Ambulatory Activity and Simple Cardiorespiratory Parameters at Rest and Submaximal Exercise

Catrine Tudor-Locke¹, Barbara E. Ainsworth², Melicia C. Whitt³, Raymond W. Thompson⁴, Cheryl L. Addy⁵, and Deborah A. Jones⁶

Catalogue Data

Key words: walking, blood pressure, heart rate
Mots-clés: marche, pression sanguine, fréquence cardiaque

Abstract/Résumé
The purpose of this study was to explore the relationship between objectively determined ambulatory activity and simple cardiorespiratory parameters (heart rate and blood pressure at rest and during submaximal exercise) in individuals who were stratified for self-reported participation (yes/any vs. no/none) in vigorous physical activity (PA). Ninety-eight subjects (African Americans: 7 M, 16 F; Caucasians: 33 M, 42 F; mean age 46.4 ± 15.4 yrs; mean BMI 26.7 ± 4.8) wore a pedometer for 21 consecutive days and completed a 10-min submaximal treadmill graded exercise test with HR (beats/min) and BP (mmHg) measured while walking at 4.8 km/hr and a 10% grade. Subjects averaged 7,618 ± 3,045 steps/day. There were no differences in steps/day by self-reported vigorous PA strata. There was an inverse relationship (r = –0.35, p = 0.03) between steps/day and resting HR in subjects who reported no vigorous PA. There was an inverse relationship (r = –0.22, p = 0.04) between steps/day and submaximal HR in all subjects. When stratified for self-reported

¹Dept. of Exercise and Wellness, Arizona State U. East, Mesa, AZ 85212; ²Dept. of Exercise and Nutritional Sciences, San Diego State U., San Diego, CA 92182; ³Center for Clinical Epidemiology & Biostatistics, U. of Pennsylvania School of Medicine, Philadelphia, PA 19104; ⁴Dept. of Exercise Science, and ⁵Dept. of Epidemiology & Biostatistics, U. of South Carolina, Columbia, SC 29208; ⁶Center for Chronic Disease Prevention & Health Promotion, U.S. Centers for Disease Control, Atlanta, GA 30341-3717, USA.
vigorous PA, the inverse relationship between steps/day and submaximal HR was stronger for those reporting no vigorous PA \((r = -0.39, p = 0.01)\) vs. those reporting any vigorous PA \((r = -0.28, p = 0.05)\). There was no relationship between steps/day and BP at rest or during exercise in this normotensive sample.

Le but de cette étude est d’analyser la relation entre l’activité ambulatoire établie objectivement et des variables cardiorespiratoires (fréquence cardiaque et pression sanguine au repos et à l’effort) chez des individus regroupés à la suite de leur auto-évaluation comme ayant oui ou non participé à des activités physiques vigoureuses (PA). Quatre-vingt-dix-huit sujets (Afro-américains: 7 H, 16 F; Blancs: 33 H, 42 F; dont l’âge est de 46,4 ± 15,4 ans et l’IMC est de 26,7 ± 4,8) portant un podomètre, durant 21 jours consécutifs, participent à une épreuve sous-maximale d’intensité progressive sur tapis roulant d’une durée de 10 min; la fréquence cardiaque (bpm) et la pression sanguine (mmHg) sont mesurées à une vitesse de marche de 4,8 km/h sur une pente de 10%. En moyenne, les sujets ont fait 7 618 pas ± 3 045 par jour. Le nombre de pas par jour ne diffère pas d’un groupe à l’autre. La relation entre le nombre de pas par jour et la fréquence cardiaque de repos chez les sujets n’ayant participé à aucune activité physique vigoureuse est inverse \((r = -0,35, p = 0,03)\). La relation entre le nombre de pas par jour et la fréquence cardiaque sous-maximale est inverse chez tous les sujets \((r = -0,22, p = 0,04)\). La relation entre le nombre de pas par jour et la fréquence cardiaque sous-maximale est plus importante chez les individus n’ayant participé à aucune activité physique vigoureuse: \(\text{non, } r = -0.39, p = 0.01; \text{ et oui, } r = -0.28, p = 0.05\). Chez ces individus normotendus, il n’y a aucune relation entre le nombre de pas par jour et la pression sanguine au repos ou à l’effort.

Introduction

Physical activity (PA) is defined as any bodily movement produced by contracting skeletal muscles that results in increased energy expenditure over the basal level (LaPorte et al., 1985). Cardiorespiratory fitness is a component of physical fitness that relates to the ability of the circulatory and respiratory systems to supply oxygen during sustained PA (U.S. Dept. Health and Human Services, 1996). Evidence suggests that low PA (or the tendency to be sedentary) and low cardiorespiratory fitness have independent health consequences (Blair et al., 1995; Wei et al., 2000; Williams, 2001). Williams conducted a meta-analysis of 23 sex-specific cohorts of PA or cardiorespiratory fitness that disclosed distinctly different relationships between these two variables—one a behavior and the other a performance attribute—and the risk of heart disease, both coronary and cardiovascular. Further, Williams concluded that, relative to the least active or least fit percentiles, the risk for cardiovascular disease endpoints reduction is greater through physical fitness than activity.

A limitation of Williams’ (2001) study is the discrepant approaches to the measurement of each variable; cardiorespiratory fitness was assessed objectively in each study in the meta-analysis by a cycle ergometer or treadmill test, whereas PA was ascertained using a plethora of self-report instruments. Misclassification biases due to the crude measurement of physical inactivity by self-reported methods is considered an important limitation (Sallis and Saelens, 2000). Objective PA assessment using electronic motion sensors such as accelerometers (Westerterp, 1999), and pedometers (Tudor-Locke and Myers, 2001a, 2001b) may provide ad-
ditional insight. The primary drawbacks to the widespread use of accelerometers are their expense ($50–450 per unit), the fact that they often require computer interfacing hardware and analysis software, and their potentially demanding data treatment requirements (Tudor-Locke and Myers, 2001a). The new generation of electronic pedometers offers a simple and inexpensive alternative (Freedson and Miller, 2000; Moreau et al., 2000; Tudor-Locke and Myers, 2001a).

Accumulating research supports the notion that the pedometer is appropriate for objectively assessing ambulatory activity, including both intentional and incidental walking behaviors (Bassett, 2000; Bassett et al., 1996; Freedson and Miller, 2000; Tudor-Locke and Myers, 2001b; Tudor-Locke et al., 2002c). The pedometer is not capable of discriminating time in intense activity, nor, like the accelerometer, can it adequately account for participation in some activities (e.g., bicycling, swimming, weight-training). Despite these limitations, however, it has been postulated that a synergistic combination of pedometer and self-report methods may lead to a better understanding of the relationship between PA and important health outcomes (Kriska, 2000), including simple cardiorespiratory parameters such as resting and exercise HR and BP that are known to change with increased aerobic exercise (Nieman, 2003; Roitman, 1998).

As part of an ongoing effort to explore the discriminative properties of PA questionnaires and pedometers, the purpose of this paper is to report the relationship between objectively determined ambulatory activity and simple cardiorespiratory parameters in individuals stratified for participation in self-reported vigorous activity. This study represents an analysis of data obtained from participants who wore a Yamax pedometer (Digiwalker, Model SW-200, Accusplit, CA) for 21 consecutive days as an objective measure of PA, and who also completed a submaximal treadmill test with measures of HR and BP responses to rest and exercise.

**Methods**

**PARTICIPANTS**

This data set has been previously described (Tudor-Locke et al., 2001) and is summarized again here. Study participants were actively recruited through word-of-mouth and posted announcements in the University of South Carolina and Columbia, SC, communities. Inclusion criteria were: (a) self-reported as healthy (no limiting conditions); (b) able to walk on a treadmill for a submaximal exercise test; and (c) willingness to comply with the research protocol. Of 139 initially enrolled, 10 dropped out (citing no time), 3 were not compliant with the study protocol, and 28 had incomplete data. Remaining participants included 49 men (11 African Americans and 38 Caucasians) and 77 women (27 African Americans and 50 Caucasians), ranging in age from 17 to 79 years. The secondary analysis herein was conducted on data obtained from 98 subjects (7 M and 16 F African Americans, and 33 M and 42 F Caucasians) from the original database, from whom both pedometer-assessed ambulatory activity and cardiorespiratory data were collected. Study sample descriptive characteristics, including age, BMI (weight in kg/height in meters\(^2\)), and pedometer-assessed steps/day are presented in Table 1. All participants read and signed a written informed consent form approved by the University of South Carolina’s Institutional Review Board.
Subjects were asked to wear the pedometer at their waist (attached to a belt) during waking hours for 21 consecutive days, and to record day-end values of accumulated steps taken during the day in a simple calendar-type log. They also completed PA questionnaires and physical fitness and anthropometric assessments (height and weight without shoes to obtain BMI, and percent body fat) as indirect measures of PA. The relationship between pedometer-assessed ambulatory activity and the body composition variables using this same data set has been described in Tudor-Locke et al. (2001). The focus of this paper is on the pedometer data and its relationship with HR and BP responses to rest and submaximal treadmill exercise. Lower HR and BP responses to submaximal exercise are simple parameters indicative of improved cardiac performance (Nieman, 2003; Roitman, 1998). The resultant economy improves the capability of the heart to respond to increased oxygen demand, and may also raise the ischemic threshold in those who suffer from angina pectoris or arrhythmias (Morris and Hardman, 1997).

A single question from the developmental version of the 2001 Behavioral Risk Factor Surveillance System (BRFSS) PA questionnaire was used to classify participation in vigorous PA: “Last week, did you do vigorous activity continuously for at least 10 minutes that caused large increases in breathing or HR, such as running, swimming, aerobics, fast bicycling, competitive sports or heavy yard work?” If subjects answered yes, they were asked how many total minutes were spent doing vigorous activity per day. Participation in vigorous PA was classified as Yes/Any (≥ 10 min of vigorous activity, n = 55) or No/None (< 10 min of vigorous activity, n = 43).

Resting HR and BP were assessed prior to undertaking a 5-stage submaximal treadmill walking protocol (Ainsworth et al., 1993). Subjects walked for the duration of the test at 4.8 km/hr; every 2 minutes the grade was increased by 2.5% increments (or approximately 1 MET) from a 0% grade during the initial stage to a 10% grade in the final stage. Within the last 30 seconds of each 2-min stage, exercise HR and BP were assessed. Heart rate in beats per minute was determined from a chest-worn HR monitor (Polar, model 61214, Country Technology Inc., Gays Mills, WI). Blood pressure (mmHg) was measured by auscultation with a mercury sphygmomanometer. The highest values for exercise HR and systolic and diastolic blood pressures (SBP and DBP, respectively) recorded during the final stage (walking at 4.8 km/hour at a 10% grade) were used for this analysis.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Age</th>
<th>BMI</th>
<th>Steps/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male (n = 40)</td>
<td>46.5 ± 16.6</td>
<td>27.3 ± 4.2</td>
<td>7,847 ± 3,090</td>
</tr>
<tr>
<td>Female (n = 58)</td>
<td>46.4 ± 14.6</td>
<td>26.3 ± 5.2</td>
<td>7,460 ± 3,030</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>African Amer. (n = 23)</td>
<td>36.9 ± 11.0</td>
<td>29.1 ± 6.0</td>
<td>7,298 ± 2,564</td>
</tr>
<tr>
<td>Caucasian (n = 75)</td>
<td>49.4 ± 15.4</td>
<td>26.0 ± 4.1</td>
<td>7,716 ± 3,187</td>
</tr>
</tbody>
</table>

Table 1 Descriptive Characteristics of Sample (mean ± SD)
Chi-square analyses were used to examine frequency distributions of gender and race between self-reported vigorous PA strata. Comparison of means between self-reported vigorous PA strata was determined using independent \( t \)-tests, having satisfied relevant statistical assumptions. Correlation matrices were computed to reveal potential confounding variables for adjustment purposes. Subsequently, adjusted Pearson product-moment correlation coefficients were calculated between the cardiorespiratory parameters and steps/day for both of the vigorous PA strata and for the total sample. Statistical analyses were conducted using SAS Version 8.01; significance was determined at alpha < 0.05.

**Results**

Based on a single survey question about participation in vigorous PA, women were significantly more likely than men to report no participation at all (55% vs. 28%, \( \chi^2 = 7.36, p < 0.01 \)). There was no difference in self-reported vigorous PA with regard to race. The means and standard deviations for age, BMI, HR, and BP for the total sample and according to vigorous PA strata are listed in Table 2. There was a statistically significant difference between self-reported vigorous PA strata for age and exercise HR, \( p < 0.05 \). No other differences were significant.

Age and BMI were inversely related to steps/day (\( r = -0.28 \) and \( -0.32 \), respectively, both \( p < 0.01 \)) and were therefore used to adjust correlation coefficients.

<table>
<thead>
<tr>
<th>Health indicator</th>
<th>Total ((N = 98))</th>
<th>Yes/Any ((n = 55))</th>
<th>No/None ((n = 43))</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>46.4 ± 15.4</td>
<td>43.4 ± 15.9</td>
<td>50.3 ± 14.0</td>
<td>2.24</td>
<td>0.03</td>
</tr>
<tr>
<td>BMI</td>
<td>26.7 ± 4.8</td>
<td>26.4 ± 4.3</td>
<td>27.1 ± 5.3</td>
<td>0.74</td>
<td>0.46</td>
</tr>
<tr>
<td>Steps/day</td>
<td>7,618 ± 3,045</td>
<td>7,171 ± 2,915</td>
<td>8,191 ± 3,145</td>
<td>1.66</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Cardiorespiratory parameters at rest

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Total ((N = 98))</th>
<th>Yes/Any ((n = 55))</th>
<th>No/None ((n = 43))</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate</td>
<td>77.7 ± 15.1</td>
<td>77.8 ± 17.2</td>
<td>77.6 ± 12.1</td>
<td>-0.04</td>
<td>0.96</td>
</tr>
<tr>
<td>Diastolic BP</td>
<td>74.6 ± 9.2</td>
<td>74.1 ± 10.4</td>
<td>75.3 ± 7.4</td>
<td>0.71</td>
<td>0.48</td>
</tr>
<tr>
<td>Systolic BP</td>
<td>116.9 ± 13.3</td>
<td>116.2 ± 12.1</td>
<td>117.8 ± 14.9</td>
<td>0.58</td>
<td>0.56</td>
</tr>
</tbody>
</table>

Cardiorespiratory parameters to exercise

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Total ((N = 98))</th>
<th>Yes/Any ((n = 55))</th>
<th>No/None ((n = 43))</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate</td>
<td>133.8 ± 19.0</td>
<td>129.9 ± 17.5</td>
<td>138.9 ± 19.9</td>
<td>2.35</td>
<td>0.02</td>
</tr>
<tr>
<td>Diastolic BP</td>
<td>74.8 ± 7.5</td>
<td>74.7 ± 7.1</td>
<td>74.9 ± 8.2</td>
<td>0.07</td>
<td>0.94</td>
</tr>
<tr>
<td>Systolic BP</td>
<td>145.5 ± 18.3</td>
<td>144.7 ± 16.4</td>
<td>146.5 ± 20.6</td>
<td>0.48</td>
<td>0.63</td>
</tr>
</tbody>
</table>

**Note:** Exercise = walking at 4.8km/hr at a 10% grade.
computed between steps/day and the cardiorespiratory indicator variables under study. Table 3 presents the adjusted correlation coefficients for both classifications of vigorous activity and for the total sample. The moderate negative correlation between resting HR and steps/day was only statistically significant, $p < 0.05$, in individuals reporting no participation in vigorous activity. Correlation between exercise HR and steps/day was low and statistically significant ($r = –0.22, p = 0.04$). When stratified for self-reported participation in vigorous PA, the relationship was stronger for those reporting no vigorous PA ($r = –0.39, p = 0.01$) vs. those reporting any ($r = –0.28, p = 0.05$). There was no relationship between steps/day and BP responses at rest or during exercise in this normotensive sample.

**Discussion**

Individuals in this sample reporting no participation in vigorous PA were older and had a higher exercise HR response than those who reported any vigorous PA. There was no difference between the self-reported vigorous PA strata on any other variable, including pedometer-determined steps/day. Initially surprising, this lack of difference in steps/day between self-reported vigorous PA strata might be explained if those who intentionally exercised engaged in less incidental activity during the
day. Alternatively, as qualitative analyses of walking behaviors indicate in other studies (Tortolero et al., 1999; Warnecke et al., 1997), those who perform more incidental activity during the day have neither the time nor desire to engage in structured exercise. We cannot make conclusions about these possible explanations from the data collected herein. What is apparent, however, is that self-reported participation in vigorous PA does not differentiate between total amounts of ambulatory movement detected with a pedometer. Thus, a single global question about participation in vigorous activity may not discriminate between different levels of habitual ambulatory activity.

For the whole sample, the only cardiorespiratory parameter assessed that was significantly related to steps/day was the exercise HR; as steps/day increased, the HR response to submaximal exercise decreased, suggesting improved fitness. This was true even after adjusting for potential confounding by age and BMI. The relationship was stronger for those reporting no vigorous PA. Interestingly, the relationship was almost significant, $p = 0.05$, in those reporting any participation in vigorous PA, suggesting an independent effect for level of habitual ambulatory activity accumulated throughout the day, regardless of intensity. Although we did not assess participation in moderate activity, this point may have important public health significance for the value of moderate PA, improved cardiovascular fitness, and reduced morbidity and mortality (Blair et al., 1992; Lee, 2001; Wei et al., 2000).

Although the BP benefits of a regular walking program are well documented (Shephard, 1997), we observed no significant relationship between the steps/day and any measure of BP in this sample that was not expressly selected based on blood pressure, yet turned out to be largely normotensive. It is interesting to note, however, that in 3 of the 4 BP variables studied, the direction of the relationship was reversed (i.e., negative vs. positive) for those reporting no vigorous PA compared to those reporting any. The relationship between steps/day and BP needs to be reexamined in a sample characterized by a more diverse range of BP. Hayashi et al. (1999) showed in a prospective study design that greater reported time spent walking to work (independent of leisure-time activity) decreased the risk of hypertension in Japanese men. The operating assumption of Hayashi’s work was that those men who spent more time actively commuting to work also had higher daily activity levels, presumably due to increased levels of ambulatory activity.

A meta-analysis of 16 intervention studies concluded that walking-based exercise programs reduce BP in adults (Kelley et al., 2001). Recent interventions that have capitalized on pedometers for measurement and motivation have demonstrated reductions in systolic blood pressure in individuals with elevated baseline BP (Moreau et al., 2001; Tudor-Locke et al., 2002b).

Validation studies of self-reported PA instruments often report relationships with measures of maximum oxygen consumption (Kriska and Caspersen, 1997), a well-known indicator of participation in vigorous PA. The more recent interest in moderate intensity activity requires that validation studies of PA assessment approaches incorporate indicators reminiscent of this type of activity, including resting and exercise HR and BP. Further, front-line program deliverers often do not have access to equipment needed to measure oxygen consumption, and field tests are typically administered that collect these simple cardiorespiratory parameters (Canadian Society for Exercise Physiology, 1998).
Surprisingly, few cross-sectional studies have examined the relationship between PA and resting and exercise HR and BP. Garcia-Palmieri et al. (1982) reported a relationship between resting HR and index of PA on the order of $r = -0.22$ to $-0.21$ (no $p$ values reported for any relationship). The relationship with resting SBP was $r = -0.06$ to $-0.09$, and with resting DBP it was $r = -0.06$ to $-0.13$. Ainsworth et al. (1993) used the same submaximal treadmill protocol we used in the present study to examine the relationship between a PA score computed from questionnaire data and exercise HR. In that study, multiple linear regression analysis was used to determine the amount of variance explained by the scoring protocols for submaximal HR ($R^2 = 0.23$ to $0.25$, $p < 0.05$). BP was not examined as part of that study.

The literature on intervention provides additional clues about the relationship between PA, specifically ambulatory activity, and outcomes indicating cardiorespiratory fitness. At least three walking interventions with previously sedentary individuals have reported a decreased HR response to submaximal exercise (Hardman et al., 1992; Stensel et al., 1994; Woolf-May et al., 1996). In another study, however, Murphy and Hardman (1998) reported that neither submaximal exercise HR nor resting BP changed in response to 10 weeks of short or long bouts of walking compared with a control group. Since the present findings suggest that level of accumulated ambulatory activity is similar in groups that differ on reported participation in vigorous activity, it may be that subjects in the latter study also did not differ by participation in vigorous activity. For example, groups assigned to the exercise conditions might have volitionally or unintentionally modified their nonexercise activity to compensate for the exercise intervention, thereby neutralizing the impact of the structured intervention.

Recognized limitations of the pedometer as a PA monitor are that it is not sensitive to intensity of activity performed and is not able to pick up nonambulatory activity including forms of intentional exercise such as weight-training, bicycling, and swimming (Tudor-Locke and Myers, 2001b). However, it may be possible to better understand PA by using a pedometer to compartmentalize individuals’ daily activity into structured exercise and residual daily activity using both a pedometer and a simple activity log (Tudor-Locke et al., 2001). Such an approach should allow researchers to explore more fully the contributions of structured and intensity-controlled exercise within the context of daily-accumulated ambulatory activity, regardless of intensity.

We recognize that the findings of the present study are based on a limited cross-sectional design of 98 adults and thus cannot be used to draw conclusions about causation. Better indicators of cardiorespiratory fitness, such as direct measures of oxygen consumption, are indicated as well. We also did not assess self-reported participation in moderate intensity activity. Public health recommendations encourage individuals to accumulate 30 minutes of moderate intensity activity, like brisk walking, on most if not all days of the week (Pate et al., 1995). Based on comparing outputs from accelerometers—from which time in activity of varying intensities can be inferred—and pedometers, this amount of moderate activity corresponds with $\approx 8,000$ pedometer-steps/day (Tudor-Locke et al., 2002a). Further, in order to achieve $>9,000$ steps/day (Tudor-Locke et al., 2001), individuals may need to perform some type of intentional activity in addition to their inciden-
tal daily demands, such as walking to work/school or structured exercise/sport (Tudor-Locke and Myers, 2001b). Before any specific number of steps/day is promoted as an optimal dose for good health, the distinct benefits on different health outcomes of increased steps/day needs to be studied in prospective designs relative to individual characteristics, including initial or baseline steps/day.

In summary, both self-reported participation in vigorous PA and accumulated steps/day taken by free-living adults are positively related to enhanced cardiopulmonary response to submaximal exercise. Specifically, individuals who reported participation in vigorous PA had a lower HR response to submaximal exercise than those who reported no vigorous PA. There was no difference in the number of steps/day taken between subjects who reported participation in vigorous PA and those who did not. Regardless of participation in vigorous PA, level of accumulated pedometer-determined steps/day was inversely related to HR response to exercise. This relationship was strongest in those reporting no vigorous PA. Because the sample was normotensive, there was no evidence of a relationship between steps/day taken or participation in vigorous PA and blood pressure at rest or during exercise. We therefore conclude that pedometer-assessed ambulatory activity, expressed as steps/day, is related to a lower HR response to acute submaximal exercise. The magnitude of this relationship is different when categorized for self-reported participation in vigorous PA versus when it is not.

Acknowledgment

This study was undertaken when the first author was a postdoctoral fellow at the Prevention Research Center, Norman J. Arnold School of Public Health, University of South Carolina. This study was supported by Grant No. U48/CCU409664 from the Centers for Disease Control and Prevention. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the Centers for Disease Control and Prevention.

We wish to acknowledge Angie Morgan, Melinda Irwin, and Bill Bartoli for their assistance with the completion of this study.

References


Received January 8, 2003; accepted in final form May 11, 2003.