Pedometer-Determined Step Count Guidelines for Classifying Walking Intensity in a Young Ostensibly Healthy Population

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Catalogue Data

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Mots-clés: exercice physique, prédiction, capteur de mouvement

Abstract/Résumé
Purpose: (a) To establish pedometer steps/min intensity categories (i.e., light, moderate, hard, very hard) for adults under controlled conditions, and (b) use these cut-points to ascertain the number of steps expected in 30 minutes of moderate intensity activity. Methods: 25 men and 25 women, ages 18–39 years, performed 6-min exercise bouts at 3 treadmill speeds (4.8, 6.4, and 9.7 km/hr). Yamax SW-200 pedometers indicated steps, and steady-state VO\(_2\) was recorded. METs were calculated by dividing steady-state VO\(_2\) by 3.5 ml·kg\(^{-1}\)·min\(^{-1}\). Linear regression was used to quantify the relationships between steps/min and METs across all speeds. Ten participants (5 M, 5 F) were randomly selected from the original 50 and constituted a holdout sample for cross-validation purposes (i.e., comparing actual and predicted METs; paired t-test). Results: The regression equation for males was: METs = −7.065 + (0.105*steps/min) \(r^2 = 0.803\). For females it was: METs = −8.805 + (0.110 * steps/min) \(r^2 = 0.830\). Cross-validation was confirmed. Conclusions: Pedometer cut-points corresponding to minimal moderate intensity walking were 96 steps/min in men and 107 steps/min in women, or roughly 100 steps/min for both. This translates to approximately 3,000 steps in 30 min of moderate-intensity ambulatory activity for both genders.
But: (a) déterminer pour des adultes dans des conditions données des niveaux d’intensité (léger, modéré, difficile, très difficile) selon le nombre de pas mesuré par un podomètre, et (b) utiliser ces balises pour prédire une certain nombre de pas à atteindre en 30 min d’activité d’intensité modérée. Méthode: 25 femmes et 25 hommes âgés de 18 à 39 ans participent à des séances de marche sur tapis roulant d’une durée de 6 min et de vitesse variée: 4,8; 6,4; et 9,7 km/h. Des podomètres de marque Yamax SW-200 indiquent le nombre de pas; la consommation d’oxygène en régime stable est enregistrée et convertie en METs en divisant le résultat par 3,5 ml·kg⁻¹·min⁻¹. On utilise une analyse de régression linéaire pour établir la relation entre la vitesse de marche et le nombre de METs, et ce, à toutes les vitesses. Dix sujets (5 femmes et 5 hommes) sont choisis au hasard parmi le groupe original pour établir la validation croisée en comparant les résultats obtenus aux résultats prédits; test t dépendant. Résultats: l’équation de régression pour les hommes est: METs = –7,065 + (0,105 * pas/min) r² = 0,803. Celle pour les femmes est: METs = –8,805 + (0,110 * pas/min) r² = 0,830. La validation croisée est démontrée. Conclusion: la balise correspondant à une intensité modérée minimale est de 107 pas/min chez les femmes et de 96 pas/min chez les hommes, soit 100 pas/min grosso modo pour les deux groupes. Cela veut dire environ 3000 pas en 30 min de marche d’intensité modérée pour les deux groupes.

Introduction

Motion sensors, including accelerometers and pedometers, have recently received increased attention because of their potential as precise physical activity measurement tools and as promising motivational devices. Of these two motions sensors, pedometers are currently the most useful for field use due in great part to their established validity (Crouter et al., 2003; Le Masurier and Tudor-Locke, 2003; Schneider et al., 2003) as well as their comparatively low cost and data management requirements (Tudor-Locke and Myers, 2001a). The emerging consensus is that the simple pedometer offers a practical solution for an inexpensive, objective, and reasonably precise monitoring tool (Bassett and Strath, 2002; Freedson and Miller, 2000; Welk, Corbin, and Dale, 2000). To be useful, however, researchers and practitioners require guidelines for evaluation purposes, including cut-points, benchmarks, or step indices associated with important activity levels.

A continued criticism is that pedometers are not typically designed to capture intensity of activity, an important feature of physical activity recommendations that is independently associated with cardiorespiratory health (Williams, 2001). Recently, however, Scruggs et al. (2003) introduced the possibility of using stepping rate (i.e., steps taken in a timed bout of activity), expressed as steps/min, to infer activity intensity. Simply put, if time frame (using a simple watch) and steps taken (using a pedometer) are known, intensity might be inferred if specific cut-points (in terms of steps/min) were available that represent meaningful intensity categories.

Inspired by the work of Freedson et al. (1998) which established similar activity count cut-points for use with uniaxial accelerometers, the purpose of this study was to: (a) define pedometer steps/min intensity categories (i.e., light, moderate, hard, and very hard) for adults under controlled conditions; and (b) use the cut-points for moderate intensity activity to ascertain the number of steps expected in 30 minutes of at least moderate intensity (steps/30 mod-min) activity, reflective

**Methods**

A convenience sample of 50 adults (25 men, age 25.4 ± 4.7 yrs, BMI 23.9 ± 2.3 kg/m²; 25 women, age 23.6 ± 3.4 yrs, BMI 22.3 ± 2.4 kg/m²) was recruited by word of mouth. Inclusion criteria were age range of 18–39 years, BMI < 30 kg/m², and familiarity with walking on a treadmill. Study participants were asked to refrain from caffeine and exercise for 4 hours prior to their laboratory appointment. Basic demographic information (age, gender) was obtained via a brief questionnaire. Height and weight were assessed directly without shoes. All participants were informed of the test procedures and risks, and all provided written informed consent prior to voluntary participation. The Institutional Review Board at Arizona State University approved all procedures.

Prior to testing, all equipment was checked for calibration and corrected where necessary. Specifically, the metabolic cart was calibrated using nitrogen and two primary standard gas mixtures to an error of 0.01%. The pneumotachometer was calibrated using a 3L syringe that delivered fixed volumes at different flow rates. Volume calibration was verified to a value of less than 0.1 L. The coefficient of variation in VO₂ measures during various walking /running speeds between the two metabolic cart machines (same brand) used was 0.42%. Pedometers (Yamax SW-200, Yamax Corp., Tokyo) were checked using a standard 20-step test (Tudor-Locke and Myers, 2001b) and found to be 100% accurate.

Participants were outfitted with a heart rate monitor (Polar CIC, Inc., Port Washington, NY) and briefly habituated to a MAX-2 metabolic cart (Physiodyne Instrument Corp., Quogue, NY). After being positioned on the treadmill (Quinton 4000, Seattle), each participant was fitted with a headpiece, a two-way non-rebreathing valve (Hans-Rudolph, Inc., Kansas City, MO), a nose clip, and a mouthpiece. Pedometers were attached at the participant’s waist according to manufacturer recommendations (i.e., assuring vertical placement) and reset to zero prior to each exercise bout. Three 6-min exercise bouts were undertaken in random order (determined a priori for each individual) at treadmill speeds of 4.8, 6.4, and 9.7 km/hr (Freedon et al., 1998), separated by at least 5 minutes of seated rest. Participants walked at the two lower speeds and ran at the highest speed. Treadmill speed was verified during each bout using a hand-held high-precision tachometer (Extech Instruments Corp., Waltham, MA) applied directly to the rotating belt.

Steady-state VO₂ for each 6-min exercise bout was obtained using indirect calorimetry. Steady state was defined as a heart rate change of less than 5 beats per minute. VO₂ and heart rate data were recorded at 30-second intervals for the entire testing session. Steady-state VO₂ for each participant was recorded as an average of the last 2 minutes of each exercise bout. Pedometers were read to determine steps taken at the end of each 6-min bout.

For each speed, actual METs were calculated by dividing steady-state VO₂ by 3.5 ml·kg⁻¹·min⁻¹. Stepping rate was computed by dividing the pedometer-determined steps taken during the 6-min bout. Stride length (meters/step) was then determined by dividing treadmill speed (meters/min) by steps/minute. Descriptive
Statistics were expressed as mean ± SD for the dependent variables under each condition effect (speed). A one-way repeated-measures ANOVA was used to test differences in dependent variables across the three speeds. Gender differences were explored using independent t-tests for all dependent variables.

Linear regression was used to quantify the relationships between steps/min and metabolic cost in terms of METs across all speeds after examining the data for potential outliers. Ten participants (5 M, 5 F) from the original 50 were randomly selected, using a table of random numbers, and constituted a holdout sample for cross-validation purposes. Specifically, we calculated the mean differences between actual and predicted METs, used a paired t-test to determine significant differences between the means, and computed a Pearson correlation coefficient between the two metabolic cost values across all speeds.

Finally, the regression equations generated were used to establish step/min cut-points corresponding to MET level categories considered representative of light (≤ 2.99 METs), moderate (3.0–5.99 METs), hard (6.0–8.99 METs), and very hard activity (≥ 9.0 METs) (Freedson et al., 1998). These categories were also used previously to set activity count cut-points for CSA accelerometers (Freedson et al., 1998). Their application in this study permits translation between these two motion sensors. The lower step/min cut-point associated with moderate intensity activity was multiplied by 30 minutes to ascertain minimum step parameters representative of public health guidelines (i.e., of at least moderate intensity).

Results

Since the holdout data did not differ significantly (with regard to any of the dependent variables) from the remaining sample, descriptive data for the entire sample

Table 1 Dependent Variables at Each Speed (M ± SD)

<table>
<thead>
<tr>
<th></th>
<th>Stepping rate (steps/min)</th>
<th>Stride length (meters/step)</th>
<th>VO₂ (ml·kg⁻¹·min⁻¹)</th>
<th>Heart rate (bpm)</th>
<th>MET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow Speed (4.8 km/hr)</td>
<td></td>
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<tr>
<td>Males</td>
<td>101.5 ± 13.0</td>
<td>0.8 ± 0.1</td>
<td>12.9 ± 1.7</td>
<td>103.2 ± 11.2</td>
<td>3.7 ± 0.5</td>
</tr>
<tr>
<td>Females</td>
<td>114.1 ± 6.1*</td>
<td>0.7 ± 0.0*</td>
<td>12.4 ± 1.2</td>
<td>100.9 ± 13.3</td>
<td>3.5 ± 0.3</td>
</tr>
<tr>
<td>Medium Speed (6.4 km/hr)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>123.6 ± 4.9</td>
<td>0.9 ± 0.0</td>
<td>18.1 ± 2.6</td>
<td>113.6 ± 13.2</td>
<td>5.2 ± 0.7</td>
</tr>
<tr>
<td>Females</td>
<td>130.8 ± 5.6*</td>
<td>0.8 ± 0.0*</td>
<td>18.7 ± 2.2</td>
<td>121.8 ± 18.1*</td>
<td>5.3 ± 0.6</td>
</tr>
<tr>
<td>Fast Speed (9.7 km/hr)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>156.3 ± 7.5</td>
<td>1.0 ± 0.0</td>
<td>35.4 ± 2.9</td>
<td>155.3 ± 14.4</td>
<td>10.1 ± 0.8</td>
</tr>
<tr>
<td>Females</td>
<td>166.1 ± 9.0*</td>
<td>1.0 ± 0.1*</td>
<td>34.6 ± 3.3</td>
<td>161.8 ± 17.7</td>
<td>9.9 ± 0.9</td>
</tr>
</tbody>
</table>

Note: Differences between genders at each speed, *p < 0.05 (independent t-tests).
are presented in Table 1. The one-way repeated-measures ANOVA confirmed significant differences in dependent variables across the three speeds (all $p < 0.001$). Since a significant gender difference was observed for stepping rate and stride length at all speeds (but not for $\text{VO}_2$ or METs; see Table 1), all subsequent analyses were accordingly stratified. Heart rate only differed significantly between men and women at the 6.4 km/hr speed.

A single outlier was identified for men under the slow walking condition; this individual had a stepping rate of 66 steps/min compared to the male mean of 101.5 steps/min at this speed. These data were subsequently removed prior to determining the final regression equation. Removal of the outlier improved the male model from $r^2 = 0.77$ to $r^2 = 0.80$. Figures 1 and 2 present the final regression results for males and females, respectively.

Using the gender-specific regression equations to predict METs in the hold-out sample, the mean difference between actual and predicted across all speeds was $-1.4 \pm 0.27$ METs for men and $0.9 \pm 0.98$ METs for women. No significant differences were found between actual and predicted METs. Across all speeds the correlation between actual and predicted METs was $r = 0.95$ for males and $r = 0.87$ for females.

**Figure 1.** Linear regression of pedometers steps/min vs. METs for males with 95% mean prediction interval.
Gender-specific pedometer step/min cut-points corresponding to MET-defined activity intensity categories are presented in Table 2. Applying the lower cut-point for moderate intensity activity, 30 minutes of at least moderate-intensity ambulatory activity corresponds to 2,880 steps in men and 3,210 steps in women, or roughly 3,000 steps/30 mod-min for both.

**Discussion**

Recently published studies continue to document the effectiveness of pedometers for motivating increased physical activity (Croteau, 2004; Iwane et al., 2000; Moreau et al., 2001; Puente-Maestu et al., 2000; Speck and Looney, 2001; Swartz and Thompson, 2002; Tudor-Locke et al., 2004). Alone however, pedometers are considered analogous to computer hardware; without the corresponding software (e.g., expected values, indices, protocols, programs) they are of limited use (Tudor-Locke, 2002). The study described herein adds to this software. Specifically, we generated cut-points for stepping rate (expressed as steps/min; useful for infer-
ring intensity of ambulatory activity) and predicted the number of steps taken in 30 minutes of moderate intensity walking under controlled conditions. Under these controlled conditions, identified step/min cut-points were associated with accepted MET levels defining gross activity intensity categories. Using an approach similar to that of Freedson et al. (1998) to establish activity cut-points for a uniaxial accelerometer, these data suggest that an additional 9–10 steps/min roughly corresponds to an incremental change of 1 MET between 3 and 9 METs.

Such pedometer steps/min cut-points and indices could be used for both interpretive and prescriptive purposes in the same way that heart rate has traditionally been used. For example, individuals could wear a pedometer and use these cut-points to interpret the intensity of their daily walk. From a prescriptive point of view, if 3,000 steps in 30 minutes—a stepping rate equal to 100 steps/minute—is considered a minimum cut-point for a 3-MET activity, an increment to a 4-MET activity could be achieved through a simple progressive prescription of approximately 3,300 steps in 30 minutes, a stepping rate equal to 110 steps/minute. We must emphasize that these cut-points and increments must be interpreted loosely. The overlap between genders, the variance observed, and the inevitable potential for misclassification, regardless of how minor, suggests that precision should not be overstated.

A previous estimate of 3,800 to 4,000 steps/30 mod-min was based on an extrapolation from steps taken over a measured distance and at externally set and controlled paces (Welk, Differding, et al., 2000). Wilde et al. (2001) asked sedentary but otherwise healthy women to record steps taken during an unsupervised 30-min walk included in a typical day of activity; those women reported approximately 3,100 steps/30 mod-min. Both of these estimates also fall within the range of steps/min cut-points congruent with moderate intensity ambulatory activity established in the present study.

In theory, public health recommendations could be achieved with as little as 3,000 to 4,000 daily steps if intensity (i.e., taken over 30 minutes) and frequency

<table>
<thead>
<tr>
<th>Activity Intensity</th>
<th>Steps/min</th>
<th>Males</th>
<th>Females</th>
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<tbody>
<tr>
<td>Light (≤ 2.99 METs)</td>
<td>&lt; 96</td>
<td>&lt; 107</td>
<td></td>
</tr>
<tr>
<td>Moderate (3.0–5.99 METs)</td>
<td>96–124</td>
<td>107–135</td>
<td></td>
</tr>
<tr>
<td>Hard (6.0–8.99 METs)</td>
<td>125–153</td>
<td>136–162</td>
<td></td>
</tr>
<tr>
<td>Very hard (≥ 9.0 METs)</td>
<td>&gt; 153</td>
<td>&gt; 162</td>
<td></td>
</tr>
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</table>

*Note: Cut-points are derived from the following equations:*

- **Males:** \( \text{METs} = -7.065 + (0.105 \times \text{steps/min}) \)
  \( r^2 = 0.803, \text{SEE} = 1.27 \text{ METs} \)
- **Females:** \( \text{METs} = -8.805 + (0.110 \times \text{steps/min}) \)
  \( r^2 = 0.830, \text{SEE} = 1.14 \text{ METs} \)
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(i.e., daily) guidelines are also adhered to. In order to reap the benefits of an active lifestyle, however, it is more likely that these 3,000 to 4,000 steps need to be taken over and above some minimal number of daily steps below which individuals might be classified as sedentary. Individuals with total daily values of less than approximately 5,000 steps/day are more frequently classified as obese, suggesting that this minimal number of steps/day may be an appropriate index of sedentary activity (Tudor Locke and Bassett, 2004; Tudor-Locke et al., 2001).

The sum of this proposed sedentary activity index and the step/30 mod-min documented in the present study approximates 8,000 to 9,000 steps/day. In 2002 an Institute of Medicine report indicated that, although some health benefits could be attained with a minimum of 30 minutes of moderate intensity daily activity, this level of itself is too little to prevent weight gain. The report recommended double the time (i.e., 60 min of moderate intensity daily activity) previously endorsed by the U.S. Surgeon General (1996). Canada’s Physical Activity Guide (Canadian Society for Exercise Physiology, 2000) specifically indicates that it takes 30–60 minutes of moderate-effort activity to realize health benefits. An equivalent step/day index (i.e., 5,000 steps from the proposed sedentary activity index plus twice the step/30 mod-min index determined from the stepping rate cut-points herein) would therefore range as high as 11,000 to 13,000 steps/day. We emphasize that such values are based solely on conjecture at this point and must be subjected to additional scrutiny.

A steps/30 mod-min index can be used by both researchers and practitioners to interpret changes in physical activity due to intervention in relation to public health recommendations. A similar method was used to demonstrate that an observed increase in pedometer-assessed ambulatory activity post-intervention translated to an extra 22.6 minutes of walking (Tudor-Locke, Myers, et al., 2002). The index can also be used to evaluate the contribution of specific activities to overall activity goals. For example, older adults took 3,729 ± 1,022 steps while participating in a structured exercise class centered around a 30-min walk (Tudor-Locke, Jones, et al., 2002), easily meeting the 3,000 to 4,000 steps/30 mod-min index as determined in the present study.

The proposed step/30 mod-min index could also be used as a prescribed increment in a behavior change program; participants might be encouraged to increase their daily step totals by 3,000 to 4,000 steps to achieve health-related benefits of increased physical activity, or 6,000 to 8,000 steps if weight maintenance is desired (Institute of Medicine, 2002). Some persons may need to initially increase their activity by smaller increments (e.g., 1,000 steps), congruent with the public health recommendations that moderate activity can be accumulated throughout the day in bouts as short as 10 minutes (Murphy and Hardman, 1998; Woolf-May et al., 1999). If the index is used as a prescribed increment, it should be packaged with the caveat that these additional steps need to be of moderate intensity (i.e., taken over at 30 minutes) and likely volitional in nature. This requires the combined use of a pedometer and an external time piece such as a watch. To be specific, an individual would need to note both time walked and steps accumulated over that time frame and compare his or her results to the index. It is also important to emphasize again that these steps need to be taken over and above one’s usual daily activities.
Since pedometers are most sensitive to vertical movements (e.g., they are not designed to detect activity related to swimming or bicycle riding), the results of this research are limited to ambulatory activities. Furthermore, there was no incline grade used and therefore the results of this study can only be generalized to similarly level physical environments. We also did not collect fitness or activity data on the subjects, limiting our ability to generalize beyond this young and ostensibly healthy sample. Finally, we must emphasize that these cut-points were set under controlled conditions, specifically during treadmill walking, which may differ from overground walking (White et al., 1998). We urge the reader to use caution when interpreting our discussion about potential practical applications of these cut-points under free-living conditions until further research is conducted outside the laboratory. In summary, we have determined step/min categorical cut-points that correspond to gross activity intensity categories (in terms of MET levels) that could be useful for prescribing and evaluating appropriate amounts of moderate intensity walking in accordance with public health recommendations.

Authors’ Note

The results of the present study do not constitute endorsement of any products used by the authors. The manuscript serves no financial interests.

References


and Thompson, D.L. (2001). Increasing daily walking lowers blood pressure in post-
Comparison of effects of supervised versus self-monitored training programmes in
Schneider, P.L., Crouter, S.E., Lukajic, O., and Bassett, D.R., Jr. (2003). Accuracy and reli-
ability of 10 pedometers for measuring steps over a 400-m walk. Med. Sci. Sports
Exerc. 35: 1779-1784.
L.B. (2003). Quantifying physical activity via pedometry in elementary physical
Speck, B.J., and Looney, S.W. (2001). Effects of a minimal intervention to increase physi-
Swartz, A.M., and Thompson, D.L. (2002). Increasing daily walking improves glucose tol-
Tudor-Locke, C. (2002). Taking steps toward increased physical activity: Using pedom-
Tudor-Locke, C., Ainsworth, B.E., Whitt, M.C., Thompson, R., Addy, C.L., and Jones, D.A.
(2001). The relationship between pedometer-determined ambulatory activity and body
Tudor-Locke, C., and Bassett, D.R., Jr. (2004). How many steps/day are enough? Prelimi-
Tudor-Locke, C., Bell, R.C., Myers, A.M., Harris, S.B., Ecclestone, N.A., Lauzon, N., and
daily physical activity intervention for individuals with type II diabetes. Int. J. Obes.
Relat. Metab. Disord. 28: 113-119.
Contribution of structured exercise class participation and informal walking for ex-
Sport 73: 350-356.
and practitioners using pedometers to measure physical (ambulatory) activity. Res.
Tudor-Locke, C., Myers, A.M., Bell, R.C., Harris, S., and Rodger, N.W. (2002). Prelimi-
nary outcome evaluation of The First Step Program: A daily physical activity inter-
U.S. Dept. of Health and Human Services. (1996). Physical Activity and Health: A Re-
port of the Surgeon General. Atlanta: U.S. Dept. HHS, Centers for Disease Control
and Prevention, National Center for Chronic Disease Prevention and Promotion.
From the Centers for Disease Control and Prevention. JAMA 276: 522.


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