1 Steps/day scale schematic linked to time spent in MVPA.

population values could be tracked and defined across the lifespan using such a common steps/day scale. Populations could be stratified and motivated and/or tracked to achieve a step/day increment coinciding with public health guidelines (e.g., 3,000 steps/day at minimally moderate intensity, and if at all possible, vigorous intensity). Smaller increments (e.g., 1,000 steps, equivalent to 10-minute bouts) could also be used to track progress on either the individual or population level. Further, as evidence continues to emerge, the likelihood of achievement of different health-related outcomes could be indicated along the graduated continuum.

A number of limitations must be acknowledged. Waist-worn pedometers and accelerometers are most sensitive to vertical accelerations (i.e., up and down motions) of the hip while ambulating (i.e., walking, jogging, running, skipping, hopping, dancing, etc.). Different devices will have different measurement mechanisms, for example, coil springs, hair springs, piezo-electric ceramics, etc., and these are patent-protected making direct comparisons between similarly named outputs challenging [75]. Differences in instrument sensitivity will affect the number of steps detected, with the greatest discrepancies resulting from divergent detection of low force accelerations. Further, as commercial items, new instrument versions appear regularly and obsolescence of specific models is always a threat [75]. However, the consistent use of research-quality pedometers does permit an opportunity for reasonable comparisons to be made across studies and between populations [28]. The instruments determined to be most suitable for the assessment of free-living physical activity have been scrutinized and include the Kenz Lifecorder, the Yamax, and the NewLifestyles NL pedometers [76]. As can be seen from the assembled tables, these instruments and other comparable instruments are well represented in research studies conducted to date. It has been noted, however, that the use of piezo-pedometers (e.g., NL series) may be more appropriate than spring-levered instruments for use in obese individuals [62]. Finally, we acknowledge that different technologies, investigators, populations, cut points, criterion measures, methodologies, etc., make rendering a simple message challenging.

Conclusions

In summary, at least in terms of normative data, it appears that healthy adults can take anywhere between approximately 4,000 and 18,000 steps/day, and that 10,000 steps/day is a reasonable target for healthy adults, although there are notable "low active populations," including the U.S. populace [3,23]. The results of controlled studies of treadmill and over-ground walking demonstrate that there is a strong relationship between cadence and intensity, at least between 64-170 steps/minute (i.e., the values catalogued in Table 4). These cadence values can be used to generate step-based translations of minimal amounts of time in MVPA, but apply most directly to bipedal locomotor activities that produce steps. At this time the five studies [38-40,43,44] that specifically queried the number of steps in moderate intensity activity have come to similar conclusions: 100 steps/minute represents a reasonable floor value (i.e., 3 METs) that can be useful as a public health heuristic value indicative of moderate intensity walking. Multiplying this cadence by 30 minutes produces a minimum of 3,000 steps. It is important that the precision of any estimate not be overstated, but instead serve as guiding value, rather than a prescriptive one. However, an appropriate translation of physical activity guidelines, specifically allowing for minimal amounts of time in MVPA, implies that steps should be taken *over and above* those taken in the course of habitual and incidental daily activities, and also should be taken in bouts of at least 10-minutes in duration. Computed translations of free-living physical activity that also includes recommended MVPA are equivalent to 7,100 to 11,000 steps/day. Direct estimates of minimal amounts of MVPA detected in the context of monitored free-living behaviour are 7,000-8,000 steps/day. Although more weight should be given to the direct estimates, the fact that the minimal values for both are similar provides more confidence in concluding that approximately 7,000-8,000 steps/day is a reasonable threshold of free-living physical activity that is also associated with current public health guidelines' emphasis on minimal amounts of time spent in MVPA. Other levels of step-defined physical activity might be associated with various health outcomes, in keeping with current understanding of dose-response relationships. A fully expanded steps/day scale that spans a wide range of incremental increases in steps/day yet communicates step-based translations of recommended minimal amounts of time in MVPA may be useful in research and practice. Finally, regardless of the specified number of steps/day, effective programs, informed by the best research on critical moderators and mediators of behaviour change (i.e., what works best for whom under what conditions and at what cost) remain implicitly necessary in terms of increasing individual and population levels of ambulatory activity.

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Author details
[1]Walking Behavior Laboratory, Pennington Biomedical Research Center, Baton Rouge, LA, USA. [2]Canadian Fitness and Lifestyle Research Institute, Ottawa, ON, Canada. [3]School of Public Health, University of Sydney, Sydney, Australia. [4]School of Human Movement Studies, University of Queensland, Brisbane, Australia. [5]School of Sport, Exercise and Health Sciences, Loughborough University, UK. [6]Department of Movement and Sports Sciences, Ghent University, Ghent, Belgium. [7]Center for the Built Environment and Health, School of Population Health, The University of Western Australia. [8]Tokyo Gakugei University, Tokyo, Japan. [9]Department of Preventive Medicine and Public Health, Tokyo Medical University, Tokyo, Japan. [10]Centro de Estudos do Laboratório de Aptidão Física de São Caetano do Sul (CELAFISCS), Brazil. [11]School of Psychological Sciences and Health,

University of Strathclyde, Glasgow, UK. [12]Department of Nutrition, Pitié-Salpêtrière Hospital (AP-HP), University Pierre et Marie Curie-Paris6, Center for Human Nutrition Research Ile-de-France (CRNH-IdF), Paris, France. [13]Department of Kinesiology, University of Georgia, Athens, GA, USA. [14]Menzies Research Institute, University of Tasmania, Hobart, Australia. [15]Centre for Physical Activity and Nutrition, Auckland University of Technology, Auckland, New Zealand. [16]Faculty of Physical Education and Recreation, University of Alberta, Alberta, Canada. [17]Faculty of Human Kinetics, Technical University of Lisbon, Lisbon, Portugal. [18]UKCRC Centre for Public Health (NI), Queen's University, Belfast, Ireland. [19]Departments of Exercise Science and Epidemiology/Biostatistics, Arnold School of Public Health, University of South Carolina, Columbia, USA.

Authors' contributions

CT-L and CLC conceived and designed the project. CT-L acquired the data and prepared analysis for initial interpretation. All authors contributed to subsequent analysis and interpretation of data. CT-L prepared a draft of the manuscript. All authors contributed to critically revising the manuscript for important intellectual content. MAT, SAC, and DAR edit checked the tables. All authors gave final approval of the version to be published and take public responsibility for its content.

Competing interests

The following authors declare they have no competing interests: CT-L, WJB, SAC, KDC, BG-C, YH, SI, SMM, NM, J-M O, DAR, MDS, GMS, JCS, PJT, and MAT. CLC is associated with the Canadian Fitness and Lifestyle Research Institute which is funding in part by the Public Health Agency of Canada (PHAC). SNB receives book royalties (<$5,000/year) from Human Kinetics; honoraria for service on the Scientific/Medical Advisory Boards for Alere, Technogym, Santech, and Jenny Craig; and honoraria for lectures and consultations from scientific, educational, and lay groups. During the past 5-year period SNB has received research grants from the National Institutes of Health, Department of Defence, Body Media, and Coca Cola.

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Time Trends for Step-Determined Physical Activity among Japanese Adults

SHIGERU INOUE[1], YUMIKO OHYA[1], CATRINE TUDOR-LOCKE[2], SHIGEHO TANAKA[3], NOBUO YOSHIIKE[4], and TERUICHI SHIMOMITSU[1]

[1]Department of Preventive Medicine and Public Health, Tokyo Medical University, Tokyo, JAPAN; [2]Walking Behavior Laboratory, Pennington Biomedical Research Center, Baton Rouge, LA; [3]Project for Energy Metabolism, Health Promotion and Exercise Program, National Institute of Health and Nutrition, Tokyo, JAPAN; and [4]Department of Nutrition, Aomori University of Health and Welfare, Aomori, JAPAN

ABSTRACT

INOUE, S., Y. OHYA, C. TUDOR-LOCKE, S. TANAKA, N. YOSHIIKE, and T. SHIMOMITSU. Time Trends for Step-Determined Physical Activity among Japanese Adults. *Med. Sci. Sports Exerc.*, Vol. 43, No. 10, pp. 1913–1919, 2011. **Purpose:** The study's purpose was to describe the most recently reported (2007) step-determined physical activity and trends from 1995 to 2007 among Japanese adults. **Methods:** Data were extracted from published reports of the Japan Heath and Nutrition Survey, which has been conducted annually by the Ministry of Health, Labour and Welfare of Japan using a nationally representative Japanese adult sample of 6502–9833 participants (≥20 yr) each year. Pedometer data were collected on an individually specified weekday in November each year. Because of the change in age distribution of the sample, steps per day were adjusted by age to examine time trends. **Results:** Men took 7321 ± 4588 (mean ± SD) steps per day and women took 6267 ± 3827 steps per day in the Japan Heath and Nutrition Survey 2007. Men took more steps per day than women in all age groups. Steps per day were lower with older age groups among men, whereas among women, the 40- to 49-yr-old age group took the highest steps per day relative to other ages. Time trends displayed a decline of age-adjusted mean steps per day (−529 steps per day among men and −857 steps per day among women) from peak values in 1998–2000 to 2007. Decreases in percent of people classified as active (age-adjusted proportion taking ≥10,000 steps per day = −5.1% among men and −5.0% among women) and increases in percent classified as sedentary (age-adjusted proportion taking <4000 steps per day = +4.8% among men and +8.2% among women) were also observed during the same period. **Conclusions:** Japanese steps per day have decreased over time from a peak around 1998–2000. The increase in the percent taking <4000 steps per day was especially noticeable among women.

Key Words: PHYSICAL ACTIVITY, STEPS PER DAY, DESCRIPTIVE EPIDEMIOLOGY, SURVEILLANCE

The health benefits of physical activity have been well documented (10,35). There is an abundance of physical activity surveillance literature published focused on US populations that indicates relatively few people practice a physically active lifestyle (1,30). Large proportions of the population in Japan and in many other countries in the world are also insufficiently active (14,36). Thus, physical activity surveillance and promotion continue to be important public health priorities around the world.

Surveillance of population physical activity provides the basic information for the planning, implementation, and evaluation of public health practice. To date, most physical activity surveillance activities have been conducted using self-report instrumentation. However, the potential for information bias from self-reported physical activity is a well-known limitation (28). For example, the proportion of people meeting recommended levels of physical activity is discrepant between self-report and accelerometry (8,30). Indeed, recent progress in physical activity assessment technologies now permits surveillance using objective methods, including accelerometers and pedometers. For example, the US National Health and Nutrition Examination Survey (NHANES) used an accelerometer to objectively monitor physical activity in 2003–2004 (30) and again in 2005–2006 (34). Pedometers have also been used in surveillance (2,3,13).

The National Health and Nutrition Survey of Japan (NHNS-J) has been monitoring pedometer-determined physical activity among Japanese since 1989 (14). However, the results of this survey are not well recognized because they have not been published in the English language. Also, time trends for step-determined physical activity have not been examined across survey years. Although the data from this survey are not available on an open-access basis, it is possible to synthesize the published cross-sectional summarized data from each year adjusted for age and to describe time trends for pedometer-determined physical activity among the Japanese population.

In the present study, the 1995–2007 levels of step-determined physical activity are reported, and age-adjusted time trends among Japanese were examined using data

Address for correspondence: Shigeru Inoue, M.D., Ph.D., 6-1-1 Shinjuku, Shinjuku-ku, Tokyo 160-8402, Japan; E-mail: inoue@tokyo-med.ac.jp.
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extracted from the series of summary reports available from the NHNS-J (14–22).

METHODS

NHNS-J. The NHNS-J has been conducted annually since 1945 by the Ministry of Health, Labour and Welfare (MHLW) in Japan. It dictates collection of fundamental information for health promotion mainly from the viewpoint of lifestyle among Japanese. The survey consists of three parts: 1) physical condition, 2) nutritional aspects, and 3) lifestyle (14). The physical condition aspect of the survey includes anthropometry, blood pressure, blood sampling, and pedometer-determined physical activity (since 1989) among other parameters. In this study, we focused solely on the results of the pedometer survey.

Data source. The results of NHNS-J are summarized by MHLW and released in a brief website report in the year after data collection. A more detailed final report is also released a few years after the survey. Because raw data from this survey are not openly accessible, we used the final reports and summarized data for secondary analyses herein (14–22). As noted above, the NHNS-J first implemented pedometer-based surveillance in 1989. However, in the early stage of this pedometer surveillance strategy, participant inclusion criteria and the method of data summarization in MHLW reports were not consistent. Thus, this study examined the most consistently collected and presented data available annually from 1995 to the newly released 2007 survey. Pedometer data extracted from the 1995–2007 NHNS-J included mean steps per day and the number of participants in MHLW-defined steps per day categories (0–1999, 2000–3999, 4000–5999, 6000–7999, 8000–9999, 10,000+ steps per day) by gender (men, women) and age categories (20–29, 30–39, 40–49, 50–59, 60–69, 70+ yr old) (14–22).

Participants in NHNS-J. The annual administration of the NHNS-J begins with a selection of 300 census units. These 300 were randomly chosen from a total of 2000 census units previously selected from the whole of Japan (about 1,960,000 census units) using a stratified random sampling method as part of the Comprehensive Survey of Living Conditions of the People on Health and Welfare. Each census unit included approximately 20 households. All households and residents aged 1 yr or older in these 300 units were asked to participate in the NHNS-J. Only individuals age 15 yr or older were invited to participate in the pedometer component of the survey. This analysis focused on step-determined physical activity of adults, which is defined as 20 yr or older in Japan. The NHNS-J sampling strategy was consistent from 1995 to 2007. For example, in the NHNS-J of 2007, the 300 census units selected included approximately 6000 households, composed of approximately 18,000 family members age 1 yr or older. All of these individuals were asked to join the survey. As a result, 8885 residents participated in the nutrition component of the NHNS-J, and 7131 participated in the pedometer component. Among these 7131, 6768 were 20 yr old or older. Numbers of participants in each year organized by gender and age are indicated in Table 1.

Pedometer-determined physical activity. The same pedometer, AS-200 (Yamasa Co., Ltd., Tokyo, Japan), was used for the NHNS-J from 1995 to 2007. Yamasa is the Japanese generic name for Yamax, a commonly used research-grade pedometer. The survey was conducted on a

TABLE 1. Numbers of participants in the pedometer part of the NHNS-J by gender and age.

	Total		20–29 yr		30–39 yr		40–49 yr		50–59 yr		60–69 yr		70+ yr	
	n	Pct.	*n*	Pct.	*n*	Pct.	*n*	Pct.	*n*	Pct.	*n*	Pct.	*n*	Pct.
Men														
1995	4404	100.0	678	15.4	836	19.0	935	21.2	782	17.8	692	15.7	481	10.9
1996	4363	100.0	663	15.2	696	16.0	884	20.3	809	18.5	786	18.0	525	12.0
1997	4195	100.0	632	15.1	606	14.4	839	20.0	859	20.5	725	17.3	534	12.7
1998	4458	100.0	621	13.9	721	16.2	830	18.6	855	19.2	830	18.6	601	13.5
1999	3938	100.0	554	14.1	627	15.9	680	17.3	802	20.4	725	18.4	550	14.0
2000	3860	100.0	522	13.5	584	15.1	654	16.9	804	20.8	745	19.3	551	14.3
2001	4200	100.0	507	12.1	651	15.5	760	18.1	887	21.1	760	18.1	635	15.1
2002	3962	100.0	478	12.1	603	15.2	636	16.1	830	20.9	766	19.3	649	16.4
2003	3849	100.0	465	12.1	607	15.8	592	15.4	766	19.9	726	18.9	693	18.0
2004	2941	100.0	310	10.5	473	16.1	440	15.0	599	20.4	589	20.0	530	18.0
2005	3066	100.0	351	11.4	455	14.8	453	14.8	578	18.9	609	19.9	620	20.2
2006	3248	100.0	311	9.6	533	16.4	485	14.9	665	20.5	586	18.0	668	20.6
2007	3082	100.0	274	8.9	506	16.4	482	15.6	561	18.2	631	20.5	628	20.4
Women														
1995	5336	100.0	827	15.5	924	17.3	1088	20.4	982	18.4	806	15.1	709	13.3
1996	5319	100.0	849	16.0	803	15.1	1051	19.8	967	18.2	928	17.4	721	13.6
1997	5209	100.0	826	15.9	751	14.4	995	19.1	1006	19.3	824	15.8	807	15.5
1998	5375	100.0	713	13.3	868	16.1	965	18.0	1057	19.7	931	17.3	841	15.6
1999	4869	100.0	740	15.2	742	15.2	793	16.3	944	19.4	890	18.3	760	15.6
2000	4613	100.0	578	12.5	718	15.6	789	17.1	973	21.1	802	17.4	753	16.3
2001	5038	100.0	637	12.6	816	16.2	842	16.7	1002	19.9	885	17.6	856	17.0
2002	4701	100.0	564	12.0	686	14.6	721	15.3	957	20.4	843	17.9	930	19.8
2003	4518	100.0	519	11.5	689	15.3	665	14.7	887	19.6	842	18.6	916	20.3
2004	3561	100.0	405	11.4	565	15.9	537	15.1	691	19.4	700	19.7	663	18.6
2005	3640	100.0	366	10.1	505	13.9	566	15.5	681	18.7	741	20.4	781	21.5
2006	3876	100.0	391	10.1	636	16.4	565	14.6	764	19.7	701	18.1	819	21.1
2007	3686	100.0	345	9.4	631	17.1	548	14.9	666	18.1	725	19.7	771	20.9

single individually specified day between Monday and Saturday in November every year. The specific dates for survey administration and pedometer monitoring were dependent on census units and on participants. Specifically, the survey office of each census unit set the survey period (e.g., a week-long period in the month of November). Participants then selected a single "typical" day during that period to monitor their physical activity with a pedometer. Craig et al. (4) have shown that a single day of pedometer data can be used for population surveillance purposes. Participants were asked to wear the device on their waist from the time they got up in the morning until the time they went to bed at night, removing the device only to engage in water-based activities. Participants recorded their steps per day on a survey log and returned it on a subsequently scheduled physical examination day.

Statistics. Mean ± SD steps per day and the proportion of participants classified in the MHLW step-defined activity categories were described by gender and age groups for the 2007 data. Regarding the time trend analysis between 1995 and 2007, 1) the mean steps per day, 2) the proportion taking ≥10,000 steps per day, and 3) the proportion taking <4000 steps per day by gender and age groups were presented. Because the age distributions of survey samples shifted over time to represent an aging population, these analyses were adjusted by age (i.e., setting the age distribution of the 1995 survey as standard).

Ethical issue. The survey was conducted on the basis of the Health Promotion Law of Japan. The Ministry of Internal Affairs and Communications of Japan reviewed and approved the survey protocols, and informed consent was obtained from participants. In this analysis, the data came from summarized reports that have been already published and do not include personal information.

RESULTS

In the NHNS-J 2007 (Table 2), mean ± SD steps per day were 7321 ± 4588 among men and 6267 ± 3827 among women. The proportion taking ≥10,000 steps per day was 23.3% among men and 16.0% among women, whereas the proportion taking <4000 steps per day was 24.8% among men and 30.6% among women. Men averaged more steps per day than women in all age groups. The gender differences were the largest in the 20- to 29-yr-old age group (1717 steps per day) and the smallest in the 60- to 69-yr-old age group (603 steps per day). Age-related declines of mean steps per day were observed in men. In women, participants age 40–49 yr old averaged the highest number of steps per day. In both genders, large declines in mean steps per day were observed among participants age 70 yr or older. Specifically, compared with 20–29 yr olds, 70-yr-old participants accumulated 3614 steps per day fewer in men and 3036 steps per day fewer in women.

The time trends for age-adjusted mean steps per day, age-adjusted proportion taking ≥10,000 steps per day, and age-adjusted proportion taking <4000 steps per day are presented in Table 3. For these indicators, 1998–2000 were the most active years in terms of pedometer-determined physical activity for both men and women. Age-adjusted mean steps per day declined from peak values in 1998–2000 to 2007 by 529 steps per day among men and by 857 steps per day among women. The age-adjusted proportion of active persons (≥10,000 steps per day) also declined among both men and women during this same time frame (−5.1% and −5.0%, respectively). In contrast, the age-adjusted proportion taking <4000 steps per day increased by 4.8% among men and by 8.2% among women.

TABLE 2. The pedometer-determined physical activity among Japanese by gender and age groups (the National Health and Nutrition Survey 2007).

		Men		Women	
Age (yr)	Steps per Day	*n*	Pct.	*n*	Pct.
All ages		3082	100.0	3686	100.0
	<1999	258	8.4	428	11.6
	2000–3999	505	16.4	701	19.0
	4000–5999	596	19.3	837	22.7
	6000–7999	532	17.3	637	17.3
	8000–9999	473	15.3	492	13.3
	≥10,000	718	23.3	591	16.0
	mean ± SD	7321 ± 4588		6267 ± 3827	
20–29		274	100.0	345	100.0
	<1999	17	6.2	19	5.5
	2000–3999	27	9.9	67	19.4
	4000–5999	45	16.4	84	24.3
	6000–7999	51	18.6	61	17.7
	8000–9999	49	17.9	44	12.8
	≥10,000	85	31.0	70	20.3
	mean ± SD	8562 ± 5187		6845 ± 3847	
30–39		505	100.0	631	100.0
	<1999	16	3.2	32	5.1
	2000–3999	71	14.1	95	15.1
	4000–5999	108	21.4	164	26.0
	6000–7999	82	16.2	137	21.7
	8000–9999	72	14.3	85	13.5
	≥10,000	157	31.1	118	18.7
	mean ± SD	8366 ± 5262		6820 ± 3501	
40–49		482	100.0	548	100.0
	<1999	18	3.7	19	3.5
	2000–3999	62	12.9	77	14.1
	4000–5999	86	17.8	133	24.3
	6000–7999	92	19.1	107	19.5
	8000–9999	83	17.2	95	17.3
	≥10,000	141	29.3	117	21.4
	mean ± SD	8147 ± 4389		7373 ± 3807	
50–59		561	100.0	666	100.0
	<1999	18	3.2	22	3.3
	2000–3999	68	12.1	108	16.2
	4000–5999	109	19.4	165	24.8
	6000–7999	117	20.9	128	19.2
	8000–9999	111	19.8	123	18.5
	≥10,000	138	24.6	120	18.0
	mean ± SD	7896 ± 3944		7063 ± 3484	
60–69		632	100.0	725	100.0
	<1999	51	8.1	63	8.7
	2000–3999	120	19.0	137	18.9
	4000–5999	124	19.6	177	24.4
	6000–7999	102	16.1	123	17.0
	8000–9999	90	14.2	101	13.9
	≥10,000	144	22.8	124	17.1
	mean ± SD	7162 ± 4435		6559 ± 3882	
70+		627	100.0	771	100.0
	<1999	138	22.0	273	35.4
	2000–3999	157	25.0	217	28.1
	4000–5999	124	19.8	114	14.8
	6000–7999	88	14.0	81	10.5
	8000–9999	68	10.8	44	5.7
	≥10,000	53	8.5	42	5.4
	mean ± SD	4948 ± 3596		3809 ± 3246	

TABLE 3. Trend of age-adjusted step counts among Japanese (the National Health and Nutrition Survey 1995–2007).

	Number of Participants		Mean Steps		Proportion of Those Who Walk ≥10,000 Steps per Day (%)		Proportion of Those Who Walk <4000 Steps per Day (%)	
	Men	Women	Men	Women	Men	Women	Men	Women
1995	4404	5336	7849	6820	26.5	18.3	19.4	23.9
1996	4363	5319	8054	7040	28.7	19.5	18.3	22.0
1997	4195	5209	8201	7264	28.9	21.3	16.8	20.1
1998	4458	5375	8144	7399	29.5	22.4	16.6	18.9
1999	3838	4869	8117	7335	28.8	21.9	17.9	19.6
2000	3860	4613	8246	7316	30.8	22.4	18.1	20.9
2001	4200	5038	7902	7219	26.9	21.9	19.2	20.9
2002	3962	4701	7946	7325	28.4	22.0	19.8	19.8
2003	3849	4518	7797	7023	26.9	21.1	20.4	23.5
2004	2941	3561	7703	6590	26.2	17.4	20.5	27.0
2005	3066	3640	7902	6811	27.6	18.0	20.6	25.0
2006	3248	3876	7759	6890	26.6	18.6	21.8	24.5
2007	3082	3686	7718	6542	25.7	17.4	21.4	27.1

Figure 1 shows the time trends for age-adjusted mean steps per day. A decline in steps per day was observed across the annual administration of the survey (Fig. 1A). Age-adjusted mean steps per day increased from 1995 to 2000 among men and from 1995 to 1998 among women but have been steadily decreasing since that time. Analyses by age groups within each gender showed steady or slight declines in all age groups recently (Fig. 1B, C).

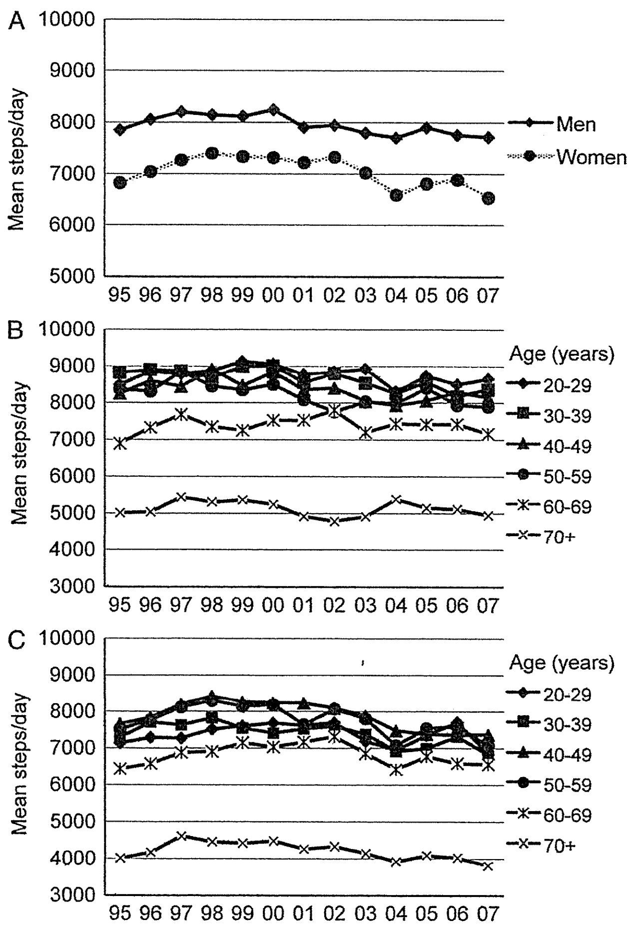

FIGURE 1—Time trends for age-adjusted mean steps per day by gender among Japanese from 1995 to 2007 (A), mean steps per day by age groups among Japanese men (B), and mean steps per day by age groups among Japanese women (C). Trends were adjusted on the basis of the age distribution of the survey sample in 1995.

The proportion taking ≥10,000 steps per day demonstrates the same trend as mean steps per day; that is, it has decreased in recent years from peak values in 1998–2000 (Fig. 2A–C).

The proportion taking <4000 steps per day generally showed a reciprocal change compared with the proportion taking ≥10,000 steps per day (Fig. 3A–C). Analyzed by gender and by age, the increase in the proportion taking <4000 steps per day was most pronounced in women in recent years, especially in the oldest age group (≥70 yr old) (Fig. 3B, C).

DISCUSSION

Although surveillance activities incorporating objectively monitored physical activity have appeared in the scientific literature recently (2,3,8,13,30,34), the NHNS-J represents the singular and therefore unique source of ongoing pedometer-based surveillance data, dating back to 1989 but consistently administered since 1995. Although the raw data are not publicly available, summary data reported in Japanese-language reports still represent an important source of objectively monitored physical activity trends.

According to the NHNS-J 2007, men took 7321 ± 4588 steps per day and women took 6267 ± 3827 steps per day. Men took more steps per day than women in all age groups. Steps per day were lower with older age groups among men, whereas among women, the 40- to 49-yr-old age group took the highest mean steps per day. The trend for steps per day in recent years indicated declines (−529 age-adjusted mean steps per day among men and −857 age-adjusted mean steps per day among women) from peak values recorded in 1998–2000 to most recently reported values collected in 2007. In addition, the growing segment of those taking <4000 steps per day and the diminishing segment taking ≥10,000 steps per day are a concerning trend over time.

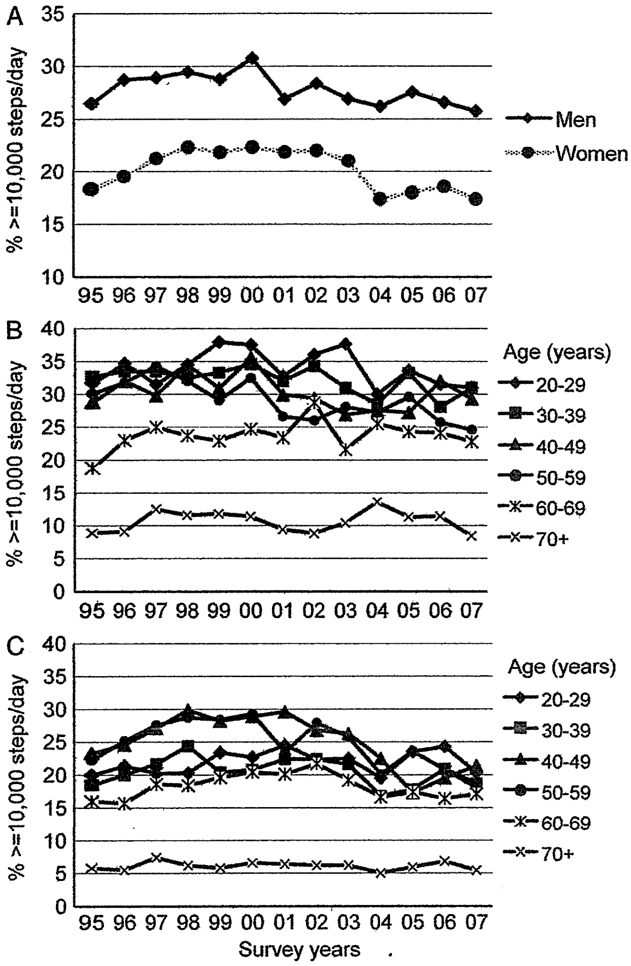

FIGURE 2—Time trends for age-adjusted proportion of persons taking ≥10,000 steps per day among Japanese from 1995 to 2007 (A), proportion of men taking ≥10,000 steps per day (B), and proportion of women taking ≥10,000 steps per day (C). Trends were adjusted on the basis of the age distribution of the survey sample in 1995.

Accelerometer-determined step data (treated to approximate pedometer-determined scaling) collected as part of the 2005–2006 US NHANES indicated that American men took 7431 steps per day and women took 5756 steps per day (34). In comparison, this Japanese sample displayed approximately the same level among men and was more active in women. Bassett et al. (2) reported that men took 5340 pedometer-determined steps per day and women took 4912 steps per day among US adults using a separate nationally representative sample. Compared with the Bassett et al. (2) study, which used a similar type of pedometer, Japanese took more steps per day than both US men and women. The pedometer-based study in Western Australia reported mean values of 10,079 steps per day among men and 9169 steps per day among women (13). These figures were much higher than these NHNS-J Japanese data.

Direct comparison of these different surveys from around the world is hampered by use of different methods, including sampling, data collection, and device used (e.g., accelerometer vs pedometer and different brands of pedometers). The Japanese survey was conducted with a nationally representative adult sample monitored for a single individually selected day between Monday and Saturday in November each year using the Yamasa AS200 pedometer. In contrast, the NHANES (30), which also uses a nationally representative sample, used a 7-d survey (although fewer days are typically accepted for analyses) rolled out during a 2-yr cycle using the ActiGraph AM7164 accelerometer (Fort Walton Beach, FL). The Bassett et al. (2) study recruited participants through an online survey panel for a 2-d survey in June and used the Accusplit AE120 (Livermore, CA), which the authors report has the same measurement mechanism as the Yamax pedometer. The Australian survey (13) was based on a randomly selected sample and a 7-d monitoring period in November to December (obviously in the southern hemisphere so different from November in Japan) and used the Yamax SW700. They required four or more valid days for inclusion in their analyses, a requirement that might selectively

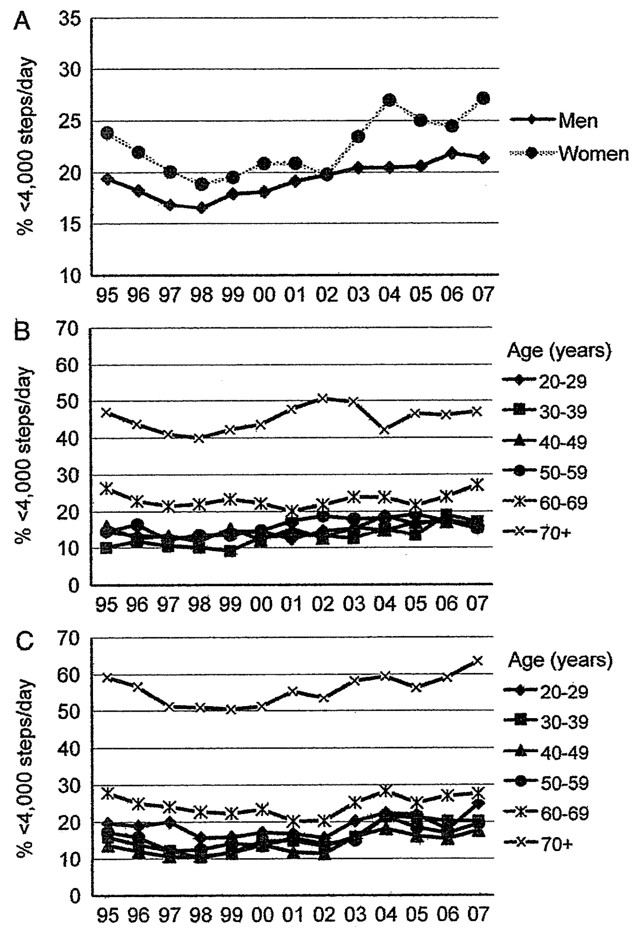

FIGURE 3—Time trends for age-adjusted proportion of persons taking <4000 steps per day among Japanese from 1995 to 2007 (A), proportion of men taking <4000 steps per day (B), and proportion of women taking <4000 steps per day (C). Trends were adjusted on the basis of the age distribution of the survey sample in 1995.

exclude the most sedentary individuals (34). Across these surveys, response rates were either not clearly reported or not very high. There is also some evidence that suggests that the pedometer survey respondents generally tend to be more active than nonrespondents (2,11). Despite these concerns and overall differences in survey administration and analyses, it could be said that the Australians walked the most, the Japanese were intermediary, and the US residents walked the least on the basis of these studies.

Three to four days of data collection are often cited as necessary to assess habitual physical activity by accelerometry (31). However, this is based on a requirement to establish a stable estimate of time in moderate-to-vigorous physical activity and not necessarily a volume indicative of physical activity collected and expressed as steps per day. For surveillance to assess population levels of physical activity, a 1-d protocol with a sufficient sample size may be sufficient (4). Regarding the device, Yamasa (same as Yamax) pedometers are well validated (6,29). Although recent reports have raised concern about this instrument's ability to accurately capture steps per day taken by overweight/obese individuals (5), the difference in accelerometer-determined steps per day across body mass index–defined weight status categories displays a similar pattern (33,37). The potential for international comparison of objectively monitored physical activity is apparent from a previous report comparing accelerometer-determined physical activity from the United States and Sweden; however, steps per day were not presented in that report (9). Clearly, more research is needed to standardize population-level surveillance efforts. Until then, researchers are encouraged to clearly report their methods, including documenting response rates, monitoring periods (including seasons), and instrumentation choices.

The 500- to 900-steps-per-day decline documented in the NHNS-J may seem trivial from an individual point of view but is likely relevant in terms of a population-level statistic. Growing popularization and adoption of motorized private transportation among Japanese have lead to an increasingly car-dependent lifestyle and may be one reason of this apparent population trend in steps per day. The fourth Nationwide Person Trip Survey, which monitors the travel behavior of Japanese, reported the modal share (proportion of trips taken by a particular mode of transportation) of cars (25). The survey results indicated that the modal share of cars has increased from 38.7% in 1992 to 42.1% in 2005. In contrast, the modal share of walking decreased from 24.1% to 20.3% during the same period. One more potential contributor to the observed decreasing trend is the increased diffusion of personal computer and Internet use during a similar period. According to the Communications Usage Trend Survey of Japan, Internet use in households has dramatically increased from 3.3% in 1996 to 91.3% 2007 (23).

In 2004, Tudor-Locke and Bassett (32) defined a sedentary lifestyle as taking <5000 steps per day. The most comparable category used by the NHNS-J is that taking <4000 steps per day. So defined, it seems that the proportion of Japanese that can be classified as sedentary has increased in recent years. This increase was more pronounced among women (+8.2% in the age-adjusted percent from peak to 2007) than among men (+4.8%). Although we can only speculate on reasons for this observation, women with a relatively low employment rate (50.3% among women ≥20 yr old vs 76.7% among men ≥20 yr old in Japan) (24) may suffer more from recent neighborhood environmental changes leading to an increased car-dependent lifestyle (26,27).

There are limitations to this study that must be acknowledged. First, this was a secondary analysis of government-collected and published data. Thus, the description of methods and original analyses must be accepted as is. For example, other researchers have categorized step-determined physical activity levels in 2500-step increments and have defined a sedentary lifestyle as taking <5000 steps per day (32). However, categorization of activity levels herein was possible only by using the NHNS-J results as published. Therefore, we necessarily defined a sedentary lifestyle as taking <4000 steps per day. Second, this survey is routinely conducted using just a single individually selected day of monitoring during a designated period. As we indicate above, Craig et al. (4) have shown that a single day of pedometer monitoring may be sufficient for estimation of group-level physical activity. However, the single day of monitoring in the NHNS-J survey was not randomly assigned. NHNS-J participants were instructed to choose a typical day for pedometer self-monitoring from the assigned survey period, and the specific date was left up to individual choice. It remains possible that the selected date represents a reactive measure on the individual level. Third, the NHNS-J was conducted in November every year. There have been some reports regarding seasonal differences in steps per day (7,12). November is the end of fall in Japan, with no extreme weather; however, it is associated with slightly lower temperatures compared with the annual average. Therefore, it is plausible that a year-round average of steps per day would be different from that collected only in November. However, we can be more confident in the evidence for time trends because the surveillance has been consistently administered in the same month, using the same protocol, and with the same instrument for many years.

Despite these limitations, these Japanese data represent a unique opportunity to examine time trends of step-determined physical activity level of Japanese adults. No other similar data source exists in the world. According to the NHNS-J, Japanese men took 7321 steps per day and women took 6267 steps per day on average in 2007. The population's mean steps per day have decreased by 500–900 steps per day between 1998–2000 and 2007. The increase in the percent taking <4000 steps per day was especially noticeable among women.

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RESEARCH ARTICLE Open Access

How much locomotive activity is needed for an active physical activity level: analysis of total step counts

Kazunori Ohkawara[1*], Kazuko Ishikawa-Takata[1], Jong Hoon Park[1], Izumi Tabata[2] and Shigeho Tanaka[1]

Abstract

Background: Although physical activity recommendations for public health have focused on locomotive activity such as walking and running, it is uncertain how much these activities contribute to overall physical activity level (PAL). The purpose of the present study was to determine the contribution of locomotive activity to PAL using total step counts measured in a calorimeter study.

Methods: PAL, calculated as total energy expenditure divided by basal metabolic rate, was evaluated in 11 adult men using three different conditions for 24-hour human calorimeter measurements: a low-activity day (L-day) targeted at a low active level of PAL (1.45), and a high-frequency moderate activity day (M-day) or a high-frequency vigorous activity day (V-day) targeted at an active level of PAL (1.75). These subjects were permitted only light activities except prescribed activities. In a separate group of 41 adults, free-living PAL was evaluated using doubly-labeled water (DLW). In both experiments, step counts per day were also measured using an accelerometer.

Results: In the human calorimeter study, PAL and step counts were 1.42 ± 0.10 and 8,973 ± 543 steps/d (L-day), 1.82 ± 0.14 and 29,588 ± 1,126 steps/d (M-day), and 1.74 ± 0.15 and 23,755 ± 1,038 steps/d (V-day), respectively. In the DLW study, PAL and step counts were 1.73 ± 0.15 and 10,022 ± 2,605 steps/d, and there was no significant relationship between PAL and daily step counts.

Conclusions: These results indicate that an enormous number of steps are needed for an active level of PAL if individuals extend physical activity-induced energy expenditure by only locomotive activity. Therefore, non-locomotive activity such as household activity should also play a significant role in increasing PAL under free-living conditions.

Background

The release of "Physical Activity and Public Health: A Recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine" in 1995 spurred extensive discussion about the amount of physical activity (PA) needed to maintain good health [1]. More recently, the World Health Organization's (WHO's) "Global Recommendations on Physical Activity for Health" [2] following the 2008 "Physical Activity Guidelines for Americans" [3] has proposed more than 150 min of moderate-intensity PA per week to maintain body weight. The evidence for this recommendation was obtained from short-term clinical trials indicating that PA in the range of 13-26 metabolic equivalent (MET)-hours per week resulted in 1-3% weight loss, consistent with weight stability over the long term [4-6]. Thirteen MET-hours are roughly equivalent to brisk walking for 150 min.

In contrast, the PA recommendation for body weight management in the 2005 "Dietary Guidelines for Americans" [7] was adopted in large part from an Institute of Medicine (IOM) report [8]. These guidelines recommended approximately 60 min of above-moderate-intensity PA on most days of the week. This recommendation was primarily based on cross-sectional data on total daily energy expenditure (TEE) measured by the doubly-labeled water (DLW) method. Although differences in study design such as the use of clinical

* Correspondence: Ohkawara@nih.go.jp
[1]Department of Health Promotion and Exercise, National Institute of Health and Nutrition, 1-23-1 Toyama, Shinjuku-ku, Tokyo 162-8636, Japan
Full list of author information is available at the end of the article