The Relationship between Heart Rate Intensity and Pedometer Step Counts in Adolescents

Key words: Physical activity, exercise, guidelines, physical fitness,

Abstract

The primary objective of this study was to examine the relationship between heart rate intensity and pedometer step counts in adolescents (mean age = 14.2, SD = 0.8 years). To determine existing levels of cardiorespiratory fitness, subjects (N = 106, boys = 47, girls = 59) completed the Queen's College Step Test and were classified as low, moderate and high cardiorespiratory fitness. Adolescents also completed a 10-minute treadmill trial wearing pedometers and heart rate monitors. Subjects were instructed to maintain their heart rate between 65-75% of their maximum heart rate (HR max) while running or walking on the treadmill. A heart rate of 65-75% HR max was associated with 146 (SD = 22) steps/minute in boys and 137 (SD = 22) steps/minute for girls. Results of the ANOVA indicated that there was a main effect for fitness level, $F_{(2,102)} = 9.36$, $P < 0.001$. The correlation between mean steps/minute and estimated VO_2 max was statistically significant ($r = 0.44$, $P < 0.001$). The results from this study suggest that a step rate of 130 steps/minute is equal to 65-75% HR max in low-fit adolescents and achieving 130 steps/minute could be used as an initial goal to improve fitness.

1 The Relationship between Heart Rate Intensity and Pedometer Step Counts in Adolescents

2 Physical activity declines precipitously during adolescence (Nader, Bradley,
3 Houts, McRitchie, & O'Brien, 2008; Sallis, 2000) and identifying strategies to
4 engage adolescents in health promoting physical activity is a research priority
5 (World Health Organization, 2005). Physical activity self-monitoring using
6 pedometers has emerged as an effective strategy for promoting lifestyle physical
7 activity among adults (Bravata *et al.*, 2007; Richardson *et al.*, 2008) and
8 preliminary evidence suggests that pedometers can be used successfully to promote
9 physical activity with adolescents over the short-term (Lubans & Morgan, 2008;
10 Lubans, Morgan, Callister, & Collins, in press; Schofield, Mummery, & Schofield,
11 2005).

12 While it is generally accepted that children and adolescents should engage in
13 at least 60 minutes of moderate-to-vigorous physical activity each day (Cavill, Biddle,
14 & Sallis, 2001; Department of Health & Aging, 2004), step recommendations for
15 youth are still emerging. The U.S. President's Council on Physical Fitness and Sports
16 (2002) recommend 11,000 and 13,000 steps/day for girls and boys respectively.
17 Tudor-Locke and colleagues (2004) developed step recommendations based on body
18 mass index (BMI) cut-off points and concluded that girls should aim for 12,000
19 steps/day and boys 15,000 steps/days. There is a need to synchronize the time-based
20 and step-based guidelines and recent studies have explored the relationship between
21 activity time and step counts (Beighle & Pangrazi, 2006; Jago *et al.*, 2006). Beighle
22 and Pangrazi (2006) found that 5,000 steps was equal to approximately 60 minutes of
23 physical activity in children. In a similar study, Jago and colleagues (Jago *et al.*, 2006)
24 attempted to establish pedometer-based physical activity targets for adolescents. The
25 authors concluded that 8,000 pedometer steps were equal to 60 minutes of moderate-

1 to-vigorous physical activity and demonstrated that a fast walk was equal to 127
2 steps/minute. While both studies provided valuable information regarding the
3 relationship between activity time and steps taken, neither study provided specific
4 detail regarding the relationship between step counts and exercise intensity as
5 measured by heart rate.

6 Heart rate is the most frequently used method for prescribing aerobic
7 exercise intensity among adults (Potteiger, 2000; Warburton, Nicol, & Bredin,
8 2007). There is a linear relationship between heart rate and energy expenditure
9 during steady state exercise (Shephard, 2003) and a close relationship between heart
10 rate and oxygen consumption (Boulay, Simoneau, Lortie, & Bouchard, 1997).
11 However, there are limitations to the prescription of exercise using heart rate.
12 Individuals with low fitness levels can improve their fitness with lower training
13 intensities than individuals with higher baseline fitness levels (Shephard, 2001) and
14 extremely deconditioned adults can improve their fitness with small increases in
15 intensity and volume (Church, Earnest, Skinner, & Blair, 2007; Warburton *et al.*,
16 2004). Currently there is no consensus on the dose-response relationship between
17 physical activity and health in young people (Janssen, 2007) and the guidelines for
18 improving physical fitness among adults are continuing to evolve as new evidence
19 describing the health benefits of activity emerge (Warburton, Nicol, & Bredin,
20 2007). Consequently there are no established guidelines to improve
21 cardiorespiratory fitness. However, it is recommended that healthy adults should
22 engage in activity of moderate-to-vigorous intensity (>70% heart rate maximum) to
23 improve cardiorespiratory fitness (American College of Sports Medicine, 1998;
24 Haskell *et al.*, 2007; Warburton, Nicol, & Shannon, 2007) and these provide some
25 guidance for interim adolescent targets.

While it remains contentious whether physical activity or physical fitness is more important to health (Boreham & Riddoch, 2001), recent studies have found that cardiorespiratory fitness is more strongly correlated with indicators of health among youth than total time spent in physical activity (Ekelund et al., 2001; Rizzo, Ruiz, Hurtig-Wennlof, Ortega, & Sjostrom, 2007). These findings have important implications and justify strategies by health professionals to promote physical activity of sufficient intensity to increase fitness. The primary objective of this study was to examine the relationship between exercise intensity as measured by heart rate and pedometer step counts in a sample of adolescents. A secondary aim was to identify specific step targets to improve cardiorespiratory fitness among adolescents based on existing fitness levels. The identification of gender and fitness specific step targets for adolescents has the potential to promote physical activity, improve exercise adherence and combat the decline in activity associated with this age group (Sallis, 2000).

Method

Participants

Participants were recruited from six secondary schools (five government schools and one independent school) in Newcastle, New South Wales, Australia. Ethics approval for the study was obtained from the ethics committees of both the University of Newcastle, New South Wales (NSW), Australia and the NSW Department of Education and Training. The study sample included 47 boys and 59 girls (N = 106). From the study sample, 27 participants consented to complete the pedometer treadmill trial on three separate occasions to determine the reliability of the testing procedures.

Measures

Cardiorespiratory fitness. The Queen's College Step Test was used to provide an estimate of cardiorespiratory fitness in this study. The Queen's College Step Test is

1 a valid and reliable measure (McArdle, Katch, Pchar, Jacobson, & Ruck, 1972) in
 2 young adults. In a recent study Chatterjee and colleagues (Chatterjee, Chatterjee,
 3 Mukherjee, & Bandyopadhyay, 2004) compared results from a VO₂ max test to an
 4 estimate of VO₂ max based on heart rate recovery from the Queen's College Step Test
 5 and found that estimated VO₂ max from the submaximal step-test results was strongly
 6 correlated ($r = 0.95$) to actual VO₂ max scores in young males (23-yrs, mean height
 7 and weight = 166cm and 54kg respectively). In another study, results from the
 8 Queen's College Step Test were compared to VO₂ max in a sample of young females
 9 (22-yrs, height and weight = 157cm and 50kg) (Chatterjee, Chatterjee, &
 10 Bandyopadhyay, 2005). The authors found a significant correlation ($r = -0.83$)
 11 between VO₂ max and Queen's College Step Test pulse rate.

12 *Yamax pedometers.* Pedometers are small electronic devices used to detect and record
 13 physical activity and consist of a tiny spring-set horizontal arm that moves up and down in
 14 response to the vertical movement of the hip during walking. Pedometers have been
 15 compared to a variety of existing measures of physical activity, including oxygen
 16 consumption ($r = 0.81$) (Eston, Rowlands, & Ingledew, 1998), uniaxial ($r = 0.86$) (Bassett et
 17 al., 2000) and triaxial accelerometry ($r = 0.99$) (Kilanowski, Consalvi, & Epstein, 1999). The
 18 *Yamax SW700* pedometer was used in the current study to calculate steps in the pedometer
 19 treadmill trial because they have been found to be more reliable than other pedometer brands
 20 (Schneider, Crouter, Lukajic, & Bassett, 2003). A recent study demonstrated that Yamax
 21 pedometers provide a reliable estimate of actual steps on treadmills at speeds up to
 22 20km/hour (Rowlands, Stone, & Eston, 2007).

23 *Procedures*

24 The 3-minute Queen's College Step Test was performed on a bench (41cm
 25 high) using standardised procedures (McArdle et al., 1972). The cadence for the step

test was established using a metronome and was set at 88 and 96 beats.min⁻¹ as recommended for females and males, respectively. Before performing the step test, research assistants described the nature of the study and demonstrated how to attach the POLAR® heart rate monitors. At the end of the three minute period, participants were asked to remain standing and their heart rates were recorded. The standard procedure of the Queen's College Step Test is for the participant to remain standing for 5 seconds after completing the test and record their pulse at the carotid artery for a 15 second count. To reduce measurement error, heart rate monitors were used to record heart rate following the test. Heart rate was recorded by a research assistant 5 seconds after completing the test, then again at 10 seconds and 20 seconds. The average of the three scores was taken and the following equations were used to predict maximum oxygen uptake capacity: Girls: $VO_2 \text{ max (ml/kg/min)} = 65.81 - 0.1847 \times \text{heart rate (beats.min}^{-1}\text{)}$ and boys: $VO_2 \text{ max (ml/kg/min)} = 111.33 - 0.42 \times \text{heart rate (beats.min}^{-1}\text{)}$. While these equations were developed with university students and generate approximately 16% error (Hoffman, 2006), this degree of error may be acceptable when testing large numbers of participants (McArdle, Katch, & Katch, 1996).

The pedometer treadmill trial was completed at a commercial health and fitness centre in the week following the Queen's College Step Test. Before completing the trial, research assistants attached the POLAR® heart rate monitors and devices were checked. Participants were instructed to complete a 10 minute treadmill test, while maintaining their heart rate at 65-75% of their heart rate maximum (HR max). The target zone of 70% HR max was equal to moderate intensity physical activity (Armstrong, 1998; Livingstone, Robson, & Totton, 2000) and identified as the necessary intensity for healthy individuals to improve cardiorespiratory fitness (ACSM, 1998). Heart rate targets were calculated using the

following equation, $HR_{max} = 220 - \text{age}$. The average age of the students was 14.2 (14.0 to 14.4) years and the participants were instructed to maintain their heart rate between 133 and 155 $\text{beats} \cdot \text{min}^{-1}$. Once the heart rate monitors were attached securely, participants completed a 3-minute warm-up at low intensity (50% HR_{max}). Following this, participants were given pedometers and instructed on how to attach the device (on the right hip in line with the knee). Heart rate monitors were then checked again and pedometers were reset to zero. The participants were then instructed to start the treadmill and increase the speed rapidly to 10 $\text{km} \cdot \text{hour}^{-1}$ (10-15 seconds). Once this speed was achieved, participants were told to keep their heart rate target by increasing and decreasing the treadmill speed as needed (target = approx. 140 $\text{beats} \cdot \text{min}^{-1}$). Participants achieved their target HR and speed within 10-20 seconds. Based on a pilot of our study method, we determined that resetting the device and restarting the timing was awkward and not necessary for the 10 minute study protocol. Therefore we included the adjustment period in the step count (error of 2-3%). During the trial, a research assistant monitored the participants to ensure they adhered to the protocol and maintained a heart rate within the designated range (65-75% HR_{max}). To determine the reliability of the pedometer treadmill trial protocol, 27 participants completed the trial on three different days over a period of one month.

Data treatment

Total steps taken for the 10 minute pedometer treadmill trial were divided by 10 to provide an estimate of steps/minute. Estimated VO_2 max calculated from heart rate recovery from the Queen's College Step Test was used to provide a measure of cardiorespiratory fitness. In accord with previous studies (Katzmarzyk, Church, & Blair, 2004; Le Masurier & Corbin, 2006), participants in the lowest quintile (20%) of cardiorespiratory fitness were grouped in the low fitness category, participants in the next two quintiles (40%) were categorized as having moderate fitness and participants

in the top two quintiles (40%) were classified as having high fitness levels. The same process was applied when the data file was split by gender.

Statistical analyses

All statistical analyses were completed using SPSS version 14.0 software and alpha levels were set at $P < 0.05$. All variables were checked for normality and satisfied the criteria. A repeated measure ANOVA was used to provide an indication of group repeatability. The 95% 'limits of agreement' (Bland & Altman, 1986; Nevill & Atkinson, 1998) and the typical error were calculated (Hopkins, 2000) to provide a measure of individual repeatability. To provide an estimate of rank order repeatability, intraclass correlations (ICC) were calculated. Independent samples t-tests were calculated to determine if there were any statistically significant differences in estimated VO_2 max or steps/minute between those who completed the additional reliability trials and the rest of the sample.

Independent samples t-tests were then used to determine if gender differences existed in mean steps/minute and estimated VO_2 max. ANOVA (cardiorespiratory fitness level x mean steps/minute) was used to examine the differences in mean steps/minute among individuals with high, moderate and low fitness levels. A Bonferroni post hoc test was used to determine where the differences existed. Additional analyses were conducted for boys and girls separately. Pearson bivariate correlations with two-tailed tests of significance were calculated to determine the relationship between estimated VO_2 max and mean steps/minute.

Results

Participants were 106 adolescents (boys = 47, girls = 59) with a mean age of 14.2 years (14.0 to 14.4). The majority of participants were born in Australia (95%) and spoke English at home (89%). No significant bias was found between trials 1-3 (means 140, 140, 141 steps/minute), $F_{(1.71, 34.26)} = 1.210$, $P > 0.05$. The typical error

was 9 steps/minute and the 95% 'limits of agreement' was ± 28 steps/minute. The ICC [95% Confidence Interval (CI)] for the first two pedometer treadmill trials (1-2) was 0.83 (0.63 - 0.92) and 0.87 (0.73 - 0.94) for the first, second and third trials (1-3). There were no statistically significant differences for estimated VO_2 max ($P > 0.05$) or steps/minute ($P > 0.05$) for participants who completed the additional reliability trials, compared to those who did not.

In the study sample, a heart rate of 65-75% HR max was equal to 142 (95% CI = 138 to 147) steps/minute. Boys (mean = 148, 95% CI = 142 to 154 steps/minute) recorded significantly more ($P < 0.05$) steps/minute than girls (mean = 139, 95% CI = 132 to 143 steps/minute) (Figure 1). Based on the results from the Queen's College Step Test, boys (mean = 47.9, 95% CI = 45.7 to 50.0 ml/kg/min) had significantly ($P < 0.001$) higher VO_2 max estimates than girls (mean = 34.5, 95% CI = 33.8 to 35.1 ml/kg/min). Boys VO_2 max estimates ranged from 31.5 to 60.1 ml/kg/min and girls scores ranged from 30.0 to 40.7 ml/kg/min.

** Table 1 near here**

** Figure 1 near here***

Table 1 shows mean steps/minute at 65-75% of HR max by cardiorespiratory fitness category. Results of the ANOVA (cardiorespiratory fitness level x mean steps/minute) analysis indicated that there was a main effect for fitness level, $F_{(2, 102)} = 9.36$, $P < 0.001$. The Bonferroni post hoc procedure indicated that adolescents classified as having high levels of fitness recorded significantly more steps/minute than individuals in both the low ($P < 0.001$) and moderate ($P < 0.05$) fitness categories. There were no statistically significant differences in steps/minute between individuals in the low and moderate categories ($P > 0.05$). When the data were stratified by gender, there was a main effect for fitness level among boys [$F_{(2, 44)} =$

1 6.48, $P < 0.001$], but not for girls [$F_{(2, 56)} = 1.96$, $P > 0.05$]. The correlation between
 2 mean steps/minute and estimated VO_2 max was statistically significant ($r = 0.44$, $P <$
 3 0.001). The correlation coefficient was stronger for boys ($r = 0.55$, $P < 0.001$) than for
 4 girls ($r = 0.26$, $P < 0.05$).

5 Discussion

6 The primary aim of this study was to examine the relationship between heart
 7 rate intensity and pedometer step counts in adolescents. Adolescents with higher
 8 levels of cardiorespiratory fitness achieved higher step counts than those with lower
 9 fitness levels. Furthermore, boys achieved significantly more steps/minute than
 10 girls. This study explored an original and potentially valuable research hypothesis
 11 and the findings have important implications for health professionals promoting
 12 physical activity and physical fitness working among adolescents.

13 Data from the current study suggest that exercising at a target heart rate of
 14 $\approx 140 \text{ beats} \cdot \text{min}^{-1}$ (65-75% of HR max) corresponds to 146 steps/minute for boys and
 15 137 steps/minute for girls. The existing step targets for youth are different for boys
 16 and girls, and based on the findings from this study, step targets to improve
 17 cardiorespiratory fitness in youth should also be gender specific. Furthermore, based
 18 on the results of the step test, mean steps/minute differed by fitness level, with fitter
 19 adolescents taking more steps than less fit adolescents, suggesting that step targets
 20 should be gender specific and tailored to existing fitness levels.

21 It is interesting to note that the step counts for adolescents with low fitness
 22 levels were similar for boys (mean = 127, 116 to 139) and girls (mean = 128, 120 to
 23 143). However, there were larger gender differences for step counts for moderate and
 24 high-fit individuals. For moderately fit adolescent girls 137 ± 27 steps/minute was
 25 equal to 65-75% HR max, whereas moderately fit boys had step counts of 147 ± 21

1 steps/minute. Larger differences were noted for adolescents classified as having high
2 levels of fitness, where 160 ± 17 steps/minute was recorded by boys, compared to 142
3 ± 13 steps/minute for girls. One possible explanation for this finding is that the range
4 of scores for estimated VO_2 max among girls (30.0 to 40.7 ml/kg/min) in the study
5 was relatively small compared to boys (31.5 to 60.1 ml/kg/min), this may reflect the
6 fact that the study did not recruit any girls with high levels of cardiorespiratory
7 fitness. Participants were given a HR target based on their predicted HR max. The
8 range of 65-75% HR max reflects the error in the accuracy of predicting HR max,
9 rather than the fitter participants exercising at the upper end of the target zone.

10 Although this is the first study to explore the relationship between heart rate
11 intensity and steps/minute, previous studies have explored the relationship between
12 step counts, exercise intensity and time spent in physical activity (Beighle & Pangrazi,
13 2006; Jago *et al.*, 2006). Beighle and Pangrazi, found that 5,000 steps was equivalent
14 to approximately 60 minutes of physical activity in a large sample of children (mean
15 age = 9.2 ± 1.8 y). Similarly, Jago and colleagues (Jago *et al.*, 2006) examined the
16 relationship between step counts and time in physical activity in 11- to 15- year-old
17 boys. The authors concluded that 8,000 steps were equal to 60 minutes of moderate-
18 to-vigorous physical activity. Unlike the first study, which did not regulate student
19 activity, the second study provided students with structured activity of moderate-to-
20 vigorous intensity. It is interesting to note, that based on the results from the first
21 study (i.e. 60 minutes of moderate-to-vigorous physical activity = 5,000 steps), the
22 BMI-referenced step recommendations (12,000-15,000 steps/day) are equal to three
23 times the existing time-based physical activity guidelines for boys (one hour a day).

24 The step count targets identified in this study could be used by adolescents to
25 set physical activity goals and provide additional feedback for motivational purposes.

1 The present study indicates that step rates of approximately 130, 140 and 150
2 steps/minute are equal to the exercise intensity necessary to increase cardiorespiratory
3 fitness (65-75% max HR) for adolescents with low, moderate and high levels of
4 fitness respectively. However, it is important to note that these steps/minute
5 recommendations were produced while walking and running on a treadmill and so
6 cannot be directly generalised to other non-ambulatory activities. Furthermore, due to
7 the weak relationship between the step counts and cardiorespiratory fitness, these step
8 targets may require further development before they can be promoted at a population
9 level.

10 While the current generation of pedometers do not provide steps/minute as a
11 display, this information would be helpful to individuals interested in identifying their
12 exercise intensity without the use of a heart rate monitor. Rowing machines provide a
13 stroke rate display, which provides individuals with an estimate of the number of
14 strokes they would need to complete at the current rate to cover a distance of 500
15 meters. A pedometer which provided a steps/minute display could be used in a similar
16 way by individuals trying to achieve cardiorespiratory fitness goals. Research has
17 demonstrated that self-management strategies such as goal setting and activity
18 monitoring are effective strategies for improving exercise adherence in both
19 adolescents (Dishman *et al.*, 2005; Dishman *et al.*, 2006) and adults (Sallis, Calfas,
20 Alcaraz, & Gehrman, 1999). The step targets identified in this study would be useful
21 for physical activity and physical fitness monitoring.

22 It is important to note the limitations of this study. Firstly, the submaximal
23 used to provide an estimate of VO_2 max has not been validated in an adolescent
24 population. While the use of a submaximal test is a limitation, results from the
25 Queen's College Step Test compare favourably with actual VO_2 max in young men

1 and women (Chatterjee *et al.*, 2005; Chatterjee *et al.*, 2004; McArdle *et al.*, 1972) and
2 the Queen's College Step Test can be completed by most participants as long as they
3 adhere to the stepping pace. Furthermore, if a maximal fitness was used in the current
4 study, it is unlikely that the low-fit participants would have participated. An additional
5 limitation of this study is that we did not exclude the 10-20 second step count during
6 the initial stage of the treadmill test when participants were achieving their target
7 heart rates. However, the 20 second adjustment time period represents only 3% of the
8 total monitoring time period (10 minutes). Finally, the study did not measure, height,
9 weight, body composition or stride length. Failure to consider anthropometric
10 characteristics (e.g. leg length/height, stride length) which may affect the mechanism
11 of physical activity measurement and fitness testing results is an ongoing problem in
12 youth studies. Future research should address these limitations and aim to eliminate
13 unnecessary sources of error.

14 This study has examined the relationship between pedometer step counts
15 and heart rate intensity. Based on the results from this study approximately 130
16 steps/minute are associated with the 65-75% HR max in both male and female
17 adolescents with low fitness levels. This information could be used by adolescents
18 to set physical activity goals. Future studies should explore the impact of
19 pedometer-based interventions incorporating step targets to improve
20 cardiorespiratory fitness. Previous studies have found that goal setting with
21 pedometers is an effective strategy for increasing physical activity among low-
22 active adolescents (Lubans & Morgan, 2008; Lubans *et al.*, in press; Schofield *et*
23 *al.*, 2005) and the use of pedometers to motivate and provide feedback for
24 improving cardiorespiratory fitness may also be more useful for individuals with
25 low fitness levels.

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1 Table 1

2 *Mean steps/minute and 95% Confidence Intervals for cardiorespiratory fitness*3 *categories*

4

Cardiorespiratory Fitness	Mean (95% Confidence Interval)		
	Total (N= 106)	Boys (n = 47)	Girls (n = 59)
LOW	129 (123 to 139)	127 (116 to 139)	128 (120 to 143)
MOD	138 (132 to 146)	147 (125 to 149)	137 (125 to 149)
HIGH	152 (146 to 159)	160 (151 to 168)	142 (137 to 148)

5

6 *NB. There were no significant differences between boys and girls for any of the fitness groups*

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Figure Caption

Figure 1: Mean steps/minute on a treadmill at 65-75% of HR max by gender (95% CI)

NB. Significant difference between boys and girls ($P < 0.05$)