A Steps/Minute Value for Moderate Intensity Physical Activity in Adolescent Females

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The number of steps/minute (i.e., cadence) that equates to moderate intensity in adolescents is not known. To that end, 31 adolescent females walked on a treadmill at 5 different speeds while wearing an ActivPAL accelerometer and oxygen uptake was recorded by indirect calorimetry. The relationship between metabolic equivalents (METs) and cadence was explored using 3 different analytical approaches. Cadence was a significant predictor of METs ($r = .70; p < .001$). Moderate intensity (3 METs) corresponded to 94 or 114 steps/minute based on the mixed model and ROC analysis, respectively. These two values, and a practical value of 100 steps/minute, were cross-validated on an independent sample of 33 adolescent females during over-ground walking at 3 speeds. The sensitivity and specificity of each value correctly identifying 3 METs were 98.5% and 87.2% for 94 steps/minute, 72.9% and 98.8 for 114 steps/minute and 96.5% and 95.7% for 100 steps/minute. Compromising on a single cadence of 100 steps/minute would be a practical value that approximates moderate intensity in adolescent females and can be used for physical activity interpretation and promotion.

The objective assessment of physical activity using step counts is gaining momentum in both descriptive (27,28) and interventional (4) research. Total steps/day can be measured by pedometer or accelerometer and serve as a practical approximation of daily ambulatory physical activity volume. Physical activity

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intensity is also of great interest as it is a fundamental component of public health recommendations (9). Recently, a number of adult studies have aimed to identify a cadence (i.e., steps/minute) which would approximate walking at a moderate intensity. Approximately 100 steps/minute has been identified as a practical cadence that can be used in public health messages for adults (29,14,1). Cadence (steps/minute) is an intuitively understandable estimate of walking speed. It can also be compared across accelerometers and, more importantly from a population perspective, pedometers if steps are counted over a known time period.

Steps/day guidelines have been recently put forward for children and adolescents (26). The authors recognized the need for relating steps/minute to a measure of intensity, such as metabolic equivalents (METs) in this population. A limited number of controlled studies have attempted to establish cadence values related to moderate intensity thresholds for children (10,12,31). However, no study of children or adolescents has used a measure of energy expenditure (METs) derived from indirect calorimetry for estimating intensity as has been previously applied in adult studies. Moderate intensity is the intensity at which adolescent are recommended to be active at (30). While some studies have used a 4 MET definition for moderate intensity (23,17) these have been focused on relatively younger adolescents (i.e., ages 12–15). Since differences between children and adults in mechanical work, energy cost and efficiency with walking disappear after the age of 10 (22), 3 METs remains a rationale indicator of moderate intensity for older adolescents (i.e., age 15 and older).

In preparation for a planned intervention study with adolescent females, a calibration study was undertaken to determine an appropriate cadence value that approximates moderate intensity measured using indirect calorimetry. Participants walked on a treadmill at 5 different speeds to elicit a cadence that relates to a physiological measure of moderate intensity, something which has not been previously done in this group. To assess their validity each cadence value was then cross-validated using an independent sample of adolescent females during over-ground walking.

Methods

Approval for both the calibration and cross-validation studies was granted by the University of Limerick Research Ethics Committee. Written informed consent was obtained from each participant and their parent/guardian and all participants filled out a pretest questionnaire which ensured that they were injury free.

Accelerometer

The ActivPAL (PAL Technologies Ltd, Glasgow, UK) is a small (53 × 35 × 7mm), lightweight (20g) single unit uniaxial physical activity monitor. It samples body accelerations at 10 Hz and can store 7+ days of data. The device outputs include a measure of steps which are presented for every 15 s epoch. The ActivPAL step output has been shown to have excellent agreement (95% limits of agreement of 3.9 to -3.3 steps/minute, mean bias 0.3 steps/minute) compared with the gold standard of video recorded steps taken by young adult females (8). The measurement of steps has also been validated during treadmill and over-ground walking conditions in adults (21,13).
Calibration Study

Participants. In the initial calibration study, 33 adolescent females were invited to participate. These adolescents were already enrolled in a school-based physical activity intervention and the calibration study was an optional portion of the baseline testing.

Treadmill Protocol. Participants reported to the laboratory in the morning following an overnight fast and having abstained from caffeine and vigorous physical activity the previous evening. Height and weight were measured using standard procedures and body mass index (BMI) was calculated as weight (in kg)/height$^2$ (in m). An ActivPAL was directly attached to the midline of the anterior right thigh using a hydrogel adhesive pad and tube grip bandage. Participants were also fitted with a Polar heart rate monitor (Polar, Finland) for the treadmill protocol. The details of this treadmill protocol have been previously described in a paper investigating the accuracy of the ActivPAL step measurement and MET estimates in adolescent and young adult females (8). This present analysis is based on the adolescent group only and is also focused on a steps/minute translation of moderate intensity, and therefore, it is novel. Briefly, participants walked on a treadmill on 0% incline at 5 speeds (3.2 kph$^{-1}$, 4.8 kph$^{-1}$, 5.6 kph$^{-1}$, 6.4 kph$^{-1}$ and 7.0 kph$^{-1}$) for 7 min at each speed. Expired gas was collected concurrently using a validated automated metabolic measurement system (AMIS 2000, Innovision, Odense, Denmark) (11).

Data Treatment. Data were not available for two participants due to incorrect initialization of the ActivPAL. Four participants declined to complete the last 2 speeds of their tests. Two participants had erroneous VO$_2$ data for 2 speeds each and data were omitted from 15 participants who ran at 7km/h$^{-1}$ speed (everyone else walked). In total, 27 data points were excluded; the final analysis was based on 133 speeds collected across 31 participants.

The ActivPAL was downloaded following each participant’s test and the output was saved in Excel. The following variables were calculated for each of the 5 speeds:

- Steps/minute: Since the ActivPAL records steps in 15 s epochs, these were summed over the last two minutes (while participants were walking at a steady pace) and averaged to derive mean steps/minute.
- VO$_2$ (ml/kg/min$^{-1}$): Oxygen uptake was averaged over the last two minutes and was then normalized by body weight.
- METs: An assumed resting energy expenditure of 3.5 ml O$_2$/kg/min$^{-1}$ was used and this was divided into the VO$_2$ (ml/kg/min$^{-1}$) to get a unique intensity value at each speed for each participant. While resting energy expenditure was measured for each individual, the MET values based on this individualized resting value were not significantly different from METs based on the assumed value (8).

Cross-Validation Study

Participants. For the cross-validation study, a convenience sample was recruited from a local youth group and 40 adolescent females agreed to participate.

Resting Metabolic Rate (RMR). Participants reported to the testing hall in a fasted state having refrained from smoking and caffeine for 2 hr, and having refrained from MPV A for 12 hr. Height and weight were measured using standard procedures and BMI was calculated as described above. Participants were then fitted with an
ActivPAL also as described above. Participants were also fitted with a Cosmed K4B² (Cosmed, model K4B², Rome, Italy) which is a lightweight mobile metabolic unit which measured breath-by-breath oxygen consumption. The K4B² device has previously been shown to have satisfactory validity for measures such as VO₂ and VCO₂ (19). Participants then remained in a reclined position on a physiotherapy plinth in a darkened, quiet room for 25 min while VO₂ data were collected.

**Over-ground Walking/Jogging Protocol.** Following the RMR, participants were asked to perform 3 over-ground locomotor activities at 3 different speeds while wearing both the portable metabolic unit and the ActivPAL. They were instructed to perform slow walking (≈2.5–4.5 km.h⁻¹), brisk walking (≈4.5–6.5 km.h⁻¹) and jogging (≈6.5–8.5 km.h⁻¹) for 7 min for each activity. Participants were asked to perform each activity at a pace that was comfortable to them, but within the assigned range of speeds for each activity. A 31 m track was marked out in the hall, and this distance was used to calculate the speed of the participant during each activity. Feedback was provided to each participant during each lap, to ensure they were traveling at a speed that was within the assigned range of speed for the activity. This approach was used to more accurately simulate real-life activity, compared with treadmill walking. Rest periods were given between each activity to allow each participant’s heart rate to return to below 100 beats/minute. Accelerometer and VO₂ data were collected concurrently during each activity. The mean value of the final two minutes of each activity was used for data analysis.

**Data Treatment.** Three participants withdrew before the calibration study began and four sets of data were excluded due to equipment malfunction. The final cross-validation sample is based on 363 speeds collected across 33 participants. The final 13 min of the RMR were averaged to establish an individualized resting energy expenditure value. The ActivPAL was downloaded following each participant’s test and the output was saved in Excel. The following variables were calculated for the RMR and each of the 3 activities:

- **Steps/minute:** Since the ActivPAL records steps in 15 s epochs, these were summed over the last two minutes and averaged to derive mean steps/minute.
- **VO₂ (ml/kg/min⁻¹):** Oxygen uptake was averaged over the last two minutes and was then normalized by body weight.
- **METs:** The RMR for each participant was divided into the VO₂ (ml/kg/min⁻¹) for each participant to derive a unique intensity value for each activity.

**Statistical Analysis**

Differences between the two groups were explored using independent sample *t* tests. Linear regression was used to model steps/minute as a function of METs and to assess the strength of the statistical relationship between the two parameters (r value). A mixed model regression analyses was then employed to obtain an equation to predict METs from cadence and also to investigate whether height or body mass affected this relationship. This approach allows for the nonindependence of each data point and the fact that not all participants contributed the same number of data points (speeds) to the analysis. A Receiver Operating Characteristics (ROC) curve was created and the area under the curve (AUC) calculated to identify a steps/minute value which maximized sensitivity (true positives) and specificity (true negatives; reducing false positives) in classifying the specified MET value correctly. Steps/
minute values were then calculated based on the mixed model approach and using ROC analysis for 3 MET and for each subsequent 1 MET increase in intensity. Sensitivity and specificity were also calculated in the cross-validation stage using the independent sample of participants to identify which steps/minute value is superior. PASW Statistics 18.0 (SPSS Inc, Chicago, IL, USA) was used for all statistical procedures.

Results

Participant characteristics for both studies are displayed in Table 1. Participants in the cross-validation group were significantly older, heavier and had a higher BMI than those in the calibration group ($p < .05$).

Calibration Study

Cadence was a significant predictor of METs ($r = .70; p < .001$) (see Table 2). Based on the equation $\text{METs} = 0.068 \times \text{steps} - 3.4$, 3 METS corresponded to 94 steps/minute. When height was added to the model the prediction equation became: $\text{METs} = 0.069 \times \text{steps} - 5.3 + 1.08 \times \text{height}$ ($r = .71; p < .001$). Using the range of heights of this particular group (1.85m-1.52m), an estimate of 3 METs was associated with a cadence range of 91–96 steps/minute. It is also possible to extend these findings to higher intensities. In this present study, using 4 METs as a threshold for moderate intensity equated to 109 steps/minute, while 5 METs was 123 steps/minute and 6 METs was 138 steps/minute. For 3 METs, the AUC from the ROC analysis displayed in Figure 1 was significantly greater than 0.5 at 0.752 ($p < .001$). The optimal threshold of 114 yielded balanced values for sensitivity (69%) and specificity (68%) for identifying participants who were walking at 3 METs.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Participant Characteristics</th>
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<tbody>
<tr>
<td></td>
<td>Calibration</td>
</tr>
<tr>
<td>Age (years)*</td>
<td>15.8 (0.4)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>1.65 (0.07)</td>
</tr>
<tr>
<td>Weight (kg)*</td>
<td>59.1 (10.9)</td>
</tr>
<tr>
<td>BMI (kg/m²)*</td>
<td>21.7 (2.8)</td>
</tr>
</tbody>
</table>

*significant difference between groups ($p<.05$)

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<tr>
<th>Table 2</th>
<th>Mean ($\pm$ SD) Energy Expenditure and Cadence at Each Speed During the Treadmill Based Calibration Phase</th>
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<tbody>
<tr>
<td>Speed (km/h)</td>
<td>METs</td>
</tr>
<tr>
<td>3.2</td>
<td>3.1 (0.6)</td>
</tr>
<tr>
<td>4.8</td>
<td>3.4 (0.8)</td>
</tr>
<tr>
<td>5.6</td>
<td>4.1 (0.9)</td>
</tr>
<tr>
<td>6.2</td>
<td>5.1 (1.1)</td>
</tr>
<tr>
<td>7.0</td>
<td>6.5 (1.1)</td>
</tr>
</tbody>
</table>
The sensitivity and specificity for the two moderate intensity (3 MET) values (established in the calibration study) were tested in over-ground walking/jogging along with a practical value of 100 steps/minute that has been used in the adult literature. The 94 steps/minute optimized true positives but it did not minimize false negatives while the higher threshold of 114 steps/minute had high specificity but lower sensitivity. The 100 steps/minute value optimized both (Table 3).

**Cross-Validation Study**

The sensitivity and specificity for the two moderate intensity (3 MET) values (established in the calibration study) were tested in over-ground walking/jogging along with a practical value of 100 steps/minute that has been used in the adult literature. The 94 steps/minute optimized true positives but it did not minimize false negatives while the higher threshold of 114 steps/minute had high specificity but lower sensitivity. The 100 steps/minute value optimized both (Table 3).

**Discussion**

A robust, adolescent-specific intensity cadence, indicative of a moderate intensity threshold that can also be used to analyze free-living data sets has not been established or fully explored. This study presents a cadence value for adolescent females which was developed using protocols similar to those used in previous adult studies (25,29,14) and was cross-validated on an independent sample of adolescent females. The number of steps/minute taken explained 50% of the variance in MET-defined energy expenditure when these adolescent females walked on a treadmill. While
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this may seem low, and the subsequent ROC curve attenuated, it is in fact higher than the variance explained in an earlier published adult study (14). The addition of height, body mass (both \( r = .71 \)) or stride frequency \( (r = .72) \) to the regression analysis did not alter this explainable level of variance. The results of the cross-validation demonstrated that, for this sample of adolescent females between 15 and 18 years of age, 100 steps/minute would be a practical compromise for setting a moderate intensity threshold which optimizes sensitivity and specificity. Setting a practical value of 100 steps/minute would increase the sensitivity while reducing the specificity slightly and reduce the sensitivity slightly while increasing the specificity compared with either 114 steps/minute or 94 steps/minute respectively. Tudor-Locke et al. (29) reported that, in adults, an additional 9–10 steps/minute corresponded to a 1 MET increase in intensity. In this present study, it would seem reasonable to conclude that each additional 15 steps/minute corresponded to approximately a 1 MET increase in intensity.

Jago et al. (10) reported that 117 steps/minute approximated moderate intensity activity in 78 11–15 year old males. These results were based on data from a slow over-ground walk of 4.83 km.h\(^{-1}\). Intensity was not directly measured in the Jago et al. study. Instead the authors considered the speed of 4.83 km.h\(^{-1}\) to approximate 3 METs based upon the Compendium of Physical Activities (2). While the use of over-ground walking in studies such as these is an advantage as it replicates real-life conditions (32), participants in the Jago et al. study were not allowed to self-pace (a pacer was used) which may not truly reflect free-living walking situations (17). Lubans et al. (12) reported that 137 steps/minute was associated with an intensity described as 65–75% of the maximum heart rate in a group of 14-year old females. Heart rate is arguably an indicator of relative intensity whereas we used an indicator of absolute intensity herein. Most recently, Vincent Graser et al. (31) reported that 12–14 year old males and females achieved moderate intensity at a steps/minute threshold of 122 and 102 steps/minute respectively. This was based on participants achieving 40–59% of their maximum heart rate on a treadmill. Again, heart rate was used to define moderate intensity, and at a much lower level than that used by Lubans et al. (2009). To emphasize, while the latter two studies did include a physiological indicator of relative intensity, a direct and objective measure of absolute oxygen uptake or MET-defined energy expenditure would be considered more appropriate for standardized research (24). Furthermore, in the Lubans et al. study \( \text{VO}_{2\text{max}} \) was estimated from a bench-stepping protocol while the remainder of the data collection took place on a treadmill. The prediction of \( \text{VO}_{2\text{max}} \) from submaximal heart rates also has inherent limitations (5).

<table>
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<tr>
<th>Analytical Approach</th>
<th>Cadence (steps/minute)</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>94</td>
<td>98.5%</td>
<td>87.2%</td>
</tr>
<tr>
<td>ROC</td>
<td>114</td>
<td>72.9%</td>
<td>98.8%</td>
</tr>
<tr>
<td>Practical</td>
<td>100</td>
<td>96.5%</td>
<td>95.7%</td>
</tr>
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Table 3  **Sensitivity and Specificity Values of Three Cadences Cross-Validated on an Independent Sample of Adolescent Females**
The fact that height was not a significant \( p = .54 \) predictor of steps/minute in the current study was surprising, especially given the range of heights of the group (1.52m-1.85m). There was only a 5 steps/minute difference between the tallest and the shortest participant (91 and 96 steps/minute respectively). A recent study of adults reported that height (specifically leg length) played a significant role in the relationship between cadence and intensity (3) such that participants with heights of 5ft to 6ft (similar to heights in the current study) ranged in their cadence from as high as 111 to as low as 94 steps/minute. In our study, height did not alter the strength of the observed association between cadence and METs but it remains possible that leg length or iliac length may still affect the relationship.

Much focus has been given to the assessment of physical activity using the traditional output from accelerometers which are known as activity counts. Accelerometer activity counts have no physiological meaning in their raw form and each device measures activity counts in a different way (16). In addition, there are a wide variety of activity count cut-points available to differentiate moderate from light intensity and light intensity from time spent in sedentary behaviors. While these cut-points aim to give accelerometer users a means of translating activity counts into a measure of intensity or energy expenditure, there are problems with comparability (20). This means that values for moderate intensity based on free-living data can vary by up to and over 200 min depending on which accelerometer activity count cut-point is used (7,18,20). It has been proposed that cadence cut-points associated with various activity intensities should be developed in the same way as activity count cut-points (29). Theoretically, these could be applied across instruments that have demonstrated validity in terms of step counting.

The results of this study are based on a specific and small convenience sample of female adolescents and its generalizeability to younger age groups and males is therefore limited. Participants in the cross-validation study were significantly older and had a higher BMI than those in the original calibration stage. While this may have undermined or inflated the sensitivity and specificity values, in real-world settings a cadence value created for adolescent females will most likely be applied to adolescent females representing a range of ages and BMIs. A different metabolic system was used in the cross-validation stage and no data are available comparing the outputs from both systems and the accuracy of the two systems appear to vary (19,11,6). While no pubertal data were available for participants it is assumed that participants would have reached mature stage (stage 5) by ages 15–18 (15). We also did not manually count steps taken at each treadmill speed, but rather relied on the output from the ActivPAL. However, in young adult females (age 15–17), the ActivPAL measured steps well compared with video recorded steps taken at the same speeds (8), so we would assume the same conclusion would hold true for adolescents. Finally, although cross-validated using a limited number of over-ground walking/jogging speeds, the cadence cut-points were established under an artificial treadmill condition. The logical next step would be to study a wide variety of over-ground speeds.

Despite these limitations, due to the dearth of data available concerning any specific cadence value indicative of a moderate intensity threshold determined using a criterion physiological measure in young people, these results add to the limited evidence base. In this age group (15–18 year old females) it would seem that a cadence of 100 steps/minute would be an acceptable heuristic and practical...
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threshold. Having a ‘universal’ cadence threshold for evaluating adolescents’ physical activity levels, and in particular one which is congruent with the adult recommendation, cannot be underestimated. It can aid in the prescription of physical activity and contribute to a step-based physical activity promotion message. This cut-point is still tentative and further research is required to establish a cadence value of use in confidently determining whether adolescents are engaging in a beneficial intensity of ambulation.

References