Original Article

Title: What is the minimum step rate required to achieve moderate intensity walking overground in adolescent girls?

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Abstract

Background: In order to promote walking, researchers have sought to identify the required step rate to maintain a health-enhancing intensity of walking. However, there is limited evidence regarding the stepping rate required to promote moderate intensity walking in adolescent girls.

Purpose: To identify the step rate equivalent to moderate intensity physical activity (MPA) in adolescent girls and to explore the influence that different anthropometric measures may have on the step rate equating to MPA in this population.

Methods: Fifty six adolescent girls (mean age 13.8(0.7) yrs) were recruited to the study. Anthropometric variables and resting metabolic rate were assessed, followed by three overground walking trials on a flat surface at approximately 2, 3 and 4 mph each lasting a minimum of 4 minutes. Oxygen uptake ($\dot{V}O_2$) was assessed using a portable gas analyser, and subsequently converted into METs. Step count was assessed by real time direct observation handtally.

Results: Employing the linear regression between step rate and METs (r^2 =0.20 SEE 0.003) suggests that 120 steps·min^{-1}was representative of MPA (3METs) equating to 7200 steps in 60 minutes. Multiple regression and mixed model regression confirmed weight related variables and maturity were significant predictors of METs (P<0.01).

Conclusion: The results suggest that at population level a step rate of 120 steps·min^{-1} may be advocated to achieve MPA in adolescent girls, although due to the small sample size used caution should be applied. At an individual level other factors such as age and weight should be considered.

Background

Walking is considered a common and accessible form of physical activity that is incorporated into everyday living and is relatively easy to measure (19, 28). In an adolescent population walking may be a convenient alternative to active play and sports participation. While existing physical activity guidelines state adolescents should engage in an average of 60 minutes and up to several hours of moderate to vigorous physical activity (MVPA) everyday, (12) step based recommendations that reflect this guideline are still emerging. Step rate or cadence (i.e. steps taken per minute) is often used to infer ambulatory intensity. Therefore, in order to promote walking, researchers have sought to identify the required step rate to maintain a health-enhancing intensity of walking (1, 5, 16, 23, 26, 30, 36).

In adults, existing public health guidelines have been translated into step based cut points that reflect intensity of walking. A step rate of 100 steps·min^{-1} is considered the minimum requirement to achieve moderate intensity activity, a reasonable heuristic used to promote 3000 steps in 30mins (1, 5, 23, 30, 36). With regard to the stepping rate required to promote moderate intensity walking in young people, and specifically adolescent girls, there is limited overground walking data. Seven youth studies have provided data on step rate that reflect intensity of walking, (13, 14, 16, 17, 20, 26, 38) and Tudor-Locke et al (37) has suggested that 6600-7000 steps in 60 minutes, or a step rate of 110-116steps·min^{-1} is representative of continuous walking at moderate intensity (at least 3METs) in 10-15 year olds. Three METs is considered the minimum requirement to achieve MPA in adolescent (15, 32). However, with the exception of studies by Harrington et al., (16) Morgan et al., (26) and Tudor-Locke et al., (38) none of these youth studies have directly assessed intensity (energy expenditure), but estimated it from walking speeds (13), the compendium of physical activities (17), and heart rate (14, 20). Harrington et al., (16) and Tudor-Locke et al (38) also estimated resting energy expenditure in participants under 18 years to calculate MET values. Therefore, the MET values reported within these studies are based on predicted MET values rather than age adjusted as reported by Morgan et al (26). Resting energy expenditure is dependent on a range of factors, and during growth, fat-free mass is a key determinant of resting metabolic rate (27). Particularly during the adolescent years, prediction of resting metabolic rate is therefore problematic for the purposes of estimating the MET equivalent of MPA.

Further, the step rates reported have either been derived from pedometer or accelerometer determined step counts, rather than real time direct observation (13, 14, 17, 20, 26), which is considered to be the more appropriate criterion (30). Otherwise, studies have derived step rates from treadmill walking (13, 14, 20, 26, 38), which is not equivalent to overground walking in terms of energy cost at walking speeds representative of MVPA (21). The step rate required to achieve moderate to vigorous intensity of walking overground in this population is therefore not currently known.

A further set of factors, such as height, leg length and weight status appear to affect step rate associated intensity and have been addressed within the adult literature (5, 23, 30). However, it is unclear what impact these factors may have on step rate in an adolescent population where growth and maturation is prevalent.

The aims of this study were therefore i) to address the limitations of previous youth studies, by directly assessing intensity and step count in order to determine the intensity of stepping (steps·min^{-1}) that is equivalent to MPA (≥3METs) in adolescent girls overground. ii) determine how many moderate intensity steps equate to 60mins MPA and iii) to explore the influence (if any) that different anthropometric measures may have on the step rate equating to MPA in this population.

Methods and Procedures

Participants

Following institutional ethics and local city council approval, parental and participant consent, a convenience sample of adolescent girls (n=56; mean age 13.8 (0.7) yrs) volunteered to take part in the study. The study was conducted at two separate locations, a local secondary school and the universities' exercise laboratory. The same protocol was followed at each location. Data were collected in the following order: a) anthropometric and resting metabolic rate measurements; b) three overground walking trials lasting between 4 and 6 minutes (mean walking time (5.03 (0.9)) minutes).

Anthropometry

Stature and body mass were measured using a portable stadiometer and flat scales (Seca 761, Seca Birmingham, UK) (SEE= 0.4, 0.7) respectively. Sitting height was measured while participants sat on a solid box (dimensions: 70x40x40cm) and was assessed whilst the spine was stretched, and head held in the Frankfort plane. Sitting height was subsequently used to calculate leg length from stature. Waist circumference was measured at minimal waist site to the nearest millimeter, using a steel tape with participants in the standing position and at the end of expiration. All measurements were made according to the procedures recommended by the International Society for Advancement of Kinanthropometry (15).

Body mass index (BMI) was calculated by dividing body weight in kilograms (kg) by height in meters^2 (kg/m^2). BMI z-scores and percentiles of BMI were calculated from the UK90 reference data (8,9)

Maturation status

Chronological age (yrs); Weight (kg); Sitting height (cm) and leg length (cm) were used to calculate maturation status reported as maturity offset (time before or after peak height velocity) and was predicted using the equation of Mirwald et al (25).

Metabolic measures

Gas exchange variables and heart rate were measured and displayed online using the Oxycon mobile portable metabolic cart (Viasys Healthcare, Hoehberg, Germany). A wearlink heart rate monitor band (Polar, Kempele, Finland) was fitted by the girls under their clothing, around the ribcage and under the chest. The participants breathed through an appropriately sized tight-fitting mask (Hans Rudolph ING, USA) with the total dead space volume, including turbine, of 120ml. The gas analyser, volume sensor and turbine were calibrated according to manufacturers' specifications before each test. Oxygen uptake ($\dot{V}O_2$) was measured continuously on a breath-by-breath basis and averaged over 5 seconds for data analysis.

For the assessment of resting metabolic rate $\dot{V}O_2$ was measured over a 20minute period while the participants were in fasted state (zero calorie intake at least 4hrs prior to testing) and sat quietly watching a DVD. One MET was calculated individually as the mean $\dot{V}O_2$ between the 10th and 15th min of the 20-min seated period. $\dot{V}O_2$ were then converted to energy expenditure reported as Kcal and kJ, using the Weir equation (40). The calculated resting energy expenditure was then standardised to 1 metabolic equivalent (MET) for each participant.

Overground walking trials

Indoor oval tracks were marked out at each location. Although the distance (34m and 48m) and dimensions of this space differed between locations the tracks were of the same shape and surface type (indoor vinyl sports flooring). Participants completed three overground walking trials at an individually prescribed step rate. Prescribed step rate for the overground walking trials were obtained from 60-s hand-tally count during 6 minute treadmill trials at 2, 3 and 4 mph (full details of the treadmill protocol are reported in MacDonald et al (21)). This was accomplished by setting a clip-on metronome to the prescribed step rate and asking each participant to match their step rate to the metronome. Total number of steps taken were measured, using real time direct observation hand-tally count by means of a researcher (observed by 2 researchers) walking behind each participant counting steps taken.

Participants started and finished each trial at the same point and were informed by the researcher half way round the last lap to stop at the finish line. In order to obtain steady state data, participants walked for between 4 and 6 minutes. The event marker on the metabolic cart was pressed immediately prior to and following each trial, for later reference in the $\dot{V}O_2$ data, and heart rate data were recorded during the last 15 seconds of each of minutes of the trials, to determine steady state. An average of 5 minutes static rest was taken between trials.

Stride length tests.

Two overground stride length tests, a 10 meter stride test and a 10 step test were conducted after the overground walking trials. Participants were instructed to walk at their normal walking pace. The 10 meter stride test began at a start line with two feet together, participant walked toward a target 15meters from the start line, their steps being counted by the researcher until the heal strike of the 10 meter point. For the 10 step test, the participant started at a start line with two feet together and walked towards a target until instructed to stop by the researcher on the heal strike of their 10th stride. The distance travelled was then measured with a measuring tape to the nearest 0.1 centimeters. Each measurement was repeated, and an average taken to be the true measure.

Data analysis

Step rate was calculated by dividing the total steps taken during each walking trial by total time walked. Walking speed was calculated by dividing the distance walked by the time walked. For each walking trial $\dot{V}O_2$ was determined from the final 2 min, and subsequently converted into METS. Descriptive statistics were expressed as mean (SD) for each variable.

Participants step rate for each walking trail were plotted against the corresponding MET values to quantify the relationship between step rate and METs and to examine the data for potential outliers (Figure1). Additionally, the modified Breush Pagen (Koenker test) (7, 18) were used to the test data for heteroskedasticity.

Multiple regressions were used to estimate overground METs from step rate and one additional variable; stride length indicators (height, leg length and two stride length tests), as in Rowe et al. (30), and from other variables and anthropometric measures (chronological age; weight, BMIz, waist circumference and maturity offset).

To account for the multiple data points observed for each participant (which is a violation of the assumption of independence in multiple regression) a mixed model regression was used to develop equations that were used to determine step rate cut points, as in Marshall et al (23) and Rowe et al (30). Sensitivity and Specificity for each step cut point obtained were also calculated. In a mixed model regression individual intercepts and slopes are estimated separately for each participant and the repeated factor is modelled as a random, rather than fixed factor (6, 35). All analyses were conducted using PASW Statistics version 18.0.0 (IBM Corp., Somers, NY, USA). Statistical significance was set at $p < 0.05$

Results

Descriptive results

Tables 1 and 2 present descriptive data for participants' physical characteristics, resting measures and response parameters during each overground walking trial. Participants covered a broad range in height, weight and BMI. One participant was classified as underweight (BMI for age < -2SD), 9 were at risk of overweight (BMI for age > +1SD <

+2SD) and 4 were overweight (BMI for age > +2SD) according to World Health Organisation (WHO) (21,22). Fifty-four (96.4%) of the participants had attained peak height velocity at the time of data collection. Average walking speed was 2.5, 3.0 and 3.4mph for the slow, moderate and fast trials respectively. With each increase in walking speed the associated energy costs in terms of $\dot{V}O_2$ and METs also increased, as did step rate and heart rate.

Linear regression between step rate and METs

Four outliers were identified (defined by ±2 Standard Deviations and tested using Cook's distance test (10)), two of which were further identified as data points from the same individual from the slow and moderate walking trials. This individual had a stepping rate of 72 and 68 steps·min^{-1} for the slow and moderate walking trials respectively compared to the mean step rate of 104 and 121 steps·min^{-1}. All observations (outlying data points) were subsequently removed from further analysis. Removal of all the outliers improved the model fit from $r^2 = 0.13$ to $r^2 = 0.20$; SEE=0.003.

Equation 1 presents the linear regression equation between step rate and METs

$$Y = 0.0217x + 0.381 \quad (Y = \text{METS},\ x = \text{step rate};\ r^2 = 0.20). \qquad [1]$$

Solving this equation for 3 METs, resulted in a step cut point of 120 steps·min^{-1}. In 60 minutes, this would equate to 7200 moderate intensity steps.

Multiple regression analyses

Results of the multiple regression analyses are presented in table 3. Each of the variables explained significant ($p<0.01$) additional variance (change in R^2) in METs when added to step rate. Weight related variables (weight, BMIz and waist circumference) accounted for the largest amount of variance (35, 29 and 32% respectively). The height related variables (height, leg length and the two stride length tests) accounted for less variability in the model than the weight related variables but still accounted for significant additional variance when added to step rate (26, 23, 26 and 22% respectively). Age accounted for a larger variance than height variables (30%), and maturity off set accounted for the least additional variance in the model (19%).

Mixed model regression

A mixed model regression was used to develop regression equations to determine step rate cut points, adjusting for the random effects of the non-independent observations (Intercept only model ICC= 0.61). The influence of the different anthropometric indexes was also tested. Step rate, weight related variables (weight, BMIz and waist circumference) and maturity off set were significant ($p<0.01$) predictors of METs. However, age and height related variables (height, leg length and the two stride length tests) did not add significantly to the prediction accuracy (p=0.13, p=0.11, p=0.74, p=0.62 and p=0.14), respectively.

Development of step rate cut points using mixed model regression

For comparison with the linear regression and previous adult studies (23, 30, 26) a generic equation (equation 2) using step rate only is provided below. Solving this equation for 3 METs, yielded a slightly lower step cut point of 117 steps·min^{-1} (sensitivity 74.3%, specificity 45.6%) compared to 120 steps·min^{-1} (sensitivity 66.2%, specificity 34.4%) in the linear regression.

As weight related variables were the best predictors of METs and weight itself is easily measured and is the most applicable to everyday situations, step rate cut points were subsequently developed (for illustration purposes) according to weight status (equation 3). Using equation 3 step rate cut points for 3 and 4 MET were developed for various weight categories from 35kg to 85kg. The mean cut point for all weights was 117 steps·min^{-1}. The range of step rates were 99-130 steps·min^{-1} (3METs) and 139-169 steps·min^{-1} (4METs). The recommendation of 60mins MVPA per day therefore corresponds to step count targets ranging from 5940-7800 steps.

$$\text{METs} = 0.024990 \text{ step rate} + 0.063649 \quad [2]$$

$$\text{METs} = 0.025232 \text{ step rate} + 0.019116 \text{ mass (kg)} - 0.941304 \quad [3]$$

Discussion

The current study has addressed the methodological limitations of prior youth studies, by directly assessing relative exercise intensity (METS derived from oxygen uptake) and steps taken overground (real time direct observation) to determine the minimum step rate required to achieve moderate intensity activity (MPA) and generate step based translation of minimal amount of MVPA (minimum number of steps required to achieve 60minutes of MVPA) in adolescent girls.

Minimum step rate required to achieve moderate intensity activity

Results of the linear regression analysis suggest that a step rate of 120 steps·min^{-1} represents, moderate intensity stepping (3METs) in adolescent girls. However, based on the mixed model regression, which takes into account the multiple data points observed for each participant, the results indicate a slightly lower step rate of 117 steps·min^{-1}. Despite the more rigorous methods adopted in the current study and differences in methodologies, gender and ages, these results are consistent with the findings of, Jago et al (17) and Graser et al (13).

In the only other study to investigate walking overground in youth (11-15 year old boys) Jago et al (17) reported pedometer determined step rates of 117 and 127 steps·min^{-1} at walking speeds of 3 and 4 mph overground. They suggested that these speeds were representative of moderate and moderate to vigorous intensity activity. However, as these walking speeds were defined by the adult compendium of physical activities (where 3 mph is indicative of 3 METS and 4 mph, 5 METs) (2), it was unclear whether the estimated MET values and corresponding step rates were representative of moderate intensity activity in this youth population. In her review, Tudor-Locke et al (37) raised a similar concern with this study.

Graser et al (13) investigated walking on a treadmill in a slightly younger group of 10-12 year old boys and girls. Exercise intensity during walking was not directly measured, but walking speeds of 3, 3.5 and 4mph were considered by the author to represent MVPA walking, concluding that step rates of 120-140 steps·min^{-1} were associated with MVPA (120 steps·min^{-1} being the minimum step rate reported for both boys and girls). Despite the differences in age of the participants and use of the treadmill, this data is in support of the current study in which a comparative walking speed of ~ 3mph was approximately equivalent to MPA, and therefore a step rate of 117-120 steps steps·min^{-1}.

In a separate study, Graser et al (14) investigated walking on a treadmill in 12-14 year old boys and girls, in which moderate intensity walking was defined using 40-59% of maximum heart rate. For the same walking speed (3mph) the minimum step rate reported for adolescent girls was 15 steps·min^{-1} lower (102 steps·min^{-1}) than in the current study (117 steps·min^{-1}). While heart rate reflects relative intensity rather than direct measures of intensity such as in the present study the difference in step rate between these studies may be explained by the increased energy cost of treadmill walking (11, 21). It is likely that the elevated energy demand for treadmill walking would be reflected in an elevated heart rate, implying that whilst the girls were walking at 3mph, they were working at a lower relative intensity reflected in a slower stepping speed.

Lubans et al (20) also used heart rate determined exercise intensity (65-75% of maximum heart rate) to examine the relationship between exercise intensity and pedometer determined step counts in a group of 14 year old boys and girls, while walking and running on a treadmill. They reported 137 steps·min^{-1} for girls was associated with a heart rate of~140 beats per minute (BPM) and that this indicated a walking pace equivalent to MPA. This step rate is considerably higher than currently or previously indicated to represent moderate intensity activity. However, 139 BPM is indicative of a 'brisk walk' (upper end of moderate intensity) as suggested by Armstrong et al (4) and therefore the higher step rates reported by Lubans et al (20) are more likely to represent MVPA and be more equivalent to walking at 4mph in the current study.

In a more recent study Harrington et al (16) reported that accelerometer determined step rates of 94 or 114 steps·min^{-1} corresponded to moderate intensity walking on a treadmill in a group of older adolescent girls (15-18yrs) depending on the analytical approach employed (mixed model and ROC analysis respectively). Consequently, they suggested that 100steps·min^{-1} may be a practical value that could be used to promote moderate intensity walking in adolescent girls. However, despite this step rate being similar to that reported by Graser et al (14) and the same used to promote moderate intensity walking in adults, the walking speed suggested to represent this step rate was considerably slower than in the current and previous youth and adult studies (2mph compared to 3mph). It is suggested that slow walking speeds may be less economical (11) and adopting slower speeds may increase the relative intensity of an activity (22, 24, 39). This may therefore explain the lower step rate for a given MET value as reported by Harrington et al (16). Harrington et al (16) also used the standard resting energy expenditure value of 3.5ml O_2·kg^{-1}·min^{-1} to calculate 1MET. Thus, corresponding MET values were not individualised. Further the use of this standard value often leads to underestimation in EE in the youth population (15, 29) which may have also led to the higher MET values for lower step rates and walking speed being reported by Harrington et al (16).

Most recently Tudor-Locke et al (38) provided heuristic thresholds for walking intensity in the youth population. They reported for 12-14yr adolescents (both boys and girls) a step rate of 110 steps·min^{-1} corresponded to moderate intensity walking (based on a combination of regression and ROC thresholds; the regression analysis returned a threshold of 106.6, CI 102.5 – 111.0 steps/minute). However, this step rate was translated from treadmill walking in 12 boys and 13 girls and although they assessed energy expenditure whilst walking, resting energy expenditure was estimated. It is possible that one, or a combination of these factors could explain the lower step rate threshold reported.

Influence of anthropometric indices on step rate associated intensity

The influence of different anthropometric indices (individual characteristics) were explored using multiple regression (as in Rowe et al) (30). Results indicated that all variables measured (weight related variables (weight, BMIz and waist circumference); height related variables (height, leg length and the two stride length tests); chronological age and maturity offset explained significant additional variance in METs when added to step rate. However, in the mixed model analysis only weight and maturity offset were significant predictors of METs, suggesting that step rate associated intensity is likely to be influenced by these variables (i.e. heavier or more somatically mature adolescents do not need to walk as fast as lighter or less mature peers to achieve MPA). This is similar to the findings of Morgan et al (26) who reported BMI to significantly influence step rate and energy expenditure in a group of children and young adolescents.

Jago et al (17) also observed in adolescent boys that those at risk of being overweight (BMI for age > +1SD < +2SD) recorded fewer steps (pedometer determined) than their normal weight counterparts. However, Jago et al (17) goes on to attribute these differences to differences in stature rather than body mass (e.g. more overweight participants tended to be taller). Similarly, within the adult literature Beets et al (5) and Rowe et al (30) suggested that leg length and height influence step rate associated intensity in adults, reporting that smaller individuals walk at a greater step rate than taller individuals for the same energy cost (5,30) Subsequently Rowe et al (30) developed height- related step rate recommendation for adults. In these studies, the influence of weight was not considered, and although weight related step rate recommendations have been considered within the adult literature (23), they were not further developed due the small differences observed and inconsistency in step rate across different analytical models. The relationship between body size, resting energy expenditure, submaximal energy expenditure and economy of motion is complex (31). However, the current study assessed individualised METs to infer MPA, and thus the effect of body mass is dealt with for the immediate requirements of the study design (i.e. that relative exercise intensity can be accurately quantified).

Step based translation of current physical activity guidelines

Results of the current study suggest that the minimum step rate required to achieve moderate intensity walking was 117 and 120 steps·min^{-1} depending on the analytical model employed. The step based translation of current PA guidelines (60 minutes of MVPA daily) would therefore be 7020 and 7200 steps respectively. While the use of a single recommendation that is able to communicate levels and intensity of ambulatory activity is attractive, due to its usability for researchers, practitioners and general public alike, Tudor-Locke et al (37) suggested a minimum step range (for example 6600-7000 steps in 60 minutes) was representative of continuous walking at moderate intensity (at least 3METs) in 10-15 year olds rather than a single guideline. More recently Tudor-Locke et al (38) proposed step rate thresholds of 90 -125 steps·min^{-1} (which would translate to 5400- 7500 steps in 60minutes across the ages of 6-20yrs). Using these thresholds, the step rate they proposed for adolescent girls equates to 6600 steps in 60minutes (38) a similar value to their previous work (37). Graser et al (14) have also suggested than one size does not fit all and the individual variation in step rate associated intensity seen within the youth population highlights the need to address step rate recommendations individually rather than with a single guideline. They also suggest that for prescriptive purposes and to inform intervention the use of a standardized minimum step rate may influence adherence as some adolescents may become bored or unchallenged, while others may find it hard to achieve and have to work above their individual moderate intensity threshold. It is also apparent within the adult literature that factors such as weight status, height and leg length have been associated with inter -individual variation in step rate associated intensity (5, 23, 30) and thus it would be useful to have additional step rate recommendations relating individual characteristics that are easily measured by anthropometric indices.

From the step rate cut points developed according to weight status in the current study there was a large deviation from the generic step rate of 117steps·min^{-1} (range 99-130 steps·min^{-1}), with lighter individuals taking more steps per minute than heavier individuals. Therefore, to achieve 60mins MPA, heavier individuals may be recommended to take more than 1000 steps/day more than necessary. This further highlights that a single recommendation may lead to an unachievable target for some individuals and that a step rate range, similar to that suggested by Tudor-Locke et al (37) may be beneficial for use with adolescent girls, to maximize adherence to intervention. In order to explore walking recommendations that are related to MVPA, we also reported step rates appropriate to achieve 4 METS according to weight status. It is clear however, that the step rate required to achieve 4 METS in some girls could not be sustained without running, and therefore walking recommendation in this population should focus on moderate intensity activity and not MVPA.

Strengths and Limitations

The current study had several strengths. To our knowledge it is the first study to have directly assessed relative exercise intensity (METS derived from oxygen uptake) using indirect calorimetry during overground walking trials in a youth population. MET values derived are therefore ‘true’ MET values, rather than estimated. Step rates have also been derived from real time direct observation rather than pedometers counts.

Limitations of this study are that its focus was on girls and did not consider boys, it therefore remains unclear what the minimum step rate require to achieve moderate intensity walking is in adolescent boys. Further, overground step rate was prescribed from treadmill step rate at set speeds of 2.0, 3.0 and 4.0mph. Treadmill step rate was replicated overground by setting a clip-on metronome to the treadmill step rate and asking each participant to match their step rate to the metronome. Despite these measures, some of the girls naturally adjusted to a self selected speed overground. It is also acknowledged that there is some evidence that auditory cuing to regulate walking speed may impact on energy expenditure (3) which was not accounted for within the study design.

Furthermore, the controlled conditions that the current study was completed under may not reflect the free living, and incidental walking behaviours of the youth population. However incidental intensity is difficult to determine using indirect calorimetry, as steady state is required for data interpretation (17) and the focus of continuous walking within the current study also allows for comparisons to be made to prior youth and adult studies in the field. It is also acknowledged that ecological validity is reduced under controlled conditions (3) and energy expenditure varies in accordance to the characteristics of the walking surface. Although the surface type and incline of the walking tracks were the same within the current study, further research is required into energy cost and equivalent step rate of walking overground on different surface types at different inclines under free living conditions.

Conclusion

In conclusion results of the current study suggest that for the purpose of a general public health message, a generic step rate of 120 steps·min^{-1} and 7200 in 60 mins may be advocated to achieve MPA in adolescent girls (walking on a flat surface). However, the current study also confirms that there is great inter-individual variation in step rate associated intensity and that the use of a single recommendation is likely to lead to an unachievable target for some individuals. Therefore, promotion of a step rate range may be beneficial for use with adolescent girls and where feasible individual step rate recommendations should be considered according to weight status. Further research is required into ways of implementing such recommendations (individualized step rates that correspond to various intensities) into a public health setting. With the recent advancement in technologies that allow self-monitoring of PA, a growing number of which are targeted at young people, this may be possible.

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Table 1. Physical characteristics

Variable	Mean±SD	Range
Age (yrs)	13.85 (0.77)	12.24-15.00
Height (cm)	159.98 (5.88)	146.40-172.60
Weight (kg)	52.15 (9.62)	34.00-75.00
Body Mass Index (BMI)	20.30 (3.47)	15.49-31.60
BMI z-score	0.17 (1.12)	-2.89-2.29
BMI percentile	53.69 (30.64)	1.09-99.81
Waist Circumference (cm)	66.40 (7.40)	53.90-88.90
Leg Length (cm)	77.42 (4.44)	68.00-90.20
Maturity offset (yrs)	1.45 (0.69)	-0.24-2.99
10 meter step test (step)	14.50 (1.21)	11.00-18.00
10 step test (m)	6.80 (0.69)	5.45-8.57
Resting $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	5.12 (0.83)	3.39-6.68

Leg length = Height- Sitting height; $\dot{V}O_2$= Oxygen uptake

Table 2. Response parameters for each overground walking trial

Variable	Walking trial 1 (Slow)	Walking trial 2 (Moderate)	Walking trial 3 (Fast)
Walking speed (mph)	2.5 (0.4)	3.0 (0.4)	3.4 (0.8)
Step rate ($steps \cdot min^{-1}$)	104 (10)	121 (7)	132 (9)
Heart Rate (bpm)	109 (11)	116 (10)	125 (12)
$\dot{V}O_2$($ml \cdot kg^{-1} \cdot min^{-1}$)	13.47 (2.16)	15.27 (2.33)	17.07 (3.19)
METs	2.61 (0.52)	2.99 (0.57)	3.35 (0.79)

$\dot{V}O_2$= Oxygen uptake; MET= metabolic equivalent

Table.3. Summary of multiple regression analysis

Model predictors	ΔR²	SEE	b	95% PI (METs)
Step Rate	0.20	0.003	0.46	2.22-3.64
Step Rate, Age (yrs)	0.30	0.061	0.50,0.31	1.89-3.98
Step Rate, Height (cm)	0.26	0.008	0.49, 0.20	2.08-3.71
Step Rate, Weight (kg)	0.35	0.005	0.49, 0.35	1.90-3.95
Step Rate, BMIz	0.29	0.594	0.47, 0.26	2.07-3.85
Step Rate, Waist circumference(cm)	0.32	0.007	0.49, 0.32	2.11-3.96
Step Rate, Leg Length (cm)	0.23	0.012	0.49, 0.16	2.14-3.72
Step Rate, 10m step test (steps)	0.22	0.073	0.45, 0.28	2.22-3.75
Step Rate, 10 step test (m)	0.26	0.041	0.46, 0.18	2.04-3.83
Step Rate, Maturity off set (yrs)	0.19	0.100	0.53, 0.40	1.79-3.90

BMIz= Body Mass Index Z scores; SEE= Standard Error of Estimates; 95% PI= 95% Prediction intervals

Note: ΔR^2= change in R^2, additional variance.

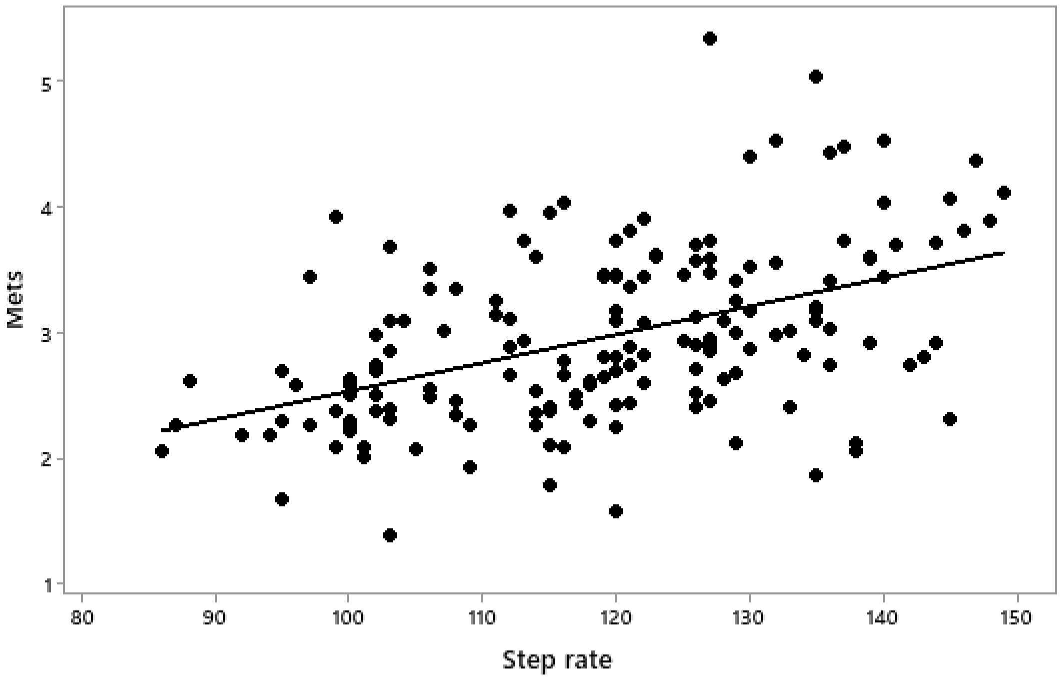

Figure 1. Scatter plot of Mets and Step Rate.