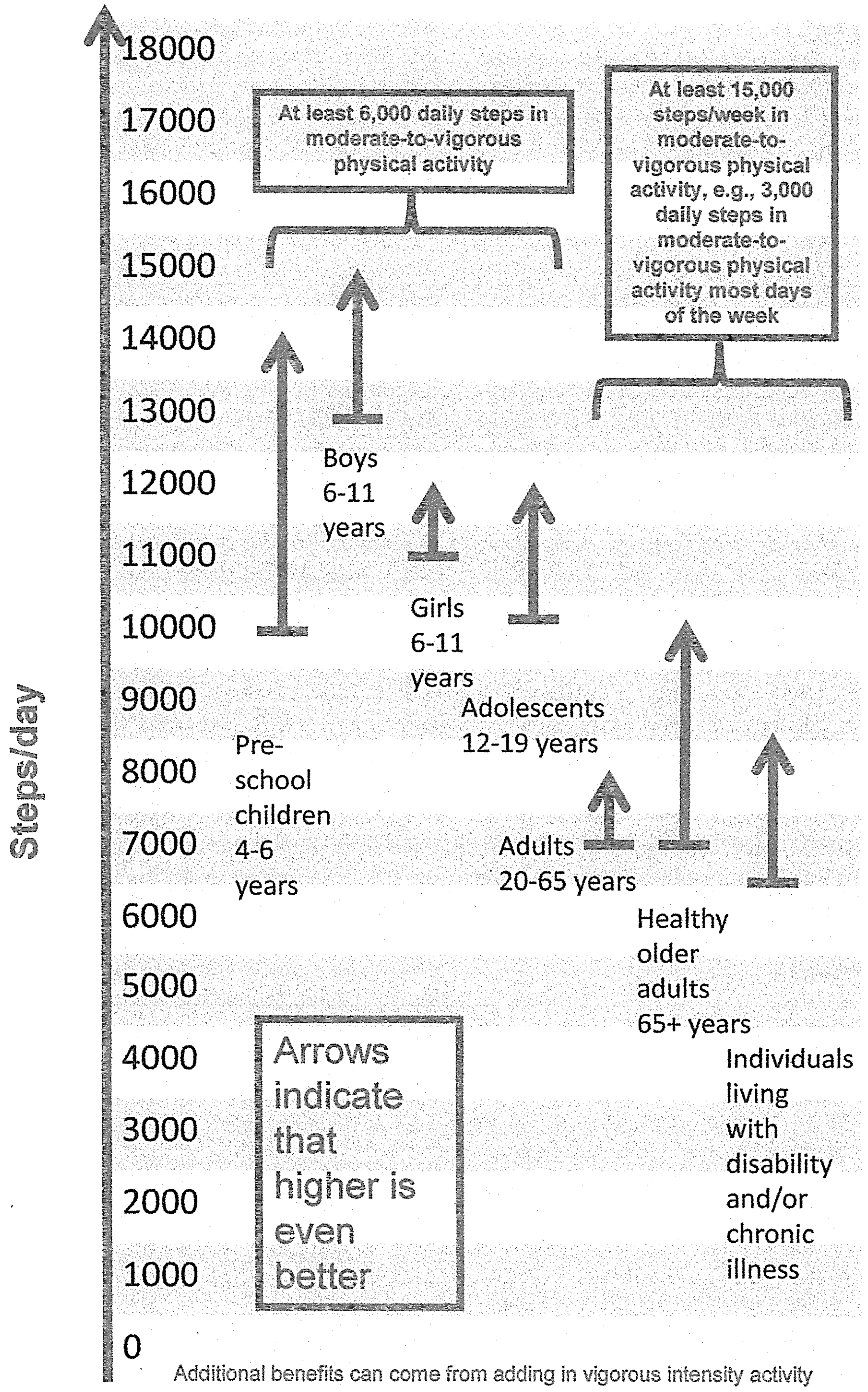

Figure 1 Steps/day scale schematic linked to time spent in MVPA.

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.

Acknowledgements
Production of this literature review has been made possible through a financial contribution from the Public Health Agency of Canada (PHAC). The funding body had no role in study design, in the collection, analysis, and interpretation of the data, in the writing of the manuscript, or in the decision to submit the manuscript for publication. The views expressed herein solely represent the views of the authors. We would like to thank Dr. David R. Bassett, Jr. (Department of Kinesiology, Recreation, and Sport Studies, The University of Tennessee, Knoxville, TN, USA) for his thorough review of this manuscript prior to submission.

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.

Received: 15 November 2010 Accepted: 28 July 2011
Published: 28 July 2011

References

1. U.S. Department of Health and Human Services: **2008 Physical Activity Guidelines for Americans: Be Active, Healthy, and Happy!** Washington, D. C; 2008.
2. Tudor-Locke C, Williams JE, Reis JP, Pluto D: **Utility of pedometers for assessing physical activity: convergent validity.** *Sports Med* 2002, 32:795-808.
3. Tudor-Locke C, Johnson WD, Katzmarzyk PT: **Accelerometer-determined steps per day in US adults.** *Med Sci Sports Exerc* 2009, 41:1384-1391.
4. Haskell WL, Lee IM, Pate RR, Powell KE, Blair SN, Franklin BA, Macera CA, Heath GW, Thompson PD, Bauman A: **Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association.** *Med Sci Sports Exerc* 2007, 39:1423-1434.
5. Physical Activity Guidelines Advisory Committee: *Physical Activity Guidelines Advisory Committee Report, 2008* Washington, D.C.: U.S. Department of Health and Human Services; 2008.
6. Public Health Agency of Canada and the Canadian Society for Exercise Physiology: **Canada's Physical Activity Guide to Healthy Active Living.** Ottawa, Ont.: Public Health Agency of Canada; 1998.
7. O'Donovan G, Blazevich AJ, Boreham C, Cooper AR, Crank H, Ekelund U, Fox KR, Gately P, Giles-Corti B, Gill JM, *et al*: **The ABC of Physical Activity for Health: a consensus statement from the British Association of Sport and Exercise Sciences.** *J Sports Sci* 2010, 28:573-591.
8. U.S. Department of Health and Human Services, U.S. Department of Agriculture: **Dietary Guidelines for Americans.** Washington, DC;, 6 2005.
9. Institute of Medicine: **Dietary Reference Intakes for Energy, Carbohydrates, Fiber, Fat, Protein and Amino Acids (Macronutrients).** Washington, DC: National Academy of Sciences; 2002.
10. Tudor-Locke C: **Steps to better cardiovascular health: how many steps does it take to achieve good health and how confident are we in this number?** *Curr Cardiovasc Risk Rep* 2010, 4:271-276.
11. Tudor-Locke C, Bassett DR Jr: **How many steps/day are enough? Preliminary pedometer indices for public health.** *Sports Med* 2004, 34:1-8.
12. Tudor-Locke C, Hatano Y, Pangrazi RP, Kang M: **Revisiting "How many steps are enough?".** *Med Sci Sports Exerc* 2008, 40:S537-543.
13. Tudor-Locke C, Craig CL, Beets MW, Belton S, Cardon GM, Duncan S, Hatano Y, Lubans DR, Olds TS, Raustorp A, *et al*: **How many steps/day are enough? For children and adolescents.** *Int J Behav Nutr Phys Act* 2011, 8:78.
14. Tudor-Locke C, Craig CL, Aoyagi Y, Bell RC, Croteau KA, De Bourdeaudhuij I, Ewald B, Gardner AW, Hatano Y, Lutes LD, *et al*: **How many steps/day are enough? For older adults and special populations.** *Int J Behav Nutr Phys Act* 2011, 8(1):80.
15. Tudor-Locke C, Myers AM: **Methodological considerations for researchers and practitioners using pedometers to measure physical (ambulatory) activity.** *Res Q Exerc Sport* 2001, 72:1-12.
16. Bohannon RW: **Number of pedometer-assessed steps taken per day by adults: a descriptive meta-analysis.** *Physical Therapist* 2007, 87:1642-1650.
17. Whitt MC, DuBose KD, Ainsworth BE, Tudor-Locke C: **Walking patterns in a sample of African American, Native American, and Caucasian women: the cross-cultural activity participation study.** *Health Educ Behav* 2004, 31:45S-56S.
18. Bassett DR Jr, Schneider PL, Huntington GE: **Physical activity in an Old Order Amish community.** *Med Sci Sports Exerc* 2004, 36:79-85.
19. Le Masurier GC, Lee SM, Tudor-Locke C: **Motion sensor accuracy under controlled and free-living conditions.** *Med Sci Sports Exerc* 2004, 36:905-910.
20. Le Masurier GC, Tudor-Locke C: **Comparison of pedometer and accelerometer accuracy under controlled conditions.** *Med Sci Sports Exerc* 2003, 35:867-871.
21. Wyatt HR, Peters JC, Reed GW, Barry M, Hill JO: **A Colorado statewide survey of walking and its relation to excessive weight.** *Med Sci Sports Exerc* 2005, 37:724-730.
22. Tudor-Locke C, Ham SA, Macera CA, Ainsworth BE, Kirtland KA, Reis JP, Kimsey CD Jr: **Descriptive epidemiology of pedometer-determined physical activity.** *Med Sci Sports Exerc* 2004, 36:1567-1573.
23. Bassett DR Jr, Wyatt HR, Thompson H, Peters JC, Hill JO: **Pedometer-measured physical activity and health behaviors in United States adults.** *Med Sci Sports Exerc* 2010, 42:1819-1825.
24. Inoue S, Takamiya T, Yoshiike N, Shimomitsu T: **Physical activity among the Japanese: results of the National Health and Nutrition Survey.** *International Congress on Physical Activity and Public Health; April 17-20; Atlanta, GA* U.S. Department of Health and Human Services; 2006, 79.
25. McCormack G, Giles-Corti B, Milligan R: **Demographic and individual correlates of achieving 10,000 steps/day: use of pedometers in a population-based study.** *Health Promot J Austr* 2006, 17:43-47.
26. De Cocker K, Cardon G, De Bourdeaudhuij I: **Pedometer-determined physical activity and its comparison with the International Physical Activity Questionnaire in a sample of Belgian adults.** *Res Q Exerc Sport* 2007, 78:429-437.
27. Sequeira MM, Rickenbach M, Wietlisbach V, Tullen B, Schutz Y: **Physical activity assessment using a pedometer and its comparison with a questionnaire in a large population survey.** *Am J Epidemiol* 1995, 142:989-999.
28. Tudor-Locke C, Bassett DR, Shipe MF, McClain JJ: **Pedometry methods for assessing free-living adults.** *J Phys Act Health* 2011, 8:445-453.
29. Krumm EM, Dessieux OL, Andrews P, Thompson DL: **The relationship between daily steps and body composition in postmenopausal women.** *J Womens Health* 2006, 15:202-210.
30. Schmidt MD, Cleland VJ, Shaw K, Dwyer T, Venn AJ: **Cardiometabolic risk in younger and older adults across an index of ambulatory activity.** *Am J Prev Med* 2009, 37:278-284.
31. Cook I, Alberts M, Lambert EV: **Relationship between adiposity and pedometer-assessed ambulatory activity in adult, rural African women.** *Int J Obes (Lond)* 2008, 32:1327-1330.
32. Cook I, Alberts M, Brits JS, Choma SR, Mkhonto SS: **Descriptive epidemiology of ambulatory activity in rural, black South Africans.** *Med Sci Sports Exerc* 2010, 42:1261-1268.
33. Bravata DM, Smith-Spangler C, Sundaram V, Gienger AL, Lin N, Lewis R, Stave CD, Olkin I, Sirard JR: **Using pedometers to increase physical activity and improve health: a systematic review.** *JAMA* 2007, 298:2296-2304.
34. Richardson CR, Newton TL, Abraham JJ, Sen A, Jimbo M, Swartz AM: **A meta-analysis of pedometer-based walking interventions and weight loss.** *Ann Fam Med* 2008, 6:69-77.

35. Kang M, Marshall SJ, Barreira TV, Lee JO: **Effect of pedometer-based physical activity interventions: a meta-analysis.** *Res Q Exerc Sport* 2009, **80**:648-655.
36. Tudor-Locke C, Lutes L: **Why do pedometers work? A reflection upon the factors related to successfully increasing physical activity.** *Sports Med* 2009, **39**:981-993.
37. Marcus BH, Forsyth L: *Motivating People to be Physically Active.* 2 edition. Champaign, IL: Human Kinetics Publishers; 2008.
38. Tudor-Locke C, Sisson SB, Collova T, Lee SM, Swan PD: **Pedometer-determined step count guidelines for classifying walking intensity in a young ostensibly healthy population.** *Can J Appl Physiol* 2005, **30**:666-676.
39. Marshall SJ, Levy SS, Tudor-Locke CE, Kolkhorst FW, Wooten KM, Ji M, Macera CA, Ainsworth BE: **Translating physical activity recommendations into a pedometer-based step goal: 3000 steps in 30 minutes.** *Am J Prev Med* 2009, **36**:410-415.
40. Rowe DA, Welk GJ, Heil DP, Mahar MT, Kemble CD, Calabro MA, Camenisch K: **Stride rate recommendations for moderate intensity walking.** *Med Sci Sports Exerc* 2011, **43**:312-318.
41. Welk GJ, Differding JA, Thompson RW, Blair SN, Dziura J, Hart P: **The utility of the Digi-walker step counter to assess daily physical activity patterns.** *Med Sci Sports Exerc* 2000, **32**:S481-488.
42. MacPherson C, Purcell C, Bulley C: **Energy expended when walking 10,000 steps at different speeds.** *Adv Physiother* 2009, **11**:179-185.
43. Abel M, Hannon J, Mullineaux D, Beighle A: **Determination of step rate thresholds corresponding to physical activity classifications in adults.** *J Phys Act Health* 2011, **8**:45-51.
44. Beets MW, Agiovlasitis S, Fahs CA, Ranadive SM, Fernhall B: **Adjusting step count recommendations for anthropometric variations in leg length.** *J Sci Med Sport* 2010, **13(5)**:509-12.
45. Ainsworth BE, Haskell WL, Whitt MC, Irwin ML, Swartz AM, Strath SJ, O'Brien WL, Bassett DR, Schmitz KH, Emplaincourt PO, *et al*: **Compendium of physical activities: an update of activity codes and MET intensities.** *Med Sci Sports Exerc* 2000, **32**:S498-504.
46. Terrier P, Schutz Y: **Variability of gait patterns during unconstrained walking assessed by satellite positioning (GPS).** *Eur J Appl Physiol* 2003, **90**:554-561.
47. McArdle WD, Katch FI, Katch V: *Exercise Physiology: Energy, Nutrition, and Human Performance.* 6 edition. Baltimore, MD: Lippincott Williams & Wilkins; 2007.
48. Tudor-Locke C, Ainsworth BE, Thompson RW, Matthews CE: **Comparison of pedometer and accelerometer measures of free-living physical activity.** *Med Sci Sports Exerc* 2002, **34**:2045-2051.
49. Swartz AM, Strath SJ, Bassett DR, O'Brien WL, King GA, Ainsworth BE: **Estimation of energy expenditure using CSA accelerometers at hip and wrist sites.** *Med Sci Sports Exerc* 2000, **32**:S450-456.
50. Miller R, Brown W: **Meeting physical activity guidelines and average daily steps in a working population.** *J Phys Act Health* 2004, **1**:218-226.
51. Behrens TK, Hawkins SB, Dinger MK: **Relationship between objectively measured steps and time spent in physical activity among free-living college students.** *Meas Phys Educ Exerc Sci* 2005, **9**:67-77.
52. Jordan AN, Jurca GM, Tudor-Locke C, Church TS, Blair SN: **Pedometer indices for weekly physical activity recommendations in postmenopausal women.** *Med Sci Sports Exerc* 2005, **37**:1627-1632.
53. Macfarlane DJ, Chan D, Chan KL, Ho EY, Lee CC: **Using three objective criteria to examine pedometer guidelines for free-living individuals.** *Eur J Appl Physiol* 2008, **104**:435-444.
54. Tudor-Locke C, Leonardi C, Johnson WD, Katzmarzyk PT, Church TS: **Accelerometer steps/day translation of moderate-to-vigorous activity.** *Prev Med* 2011.
55. Troiano RP, Dodd KW: **Differences between objective and self-report measures of physical activity. What do they mean?** *The Korean Journal of Measurement and Evaluation in Physical Education and Sport Science* 2008, **10**:31-42.
56. Church TS, Earnest CP, Skinner JS, Blair SN: **Effects of different doses of physical activity on cardiorespiratory fitness among sedentary, overweight or obese postmenopausal women with elevated blood pressure: a randomized controlled trial.** *JAMA* 2007, **297**:2081-2091.
57. Church TS, Martin CK, Thompson AM, Earnest CP, Mikus CR, Blair SN: **Changes in weight, waist circumference and compensatory responses with different doses of exercise among sedentary, overweight postmenopausal women.** *PLoS ONE* 2009, **4**:e4515.
58. Martin CK, Church TS, Thompson AM, Earnest CP, Blair SN: **Exercise dose and quality of life: a randomized controlled trial.** *Arch Intern Med* 2009, **169**:269-278.
59. McKercher CM, Schmidt MD, Sanderson KA, Patton GC, Dwyer T, Venn AJ: **Physical activity and depression in young adults.** *Am J Prev Med* 2009, **36**:161-164.
60. Dwyer T, Hosmer D, Hosmer T, Venn AJ, Blizzard CL, Granger RH, Cochrane JA, Blair SN, Shaw JE, Zimmet PZ, Dunstan D: **The inverse relationship between number of steps per day and obesity in a population-based sample: the AusDiab study.** *Int J Obes (Lond)* 2007, **31**:797-804.
61. Tudor-Locke C, Bassett DR, Rutherford WJ, Ainsworth BE, Chan CB, Croteau K, Giles-Corti B, Le Masurier G, Moreau K, Mrozek J, *et al*: **BMI-referenced cut points for pedometer-determined steps per day in adults.** *J Phys Act Health* 2008, **5(Suppl 1)**:S126-139.
62. Crouter SE, Schneider PL, Bassett DR Jr: **Spring-levered versus piezo-electric pedometer accuracy in overweight and obese adults.** *Med Sci Sports Exerc* 2005, **37**:1673-1679.
63. Tudor-Locke C, Brashear MM, Johnson WD, Katzmarzyk PT: **Accelerometer profiles of physical activity and inactivity in normal weight, overweight, and obese U.S. men and women.** *Int J Behav Nutr Phys Act* 2010, **7**:60.
64. Hamilton MT, Hamilton DG, Zderic TW: **Role of low energy expenditure and sitting in obesity, metabolic syndrome, type 2 diabetes, and cardiovascular disease.** *Diabetes* 2007, **56**:2655-2667.
65. Katzmarzyk PT, Church TS, Craig CL, Bouchard C: **Sitting time and mortality from all causes, cardiovascular disease, and cancer.** *Med Sci Sports Exerc* 2009, **41**:998-1005.
66. Bouchard C: **Physical activity and health: introduction to the dose-response symposium.** *Med Sci Sports Exerc* 2001, **33**:S347-350.
67. Ham SA, Kruger J, Tudor-Locke C: **Participation by US adults in sports, exercise, and recreational physical activities.** *J Phys Act Health* 2009, **6**:1-10.
68. Tudor-Locke C, Bassett DR, Swartz AM, Strath SJ, Parr BB, Reis JP, Dubose KD, Ainsworth BE: **A preliminary study of one year of pedometer self-monitoring.** *Ann Behav Med* 2004, **28**:158-162.
69. Miller R, Brown W, Tudor-Locke C: **But what about swimming and cycling? How to 'count' non-ambulatory activity when using pedometers to assess physical activity.** *J Phys Act Health* 2006, **3**:257-266.
70. Pate RR, Pratt M, Blair SN, Haskell WL, Macera CA, Bouchard C, Buchner D, Ettinger W, Heath GW, King AC, *et al*: **Physical activity and public health. A recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine.** *JAMA* 1995, **273**:402-407.
71. Le Masurier GC, Sidman CL, Corbin CB: **Accumulating 10,000 steps: does this meet current physical activity guidelines?** *Res Q Exerc Sport* 2003, **74**:389-394.
72. Wilde BE, Soidman CL, Corbin CB: **A 10,000-step count as a physical activity target for sedentary women.** *Res Q Exerc Sport* 2001, **72**:411-414.
73. Tudor-Locke C, Jones R, Myers AM, Paterson DH, Ecclestone NA: **Contribution of structured exercise class participation and informal walking for exercise to daily physical activity in community-dwelling older adults.** *Res Q Exerc Sport* 2002, **73**:350-356.
74. Payn T, Pfeiffer KA, Hutto B, Vena JE, LaMonte MJ, Blair SN, Hooker SP: **Daily steps in midlife and older adults: relationship with demographic, self-rated health, and self-reported physical activity.** *Res Q Exerc Sport* 2008, **79**:128-132.
75. Tudor-Locke C: **A short list about what I do and don't know: about objective monitoring of physical activity.** *Curr Sports Med Rep* 2010, **9**:71-72.
76. Schneider PL, Crouter SE, Lukajic O, Bassett DR Jr: **Accuracy and reliability of 10 pedometers for measuring steps over a 400-m walk.** *Med Sci Sports Exerc* 2003, **35**:1779-1784.
77. Office for Lifestyle-Related Diseases Control, General Affairs Division, Health Service Bureau, Ministry of Health Labour and Welfare of Japan: **Exercise and Physical Activity Reference for Health Promotion 2006 (EPAR2006): Physical Activity, Exercise, and Physical Fitness.**Edited by: Tabata I. Japan: National Institute of Health and Nutrition; 2006.
78. Behrens TK, Dinger MK: **Ambulatory physical activity patterns of college students.** *Am J Health Educ* 2005, **36**:221-227.
79. Hornbuckle LM, Bassett DR, Thompson DL: **Pedometer-determined walking and body composition variables in African-American women.** *Med Sci Sports Exerc* 2005, **37**:1069-1074.

80. Bennett GG, Wolin KY, Puleo E, Emmons KM: **Pedometer-determined physical activity among multiethnic low-income housing residents.** *Med Sci Sports Exerc* 2006, **38**:768-773.
81. De Cocker KA, De Bourdeaudhuij IM, Cardon GM: **What do pedometer counts represent? A comparison between pedometer data and data from four different questionnaires.** *Public Health Nutr* 2008, **12**:74-81.
82. Mitsui T, Shimaoka K, Tsuzuku S, Kajioka T, Sakakibara H: **Pedometer-determined physical activity and indicators of health in Japanese adults.** *J Physiol Anthropol* 2008, **27**:179-184.
83. Tudor-Locke C, Johnson WD, Katzmarzyk PT: **Relationship between accelerometer-determined steps/day and other accelerometer outputs in U.S. adults.** *J Phys Act Health* 2011, **8**:410-419.
84. Clemes SA, Hamilton SL, Griffiths PL: **Summer to winter variability in steps counts of normal weight and overweight adults living in the U.K.** *J Phys Act Health* 2011, **8**:36-44.

doi:10.1186/1479-5868-8-79
Cite this article as: Tudor-Locke *et al.*: **How Many Steps/day are Enough? For Adults.** *International Journal of Behavioral Nutrition and Physical Activity* 2011 **8**:79.

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.

Submitted for publication January 2011.
Accepted for publication March 2011.

0195-9131/11/4310-1913/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/MSS.0b013e31821a5225

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.

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	

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 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).

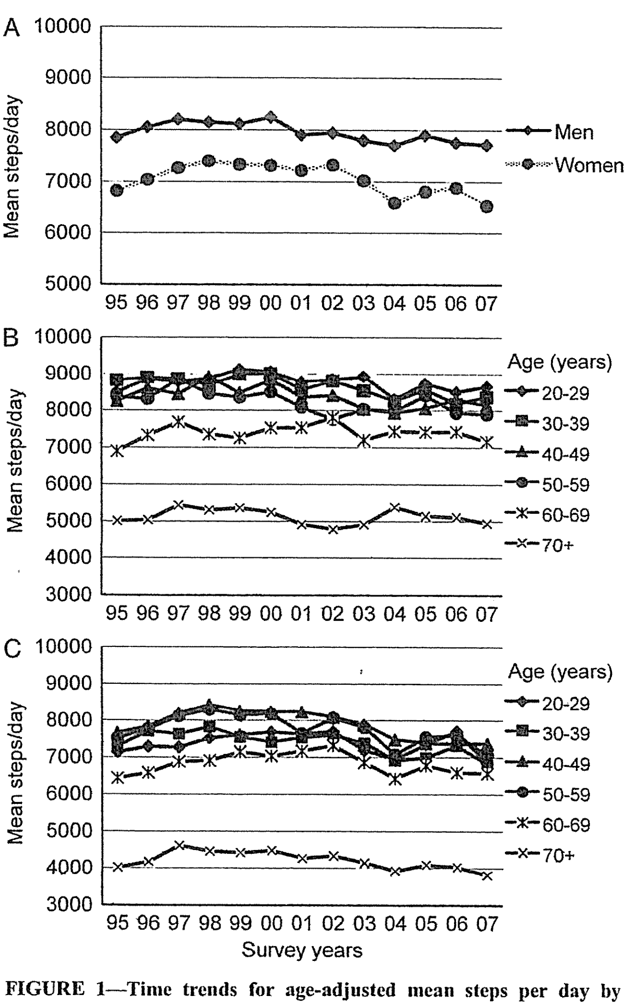

FIGURE 1—Time trends for age-adjusted mean steps per day by gender among Japanese from 1995 to 2007 (A), mean steps per day by age groups among Japanese men (B), and mean steps per day by age groups among Japanese women (C). Trends were adjusted on the basis of the age distribution of the survey sample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

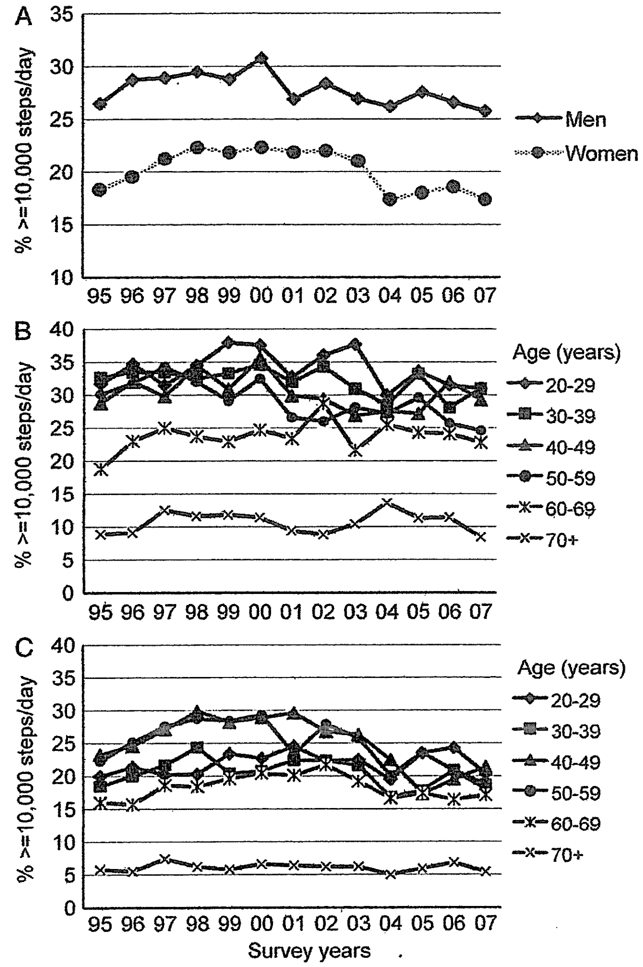

FIGURE 2—Time trends for age-adjusted proportion of persons taking ≥10,000 steps per day among Japanese from 1995 to 2007 (A), proportion of men taking ≥10,000 steps per day (B), and proportion of women taking ≥10,000 steps per day (C). Trends were adjusted on the basis of the age distribution of the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

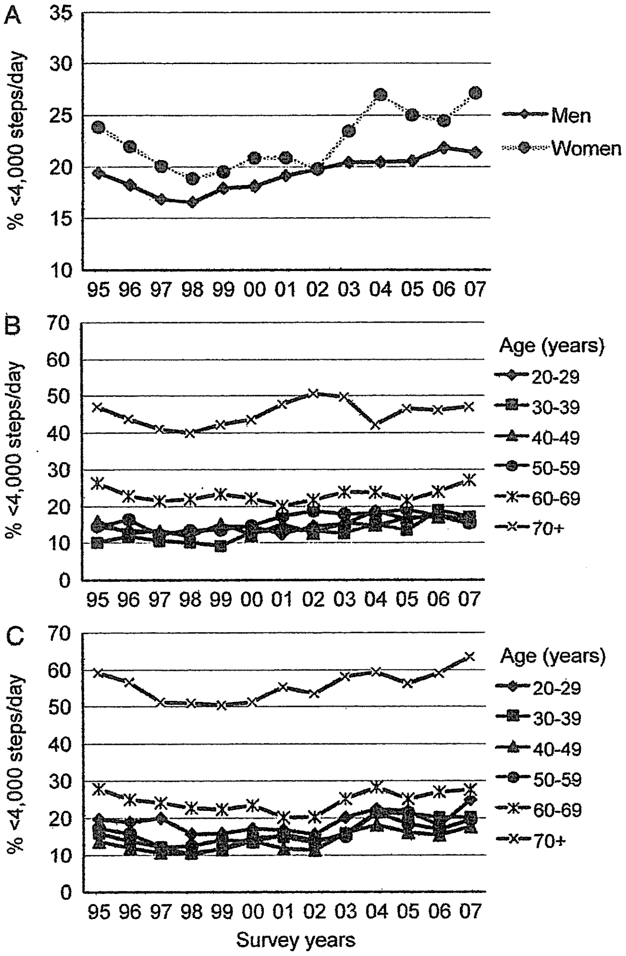

FIGURE 3—Time trends for age-adjusted proportion of persons taking <4000 steps per day among Japanese from 1995 to 2007 (A), proportion of men taking <4000 steps per day (B), and proportion of women taking <4000 steps per day (C). Trends were adjusted on the basis of the age distribution of the survey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

This study was supported by a grant-in-aid from the Ministry of Health, Labour and Welfare of Japan (Comprehensive Research on

Prevention of Cardiovascular Diseases and Other Lifestyle Related Diseases: H20-Junkankitou-Ippan-001 and H21-Junkankitou-Ippan-007) and a grant-in-aid for scientific research from the Japan Ministry of Education, Culture, Sports, Science and Technology.

All authors have no other conflicts of interest, including related directorships, stock holdings, or contracts.

The results of the present study do not constitute endorsement by the American College of Sports Medicine.

REFERENCES

1. Adabonyan I, Loustalot F, Kruger J, Carlson SA, Fulton JE. Prevalence of highly active adults—Behavioral Risk Factor Surveillance System, 2007. *Prev Med.* 2010;51(2):139–43.
2. Bassett DR Jr, Wyatt HR, Thompson H, Peters JC, Hill JO. Pedometer-measured physical activity and health behaviors in U.S. adults. *Med Sci Sports Exerc.* 2010;42(10):1819–25.
3. Craig CL, Cameron C, Griffiths JM, Tudor-Locke C. Descriptive epidemiology of youth pedometer-determined physical activity: CANPLAY. *Med Sci Sports Exerc.* 2010;42(9):1639–43.
4. Craig CL, Tudor-Locke C, Cragg S, Cameron C. Process and treatment of pedometer data collection for youth: the Canadian Physical Activity Levels among Youth study. *Med Sci Sports Exerc.* 2010;42(3):430–5.
5. Crouter SE, Schneider PL, Bassett DR Jr. Spring-levered versus piezo-electric pedometer accuracy in overweight and obese adults. *Med Sci Sports Exerc.* 2005;37(10):1673–9.
6. Crouter SE, Schneider PL, Karabulut M, Bassett DR Jr. Validity of 10 electronic pedometers for measuring steps, distance, and energy cost. *Med Sci Sports Exerc.* 2003;35(8):1455–60.
7. Dasgupta K, Joseph L, Pilote L, Strachan I, Sigal RJ, Chan C. Daily steps are low year-round and dip lower in fall/winter: findings from a longitudinal diabetes cohort. *Cardiovasc Diabetol.* 2010;9:81.
8. Hagströmer M, Oja P, Sjöström M. Physical activity and inactivity in an adult population assessed by accelerometry. *Med Sci Sports Exerc.* 2007;39(9):1502–8.
9. Hagströmer M, Troiano RP, Sjöström M, Berrigan D. Levels and patterns of objectively assessed physical activity—a comparison between Sweden and the United States. *Am J Epidemiol.* 2010; 171(10):1055–64.
10. Haskell WL, Lee IM, Pate RR, et al. Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Med Sci Sports Exerc.* 2007;39(8):1423–34.
11. Inoue S, Ohya Y, Odagiri Y, et al. Characteristics of accelerometry respondents to a mail-based surveillance study. *J Epidemiol.* 2010; 20(6):446–52.
12. Kang M, Bassett DR, Tudor-Locke C, Barreira TV, Ainsworth B. Measurement effects of seasonal and monthly variability on pedometer-determined data. *J Phys Act Health.* (in press).
13. McCormack G, Giles-Corti B, Milligan R. Demographic and individual correlates of achieving 10,000 steps/day: use of pedometers in a population-based study. *Health Promot J Austr.* 2006; 17(1):43–7.
14. Ministry of Health, Labour and Welfare of Japan. The National Health and Nutrition Survey [Internet]. [cited 2011 Jan 7]. Available from: http://www.mhlw.go.jp/bunya/kenkou/kenkou_eiyou_chousa.html.
15. Ministry of Health, Labour and Welfare of Japan. *The Report of the Japan Health and Nutrition Survey 1995.* Tokyo (Japan): Dai-ichi Shuppan; 1997. p. 121.
16. Ministry of Health, Labour and Welfare of Japan. *The Report of the Japan Health and Nutrition Survey 1996.* Tokyo (Japan): Dai-ichi Shuppan; 1998. p. 116.
17. Ministry of Health, Labour and Welfare of Japan. *The Report of the Japan Health and Nutrition Survey 1997.* Tokyo (Japan): Dai-ichi Shuppan; 1999. p. 119.
18. Ministry of Health, Labour and Welfare of Japan. *The Report of the Japan Health and Nutrition Survey 1998.* Tokyo (Japan): Dai-ichi Shuppan; 2000. p. 118.
19. Ministry of Health, Labour and Welfare of Japan. *The Report of the Japan Health and Nutrition Survey 1999.* Tokyo (Japan): Dai-ichi Shuppan; 2001. p. 116.
20. Ministry of Health, Labour and Welfare of Japan. *The Report of the Japan Health and Nutrition Survey 2000.* Tokyo (Japan): Dai-ichi Shuppan; 2002. p. 114.
21. Ministry of Health, Labour and Welfare of Japan. *The Report of the Japan Health and Nutrition Survey 2001.* Tokyo (Japan): Dai-ichi Shuppan; 2003. p. 129.
22. Ministry of Health, Labour and Welfare of Japan. *The Report of the Japan Health and Nutrition Survey 2002.* Tokyo (Japan): Dai-ichi Shuppan; 2004. p. 134.
23. Ministry of Internal Affairs and Communications of Japan. The Communications Usage Trend Survey of Japan [Internet]. [cited 2011 Feb 18]. Available from: http://www.soumu.go.jp/johotsusintokei/statistics/statistics05a.html. Japanese.
24. Ministry of Internal Affairs and Communications of Japan. The Labour Force Survey of Japan 2007 [Internet]. [cited 2011 Jan 7]. Available from: http://www.stat.go.jp/data/roudou/report/2007/ft/index.htm. Japanese.
25. Ministry of Land, Infrastructure, Transport and Tourism of Japan. The report of the 4th Nationwide Person Trip Survey 2005 [Internet]. [cited 2011 Jan 7]. Available from: http://www.mlit.go.jp/crd/tosiko/zpt/index.html. Japanese.
26. Owen N, Humpel N, Leslie E, Bauman A, Sallis JF. Understanding environmental influences on walking; review and research agenda. *Am J Prev Med.* 2004;27(1):67–76.
27. Saelens BE, Handy SL. Built environment correlates of walking: a review. *Med Sci Sports Exerc.* 2008;40(7 suppl):S550–66.
28. Sallis JF, Saelens BE. Assessment of physical activity by self-report: status, limitations, and future directions. *Res Q Exerc Sport.* 2000; 71(2 suppl):S1–14.
29. Schneider PL, Crouter SE, Bassett DR. Pedometer measures of free-living physical activity: comparison of 13 models. *Med Sci Sports Exerc.* 2004;36(2):331–5.
30. Troiano RP, Berrigan D, Dodd KW, Mâsse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. *Med Sci Sports Exerc.* 2008;40(1):181–8.
31. Trost SG, McIver KL, Pate RR. Conducting accelerometer-based activity assessments in field-based research. *Med Sci Sports Exerc.* 2005;37(11 suppl):S531–43.
32. Tudor-Locke C, Bassett DR Jr. How many steps/day are enough? Preliminary pedometer indices for public health. *Sports Med.* 2004;34(1):1–8.
33. Tudor-Locke C, Brashear MM, Johnson WD, Katzmarzyk PT. Accelerometer profiles of physical activity and inactivity in normal weight, overweight, and obese U.S. men and women. *Int J Behav Nutr Phys Act.* 2010;7:60.
34. Tudor-Locke C, Johnson WD, Katzmarzyk PT. Accelerometer-determined steps per day in US adults. *Med Sci Sports Exerc.* 2009; 41(7):1384–91.
35. US Department of Health and Human Services. 2008 physical activity guidelines for Americans, be active, healthy, and happy! [Internet]. [cited 2011 Jan 7]. Available from: www.health.gov/paguidelines.
36. World Health Organization. The world health report 2002—reducing risks, promoting healthy life. [cited 2011 Jan 7]. Available from: http://www.who.int/whr/2002/en/index.html.
37. Yoshioka M, Ayabe M, Yahiro T, et al. Long-period accelerometer monitoring shows the role of physical activity in overweight and obesity. *Int J Obes (Lond).* 2005;29(5):502–8.

Ohkawara *et al. BMC Research Notes* 2011, **4**:512
http://www.biomedcentral.com/1756-0500/4/512

BMC
Research Notes

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

trials vs. cross-sectional studies likely contribute to the different PA recommendations, the use of different methods to measure PA may also play a role in these differences.

Physical activity-induced EE (PAEE) can be classified into two components: exercise-induced EE and non-exercise activity thermogenesis (NEAT) [9]. NEAT, a large component of daily PA, is the energy expended for everything that is not sleeping, eating, or sports-like exercise [10]. It includes the energy expended walking to work, performing yard work, undertaking agricultural tasks, and household activities such as typing, vacuuming, dishwashing, and fidgeting. Many of these activities can also be defined as non-locomotive activities. However, NEAT, especially NEAT due to non-locomotive activity, is difficult to measure under free-living conditions. In fact, only supervised exercise was counted towards PAEE in clinical trials that supported the WHO Global Recommendations for body weight management [4-6]. In contrast, in the IOM report, walking distance modeled for each activity level was estimated by a factorial approach to approximate TEE measured by the DLW method; any additional EE for achieving at the "active" level from the "sedentary" level was explained by brisk walking. We hypothesized that if non-locomotive activity was counted towards total PAEE, it could explain the discrepancy between the data used for the WHO Global Recommendations and that for the recommendations in the 2005 Dietary Guidelines for Americans. Moreover, this may also explain the discrepancy between walking equivalence as indicated in the IOM report and the average steps observed under free-living conditions. Therefore, the purpose of this study was to determine the contribution of locomotive activity to total PAEE based on the relationship between total step counts and PAL under free-living conditions and using a human calorimeter. This study results should also indicate a role of non-locomotive activity to increase PAL in a daily living.

Methods

Subjects

Subjects in the two protocols were recruited separately. The study protocols were approved by the Ethics Committee of the National Institute of Health & Nutrition, and signed informed consent was obtained from all subjects. Protocol 1: 11 adult men participated in a human calorimeter study. Age, height, weight, and body mass index (BMI) for subjects in Protocol 1 were 24.7 ± 5.8 year (mean, SD), 168.1 ± 3.9 cm, 64.5 ± 7.9 kg, and 22.8 ± 2.8 kg/m^2, respectively. Protocol 2: Subjects were recruited through health care centers or at workplaces from various prefectures of the Kanto area (central Japan). 41 adults (12 males and 29 females) participated in a DLW study. Age, height, weight, and BMI for the subjects in Protocol 2 were 31.6 ± 9.1 year, 163.1 ± 8.9 cm, 57.8 ± 11.1 kg, and 21.6 ± 2.5 kg/m^2, respectively. They were college students, housewives, or desk workers. They did not report care for aging parents but three of them engaged in care for their children. All subjects were free of chronic diseases that could affect metabolism or daily physical activity.

Study concept

In Protocol 1 using a human calorimeter, each subject completed 24 h human calorimeter measurements under each of 3 different conditions. The concept of this study protocol was that subjects basically obtained PAEE from only prescribed locomotive activities since they were only permitted to carry out light activity in a sitting position during the rest of daytime. In Protocol 2 using DLW, subjects were measured total EE in a free-living condition. Obtained total EE should include PAEE induced by both of locomotive and non-locomotive activities. Thus, results from Protocol1 provide amount of locomotive activity for an active level of PAL if individuals extend PAEE from only locomotive activity. Furthermore, the gap of total step counts between Protocol 1 and 2 at same level of PAL may indicate the contribution of non-locomotive activity for maintaining an active level of PAL in daily-living condition.

Human calorimeter (study 1 protocol)

In Protocol 1 using a human calorimeter, body weight and height were measured while subjects were in a fasting state. Each subject completed 24 h human calorimeter measurements under each of 3 different conditions: 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). The subjects went to bed at 2400 and were gently awakened at 0700 (7 h). After getting up, subjects were permitted to use the toilet and were required to return to bed immediately. Then, the subjects remained in a supine position without movement until 0800. Basal metabolic rate (BMR) was determined as the mean metabolic rate between 0715 and 0800. Coefficient of variation (CV) for BMR over 3 days was 1.7% as previously reported [11]. Prescribed physical activity in L-day consisted of 30 min of walking at 3.2 km/h, 30 min of walking at 5.6 km/h, and 15 min of jogging at 8.0 km/h. On the basis of the L-day, we modeled M-day and V-day targeted at 1.75 of PAL with additional walking or jogging time (Table 1). Except for prescribed activity including BMR measurement and eating, and use of the toilet, the subjects were only permitted to carry out light activity in a sitting position, such as

Table 1 Amount of prescribed physical activity during 24-h calorimeter stays in Protocol 1 [a]

	L-day	M-day	V-day
Normal walking (3.2 km/h)	30 min × 1	30 min × 1	30 min × 1
Brisk walking (5.6 km/h)	30 min × 1	30 min × 1	30 min × 1
		15 min × 11	15 min × 4
Jogging (8.0 km/h)	15 min × 1	15 min × 1	15 min × 4
Total	75 min	240 min	180 min

[a] L-day: low activity day, M-day: a day with high-frequency moderate physical activity, V-day: a day with high-frequency vigorous physical activity

reading, writing, and viewing television. Sleeping was not permitted during daytime. The order of the days was randomly determined for each subject. The experimental protocol was previously described in detail elsewhere [11].

An open-circuit indirect human calorimeter was used to measure 24-h EE and BMR [12,13]. Briefly, the respiratory chamber was an airtight room (20,000 L) equipped with a bed, desk, chair, TV with video deck, CD player, telephone, toilet, sink, and treadmill. The temperature and relative humidity in the room were controlled at 25°C and 55%, respectively. The oxygen and carbon dioxide concentrations of the air supply and exhaust were measured by mass spectrometry. For each experiment, the gas analyzer (ARCO-1000A-CH, Arco System, Kashiwa, Japan) was initially calibrated using a certified gas mixture and atmospheric air. The flow rate exhausted from the calorimeter was measured by pneumotachography (FLB1; Arco System, Kashiwa, Japan). The flow meter was calibrated before each measurement, and the flow rate was maintained at 90 L/min (ATP). $V^{\cdot}$ O2 and carbon dioxide production ($V^{\cdot}$ CO2) were determined by the flow rate of exhaust from the chamber, and the concentrations of the inlet and outlet air of the chamber, respectively [12]. EE was estimated from $V^{\cdot}$ O2 and $V^{\cdot}$ CO2 using Weir's equation [14]. The accuracy and precision of our human calorimeter for measurement of EE as determined by the alcohol combustion test was 99.8 ± 0.5% over 6 h and 99.4 ± 3.1% over 30 min. The subjects entered the chamber at 1750 and stayed until 1805 the next day. Sampling data were collected between 1800 and 1800 (24 h).

Doubly-labeled water method (study 2 protocol)

Urine samples were collected early in the morning on the first study day at the study site, and body height and weight were also measured at that time. Then, a single dose of approximately 0.06 g/kg body weight of ^2H_2O (99.8 atom%, Cambridge Isotope Laboratories, MA, USA) and 1.4 g/kg body weight of $H_2{}^{18}O$ (10.0 atom%, Taiyo Nippon Sanso, Tokyo, Japan) was administered orally to each subject. After isotope administration, participants were asked to collect urine samples on day 1 (the next day after the DLW dose) and on other 7 additional days (days 2, 3, 7, 8, 13, 14, and 15) during the study period at the same time of day in their home. On the last day, body weight was measured in the fasting state. Over the entire study days, the subjects were instructed to maintain their normal daily activities and eating patterns,

Gas samples for isotope ratio mass spectrometry (IRMS) were prepared by equilibration of urine samples with a gas. The gas used for equilibration of ^{18}O was CO_2, and H_2 was used to equilibrate ^2H. A Pt catalyst was used for equilibration of ^2H. Urine was analyzed by IRMS using a DELTA Plus spectrometer (Thermo Electron Corporation, Bremen, Germany). ^2H and ^{18}O zero-time intercepts and elimination rates (k_H and k_O) were calculated using least-squares linear regression on the natural logarithm of the isotope concentration as a function of the time elapsed since dose administration. The zero-time intercepts were used to determine the isotope pool sizes. The TEE (kcal/day) calculation was performed using a modification of Weir's formula [14] based on the CO_2 production rate (rCO_2) and respiratory quotient (RQ). rCO_2 was calculated as follows: $rCO_2 = 0.4554 \times TBW \times (1.007ko-1.041k_H)$. The ratios of ^{18}O and ^2H dilution spaces were 1.030 ± 0.013 (Range; 1.001-1.056) and the coefficient of determination (R^2) for multi-point regression equations was ≥ 0.99 for both ^{18}O and ^2H. These values were within recommended ranges by the International Atomic Energy Agency [15]. Food quotient (FQ) calculated by the equation of Black et al. was used instead of RQ [16]. The dietary survey for calculating FQ was conducted using a self-administered diet history questionnaire (DHQ) [17,18] which was reported on the validity of energy intakes [19]. In the present study, estimated average of FQ values were adopted in the groups of college students (FQ: 0.864), housewives (FQ: 0.872) and others (FQ: 0.880), respectively. This assumes that under conditions of perfect nutrient balance the FQ must equal the RQ [16,20].

Basal metabolic rate and physical activity level

In Protocol 1, BMR was measured during human calorimeter stays, as further described in the "Human calorimeter" section. In Protocol 2, BMR was measured in the supine position in the early morning, 12 h or longer after the last meal, on the morning of the first or second visit to the study sites. The measurement was performed using a Douglas bag for 10 min × 2 with a 1 min break between measurements. After expired air was sampled, the O_2 and CO_2 concentrations were measured using a mass spectrometer (ARCO-1000, Arco System, Kashiwa, Japan) and the volume of expired air was measured with a certified dry gas meter (DC-5, Shinagawa, Tokyo, Japan). BMR was estimated from O_2 consumption and CO_2 production using Weir's equation [14]. CV for BMR over 3 days was 2.2% in this protocol. PAL was estimated by dividing TEE by BMR in both protocols.

Anthropometry

A digital scale was used to measure body weight to the nearest 0.1 kg while subjects were dressed in light clothing. Barefoot standing height was measured to the nearest 0.1 cm using a wall-mounted stadiometer. Body mass index was calculated as body weight (kg) divided by height squared (m^2).

Step counts and physical activity energy expenditure

Step counts were measured using a uniaxial accelerometer (Lifecorder or Lifecorder EX, Suzuken Co. Ltd., Nagoya, Japan) in both protocols. Based on the previous study [21], PAEE in light, moderate, or vigorous intensity was also calculated in the DLW study. This accelerometer has been widely used in many countries due to its reasonable cost and reliable validity which could estimate EE for locomotive activity accurately [21-23]. The accelerometer was attached to the left side of the waist at the midline of the left thigh.

Statistical analysis

All values are presented as means ± SDs. Differences were considered to be statistically significant if the P value was less than 0.05. In Protocol 1, the 24-h EE, BMR, PAL, and step count values obtained from the 3 conditions were compared by one-way analysis of variance with repeated measurements, and significant differences were analyzed using Scheffé's post-hoc test. In Protocol 2, correlations between step counts per day and PAL were assessed using Pearson's correlation coefficients (r). All statistical analyses were performed using SPSS version 14.0 J for WINDOWS (SPSS Inc, Chicago, IL).

Results

The results of Protocol 1 using a human calorimeter are shown in Table 2. There was no significant difference between BMRs on the L-day, M-day, or V-day. PALs on the M-day and V-day were significantly higher than on the L-day. According to the system of PAL categorization described in the IOM report [8], mean PAL values on the M-day and V-day would be classified as "active" and mean PAL on the L-day would be classified as "low activity". Figure 1 shows how many steps subjects would need to walk or jog throughout a day under controlled laboratory settings to increase PAEE from the "low activity" level to the "active" level. An additional 14,782 ± 650 steps/d corresponded to increase 0.32 ± 0.12 of PAL value calculated by subtracting L-day activity from V-day activity and an additional 20,615 ± 741 steps/d corresponded to a difference of 0.40 ± 0.13 PAL value between M-day and L-day activity.

Table 2 Energy expenditure, physical activity levels, and step counts during 24-h calorimeter stays in Protocol 1 [a]

	L-day	M-day	V-day
24-h EE (kcal/day)	2228 ± 143	2816 ± 197[c]	2813 ± 163[c]
BMR (kcal/day)	1577 ± 129	1553 ± 114	1627 ± 157
Physical activity level [b]	1.42 ± 0.10	1.82 ± 0.14[c]	1.74 ± 0.15[c]
Steps (counts/day)	8973 ± 543	29588 ± 1126[c]	23755 ± 1038[c] [d]

[a] Values are means ± SDs, L-day: low activity day, M-day: a day with high-frequency moderate physical activity, V-day: a day with high-frequency vigorous physical activity, 24-h EE: 24-hour total energy expenditure, BMR: basal metabolic rate

[b] Physical activity level was calculated as 24-h EE divided by BMR

[c] Significant differences compared with values for L-day in each variable (P < 0.05)

[d] Significant differences compared with values for M-day in each variable (P < 0.05)

Results from Protocol 2 using the DLW method are shown in Figure 2. Mean steps/d and PAL under free-living conditions were 10,022 ± 2,605 and 1.73 ± 0.15, respectively, among all subjects. The ranges of steps/d and PAL were 5,092-13,619 and 1.57-1.97, respectively, in male subjects (n = 12) and 5,288-15,242 and 1.41-2.00, respectively, in female subjects (n = 29). No

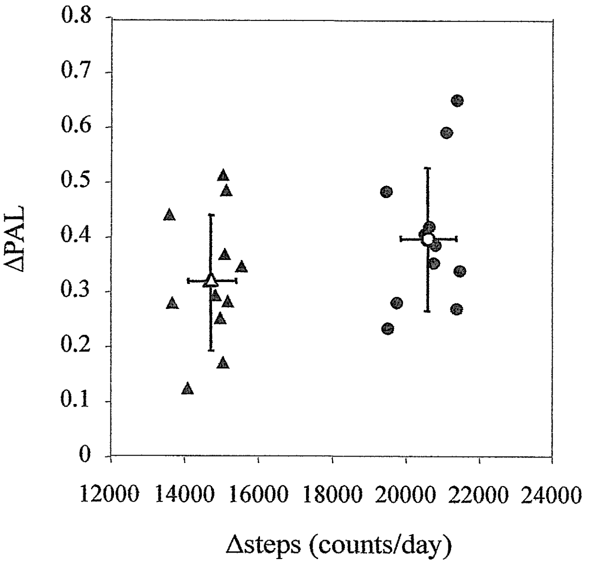

Figure 1 Relationships between delta PAL and delta step counts calculated as M-day or V-day minus L-day in Protocol 1 using a human calorimeter. Filled circles: values for a day with high-frequency moderate physical activity (M-day) minus values for a low active day (L-day), Filled triangles: values for a day with high-frequency vigorous physical activity (V-day) minus values for an L-day. Open circles or triangles and black lines are means ± SDs.

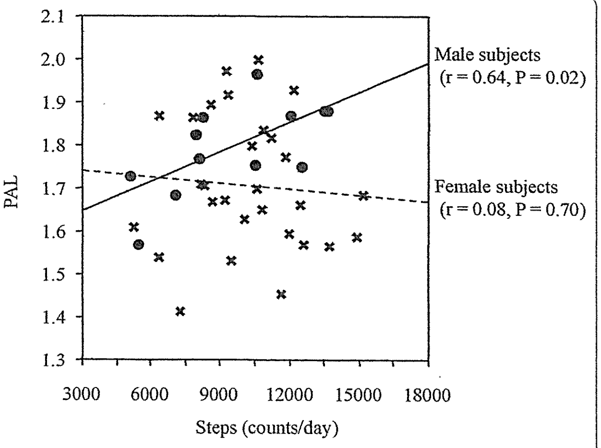

Figure 2 Relationships between physical activity level (PAL) and step counts per day under free-living conditions in Protocol 2 using doubly labeled water. Filled circles: male subjects, Crosses: female subjects.

significant relationship was observed between steps/d and PAL among all subjects (*r* = 0.06, *P* = 0.70) or in female subjects (*r* = 0.08, *P* = 0.70) although there was a significant relationship between these variables among male subjects (*r* = 0.64, *P* = 0.02). Furthermore, there was no significant relationship between PAEE in light, moderate, or vigorous intensity and PAL in either sex. Note that the step/d and PAL values in Protocol 2 are not necessarily representative values for healthy Japanese adults.

Discussion

To clarify how much locomotive activity is needed for an active physical activity level, we examined the relationship between total step counts and PAL both under free-living conditions and in a human calorimeter. In the human calorimeter study, more than an additional 10,000 steps were needed to increase PAL from the "low activity" level (1.4-1.59 of PAL) to the "active" level (1.6-1.89 of PAL) as defined in an IOM report if PAEE was primarily due to walking or jogging (Table 3). On the other hand, in DLW study, average PAL and step counts under free-living conditions were 1.73 ± 0.15 and 10,022 ± 2,605 steps/d in 41 healthy adults. Thus, the gap of total step counts between these two study protocols was large even at a similar level of PAL. These results deduce that both of locomotive activity as well as non-locomotive activity such as typing, vacuuming, and dish-washing may be significant contributor to total PAEE in daily life.

Even in human calorimeter studies, it is difficult to determine the relationship between PAEE from walking or jogging and step counts throughout a 24-hour protocol since subjects are typically permitted to engage *ad libitum* in light physical activity in addition to the prescribed exercises. de Jonge et al. [24] examined how much treadmill time is required to achieve 1.4 or 1.8 level of PAL in total 24-hour EE. The goal of that study was to develop a method for predicting an individual's 24-hour EE in a human calorimeter at these levels of PA. Average treadmill walking time was 177 ± 22 min on high-activity days (PAL: 1.78 ± 0.03) and 39 ± 9 min on low-activity days (PAL: 1.37 ± 0.02). These results indicate that 140 min of walking roughly corresponds to increase 0.40 of PAL. Note that subjects in that study conducted treadmill walking at 4.8 km per hour and at a 3% incline, and step counts were not reported in that study [24]. Subjects in the present study conducted all of their walking or jogging on a flat surface. Surprisingly, more than 120 min of extra walking time is needed to increase PAL from the "low activity" level to the "active" level, even if this PA consisted of combined

Table 3 Physical activity level (PAL) categories and walking equivalence in the IOM report

PAL Category	PAL Range	PAL	Walking Equivalence (km per day at 4.8-6.4 km per hour) [a]		
			Lightweight Individuals (44 kg)	Medium-Weight Individuals (70 kg)	Heavy Individuals (120 kg)
Sedentary	1.0-1.39	1.25	0	0 (0 min)	0
Low activity	1.4-1.59				
Mean		1.5	4.6	3.5 (35 min)	2.4
Active	1.6-1.89				
Minimum		1.6	9.3	7.0	4.8
Mean		1.75	15.8	11.7 (125 min)	8.5
Very active	1.9-2.49				
Minimum		1.9	22.4	16.5	12.0
Mean		2.2	36.0	26.7 (285 min)	19.7
Maximum		2.	49.6	36.8	27.2

[a] In addition to energy spent for general activities in normal daily life

This table was modified from the table cited on page 161, chapter 5 in the 2005 Institute of Medicine (IOM) report brisk walking (5.6 km/h) and jogging (8.0 km/h) or walking at 4.8 km/h at a 3% incline. Furthermore, if we express PA in terms of step counts based on data from the present study, approximately 24,000 steps correspond to average 1.74 of PAL on a high-frequency vigorous-activity day and approximately 30,000 steps correspond to average 1.82 of PAL on a high-frequency moderate-activity day. The results of our DLW study found a maximum step count per day of approximately 15,000 steps, but the maximum PAL value was 2.00, classified as "very active" in the IOM report. Westerterp et al. [25] reported that the proportion of PAEE induced by standing, standing-active, and cycling was relatively large in 24-hour EE if subjects spent a normal day at 1.75 of PAL. Another study by Johannsen et al. [26] examined differences in posture allocation in daily living between lean and obese women using the Intelligent Device for Energy Expenditure and Activity (IDEEA) (MiniSun LLC, Fresno, CA), which analyzes the type, onset, duration and intensity of fundamental movements such as lying, sitting, standing, and locomotion. This study found that obese women spent significantly less time standing than lean women (163 ± 58 vs. 284 ± 134 min/day), although there was no significant difference in locomotive time between the two groups (lean: 60 ± 29 min/day, obese: 48 ± 16 min/day). Activities classified in the "standing" category included all non-locomotive activity. Thus, we can speculate that some people expend a large part of their PAEE due to non-locomotive activity.

A few previous studies have analyzed the relationship between step counts per day and PAL as measured by DLW under free-living conditions [27,28]. Fogelholm et al. [27] compared four different field measures of average daily EE with criterion data obtained by the DLW method in 20 overweight premenopausal women. In that study, the field measures (24-h activity measured by an accelerometer, reported vigorous activity, monitored vigorous activity as determined by heart rate, and daily steps) did not show a significant relationship with TEE adjusted for resting metabolic rate (r = -0.07-0.26; $P > 0.20$). In contrast, Colbert et al. [28] reported that in 56 older adults, a significant relationship was observed between daily step counts and PAEE adjusted for body weight determined using DLW (Spearman correlation coefficient = 0.585, $P < 0.001$). In the present study, a significant relationship between steps/d and PAL was observed only in male subjects. Thus, we speculate that women expend more energy through non-locomotive activity. Therefore, significant variability may be seen in the relationship between step counts per day and PAL in female subjects. However, variability was also observed in male subjects. This variability is likely due to several factors, such as culture, occupation, place of residence, age, etc.

Physical activity recommendations for body weight maintenance as well as chronic disease prevention have proposed conducting more than moderate intensity of physical activity [1-3]. On the other hand, the increase of PAL is strongly associated with body weight maintenance [7]. Our study results showed that there was a not significant relationship between total step counts and PAL in female subjects and the number of total step counts was relatively small in some subjects even though their PAL levels were around 1.75. Thus, light activities such as household activity may also contribute to obtain PAEE to reach at the recommended level. The acceptance of light activity for counting into total PA amount in the recommendations gives individuals some options of PA performance.

The strength point of this study was the use of human calorimeter and DLW method to measure 24-h energy expenditure accurately. However, there were some limitations in the present study: PA intensity such as light, moderate, or vigorous intensity should be considered for clarifying relationships between PAL and amount of PA. Additionally, we could not directly measure non-locomotive activity under free-living conditions. These were due to technical limitations. Furthermore, Only 11 males and 29 females participated in the DLW study, thus, future studies using a larger number of subjects are needed to further investigate the relationship between step count or PA amount in each intensity and PAL in both sexes, and to determine what factors are related to this variability.

Conclusions

Our human calorimeter study showed that to increase PAEE from "low" to "active" levels through brisk walking, an additional 165 min of walking time at 5.6 km per hour (more than an additional 25,000 steps/d) was needed in subjects with a 65 kg body weight. These walking times and step counts were different from those determined under free-living conditions in our DLW study. These findings suggest 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, a component of NEAT, may also play a significant role in increasing PAL under free-living conditions. Future studies are needed to clarify the contribution of non-locomotive activity to total PAEE using accurate measurement methods.

Acknowledgements and funding

This study was supported by Health and Labor Sciences Research Grants for Comprehensive Research on Life-Style Related Diseases including Cardiovascular Diseases and Diabetes Mellitus from the Japanese Ministry of Health, Labor, and Welfare (PI: S Tanaka). Heartfelt thanks are due to the subjects who participated in this study. We wish to thank the members of the National Institute of Health and Nutrition.

Author details

[1]Department of Health Promotion and Exercise, National Institute of Health and Nutrition, 1-23-1 Toyama, Shinjuku-ku, Tokyo 162-8636, Japan. [2]Faculty of Sport and Health Sciences, Ritsumeikan University, Shiga 525-8577, Japan.

Authors' contributions

KO, ST, and KI designed the study; KO, ST, KI, JP, and IT performed the experiments; KO, ST, and KI analyzed the data; KO, ST, and KI wrote a draft of the manuscript; JP and IT reviewed and edited the manuscript. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

Received: 22 August 2011 Accepted: 24 November 2011
Published: 24 November 2011

References

1. Pate RR, Pratt M, Blair SN, Haskell WL, Macera CA, Bouchard C, Buchner D, Ettinger W, Heath GW, King AC, *et al*: **Physical activity and public health. A recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine.** *JAMA* 1995, 273:402-407.
2. World Health Organization: **Global recommendations on physical activity for health.** 2010.
3. Office of Disease Prevention & Health P, US Department of Health and Human Services: *2008 Physical Activity Guidelines for Americans* 2008.
4. Irwin ML, Yasui Y, Ulrich CM, Bowen D, Rudolph RE, Schwartz RS, Yukawa M, Aiello E, Potter JD, McTiernan A: **Effect of exercise on total and intra-abdominal body fat in postmenopausal women: a randomized controlled trial.** *JAMA* 2003, 289:323-330.
5. McTiernan A, Sorensen B, Irwin ML, Morgan A, Yasui Y, Rudolph RE, Surawicz C, Lampe JW, Lampe PD, Ayub K, Potter JD: **Exercise effect on weight and body fat in men and women.** *Obesity (Silver Spring)* 2007, 15:1496-1512.
6. Slentz CA, Aiken LB, Houmard JA, Bales CW, Johnson JL, Tanner CJ, Duscha BD, Kraus WE: **Inactivity, exercise, and visceral fat. STRRIDE: a randomized, controlled study of exercise intensity and amount.** *J Appl Physiol* 2005, 99:1613-1618.
7. United States Dept. of Health and Human Services: **United States. Dietary Guidelines Advisory Committee: Dietary guidelines for Americans 2005.** 2005.
8. Institute of Medicine: **Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty, Acids, Cholesterol, Protein and Amino Acids.** Washington, D.C.: The National Academies Press; 2005.
9. Levine JA, Eberhardt NL, Jensen MD: **Role of nonexercise activity thermogenesis in resistance to fat gain in humans.** *Science* 1999, 283:212-214.
10. Levine JA: **Nonexercise activity thermogenesis (NEAT): environment and biology.** *Am J Physiol Endocrinol Metab* 2004, 286:E675-685.
11. Ohkawara K, Tanaka S, Ishikawa-Takata K, Tabata I: **Twenty-four-hour analysis of elevated energy expenditure after physical activity in a metabolic chamber: models of daily total energy expenditure.** *Am J Clin Nutr* 2008, 87:1268-1276.
12. Futami J, Tanaka S, Yamamura C, Oka J, Ishikawa-Takata K, Kashiwazaki H: **Measurement of energy expenditure by whole-body indirect human calorimeter–evaluation of validity and error factors.** *J Jpn Soc Nutr Food Sci* 2003, 56:229-236.
13. Yamamura C, Tanaka S, Futami J, Oka J, Ishikawa-Takata K, Kashiwazaki H: **Activity diary method for predicting energy expenditure as evaluated by a whole-body indirect human calorimeter.** *J Nutr Sci Vitaminol* 2003, 49:262-269.
14. Weir JB: **New methods for calculating metabolic rate with special reference to protein metabolism.** *J Physiol* 1949, 109:1-9.
15. Interneational Atomic Energy Agency: **Assessment of body composition and total energy expenditure in humans using stable isotope techniques.** 2009.
16. Black AE, Prentice AM, Coward WA: **Use of food quotients to predict respiratory quotients for the doubly-labelled water method of measuring energy expenditure.** *Hum Nutr Clin Nutr* 1986, 40:381-391.
17. Sasaki S, Yanagibori R, Amano K: **Self-administered diet history questionnaire developed for health education: a relative validation of the test-version by comparison with 3-day diet record in women.** *J Epidemiol* 1998, 8:203-215.
18. Sasaki S, Ushio F, Amano K, Morihara M, Todoriki O, Uehara Y, Toyooka E: **Serum biomarker-based validation of a self-administered diet history questionnaire for Japanese subjects.** *J Nutr Sci Vitaminol* 2000, 46:285-296.
19. Okubo H, Sasaki S, Rafamantanantsoa HH, Ishikawa-Takata K, Okazaki H, Tabata I: **Validation of self-reported energy intake by a self-administered diet history questionnaire using the doubly labeled water method in 140 Japanese adults.** *Eur J Clin Nutr* 2008, 62:1343-1350.
20. Jones PJ, Leitch CA: **Validation of doubly labeled water for measurement of caloric expenditure in collegiate swimmers.** *J Appl Physiol* 1993, 74:2909-2914.
21. Kumahara H, Schutz Y, Ayabe M, Yoshioka M, Yoshitake Y, Shindo M, Ishii K, Tanaka H: **The use of uniaxial accelerometry for the assessment of physical-activity-related energy expenditure: a validation study against whole-body indirect calorimetry.** *Br J Nutr* 2004, 91:235-243.
22. McClain JJ, Craig CL, Sisson SB, Tudor-Locke C: **Comparison of Lifecorder EX and ActiGraph accelerometers under free-living conditions.** *Appl Physiol Nutr Metab* 2007, 32:753-761.
23. Schneider PL, Crouter SE, Bassett DR: **Pedometer measures of free-living physical activity: comparison of 13 models.** *Med Sci Sports Exerc* 2004, 36:331-335.
24. de Jonge L, Nguyen T, Smith SR, Zachwieja JJ, Roy HJ, Bray GA: **Prediction of energy expenditure in a whole body indirect calorimeter at both low and high levels of physical activity.** *Int J Obes Relat Metab Disord* 2001, 25:929-934.
25. Westerterp KR: **Assessment of physical activity: a critical appraisal.** *Eur J Appl Physiol* 2009, 105:823-828.
26. Johannsen DL, Welk GJ, Sharp RL, Flakoll PJ: **Differences in daily energy expenditure in lean and obese women: the role of posture allocation.** *Obesity (Silver Spring)* 2008, 16:34-39.
27. Fogelholm M, Hiilloskorpi H, Laukkanen R, Oja P, Van Marken Lichtenbelt W, Westerterp K: **Assessment of energy expenditure in overweight women.** *Med Sci Sports Exerc* 1998, 30:1191-1197.
28. Colbert LH, Matthews CE, Havighurst TC, Kim K, Schoeller DA: **Comparative Validity of Physical Activity Measures in Older Adults.** *Med Sci Sports Exerc* 2010, 43:867-876.

doi:10.1186/1756-0500-4-512
Cite this article as: Ohkawara *et al.*: How much locomotive activity is needed for an active physical activity level: analysis of total step counts. *BMC Research Notes* 2011 4:512.

日本人の代謝基準値の再評価

田中　茂穂

独立行政法人国立健康・栄養研究所健康増進研究部エネルギー代謝研究室長

体育の科学　第61巻　第8号（2011.8）別刷