Physiological Responses to Single versus Double Stepping Pattern of Ascending the Stairs

Abdul Rashid Aziz and Kong Chuan Teh

Abstract The aim of this study was to compare the physiological responses and energy cost between two ascending patterns, the single-step (SS) and the double-step (DS), in climbing a public staircase. In the SS pattern, a person climbs one step at a time whilst in the double-step (DS) pattern, the individual traverses two steps in a single stride. Advocates of each stepping pattern claimed that their type of ascent is physically more taxing and expends more calories. Thirty subjects (10 males and 20 females) climbed a typical 11-storey flat (each step height of 0.15 m, a total of 180 steps and a vertical displacement of 27.0 m). The subjects climbed using either the SS pattern at a tempo of 100 steps · min⁻¹ or the DS pattern at 50 steps · min⁻¹. The prescribed stepping frequencies ensured that an equal amount of total work was performed between the SS and DS patterns. The climbing patterns were performed in random order. Physiological measures during the last 30 s of the climbs were used in the comparative analysis. The results showed that ventilation, oxygen uptake and heart rate values were significantly higher (all \( p < 0.01 \)) in the SS as compared to the DS pattern. However, the caloric expenditure during the SS pattern was calculated to be only marginally higher than the DS pattern. In conclusion, ascending with the SS pattern led to significantly higher physiological responses compared to the DS pattern. The higher caloric expended with the SS compared to the DS pattern was deemed to be of little practical significance.

Introduction

Singapore is a land-scarce country with more than 86% of its population living in government-built high-rise apartment buildings, called flats (Ministry of Information and the Arts, 1999). The staircases in these flats are within 5–40 m from the occupants’ doorsteps, and thus the majority of the Singaporeans have convenient access to this simple mode of exercise. This unique residential profile prompted our laboratory to initiate a series of investigations on stair-climbing activity using the public access staircase of these flats (Tan et al., 2004; Teh and Aziz, 2002; Teh and Aziz, 2000). Anecdotal feedback from subjects involved in these studies indicated that many have practised climbing stairs using an ascending pattern of either a single- or double-step pattern. In the single-step (SS) pattern, the individual climbs one step at a time whilst for the double-step (DS) pattern, the individual covers two steps in a single stride.

Interestingly, supporters of both step patterns perceive and claim that their type of ascending pattern involves a greater effort and therefore expends more calories. The SS pattern means stepping on every single step on the stairs throughout the ascent and this consequently generates a faster stepping rate. This may have made the individual feel that that he is performing relatively more work. On the other hand, the DS pattern appears to require a greater physical exertion since the climber needs to stretch his forward foot further and lift himself over a greater vertical distance during the push-off step. This may lead to a greater need to maintain body balance that could co-activate other muscles and hence result in greater physiological perturbations. Theoretically therefore, both ascending patterns have some basis to effect a higher metabolic and physiological cost. On the other hand, previous studies on climbing have shown that oxygen uptake (\( \dot{V}O_2 \)) and heart rate (HR) were rather similar during stepping at various different cadences (Butts et al., 1993; Grier et al., 2002; Howley et al., 1992). But these investigators have used a step-ergometer or step-bench rather than actual stairs as their mode of climb. Clearly, findings from these studies were limited since the evidence indicated that there are biomechanical and physiological differences between bench-stepping motion (i.e., climbing with both feet on each step) and the natural climbing action (i.e., climbing foot over foot) (Shiomi, 1994).

Most people who exercise aim to maximize their energy expenditure during every workout. Therefore, determining
which of the two typical climbing patterns (i.e., SS or DS) would expend more calories is clearly an important issue for those who regularly use stairclimbing as a form of physical activity. The purpose of this study is to compare the physiological responses and energy cost between the SS and DS step patterns while ascending a typical public staircase.

Methods

Subjects
Thirty subjects (10 males and 20 females) volunteered for the study (Table 1). Subjects were low to moderately active and engaged in various physical activities for at least 30 min once a week. None of them had used the stairs or stepping equipment as their primary mode or equipment of exercise. All subjects completed a pre-participation medical questionnaire before undergoing any experimental procedures. They were briefed on the benefits and potential risks involved and provided written consent to participate in the study, which was approved by the institutional ethics committee.

Procedures
Laboratory measurements
Prior to the field stairclimbing measurement, subjects underwent a maximal exercise test on a treadmill to determine their maximum heart rate (HRmax) and maximal oxygen uptake (VO2max) in the laboratory. The detailed protocol of this test is described elsewhere (Teh and Aziz, 2000; Teh and Aziz, 2002).

Field stairclimbing measurements
All ascending trials were conducted at a government-built flat that was randomly chosen at the beginning of the study. Although there is a slight variation throughout the country, most of these government-built flats are of a standard design. The subjects were required to climb 11 storeys (22 flights) from the first to the twelfth floor. The height of each step is 0.15 m, with a total of 180 steps. Therefore the total vertical distance covered during the ascent is (0.5 m × 180 steps) 270.0 m. Due to the design of the staircase, there is a horizontal level landing distance (~2.0 m square) between the flights of stairs.

Two ascending patterns consisting of the single- (SS) and double-step (DS) pattern were compared in this investigation. Based on our previous work (Teh and Aziz, 2000; Teh and Aziz, 2002), these two climbing patterns are commonly used by members of the public to ascend such public staircases. In the SS pattern, the subject climbed one step at a time, i.e., a vertical displacement of 0.15 m per step, while in the DS pattern the subject traversed two steps in a single stride, i.e., a vertical displacement of 0.30 m. It is noted that individuals will naturally climb at a much faster pace when they are required to set foot on every single step. Thus, to ensure that both stepping patterns attain a similar total vertical distance displacement within the same time duration, the stepping rate for the SS pattern was set at 100 steps · min−1 and the DS pattern was set at 50 steps · min−1. This then allows an unbiased comparison between a fast climbing pace with a relatively smaller vertical displacement (i.e., SS pattern, transverse 0.15 m each step at 100 steps · min−1) and another that is slower but with a greater vertical displacement (i.e., DS pattern, transverse 0.30 m each step at tempo of 50 steps · min−1). This also meant that the total work performed by the subjects during the SS and DS patterns were relatively equivalent.

It was expected that the climb time for both the SS and DS patterns would be identical, but in practice, the SS pattern had a consistently faster average climb time due to the presence of the 2-m landing area between each of the flights of steps. For both the SS and DS patterns, we instructed the subjects to travel over the landing distance in only four strides. We ensured that subjects followed this instruction closely by having all subjects rehearse the four-stride approach prior to the actual ascent. Thus during the actual ascending trial, the subject walked horizontally across the landing area in four strides following the beeping sounds (as dictated by either the SS or DS pattern) of the metronome with his/her normal gait. Given that there are altogether 11 landings during the entire ascent and the time taken to cover the four steps was slower in the DS pattern, it was estimated that the DS pattern took an average 2.4 s longer to transverse each of the landing areas than the SS pattern. Thus, it was expected that the SS pattern’s climb time would consistently be faster than the DS pattern by an average duration of 26.4 s (11 × 2.4 s).

The subjects were thoroughly briefed on the procedures prior to their ascent trials. Each subject was allowed three practice trials up to the 2nd floor for each ascending pattern to ensure consistency of climbs among subjects. They were instructed to step according to the pace of the metronome as closely as possible and adopt their usual or natural stepping stance (i.e., step-stride) throughout the climb. The subjects were also not allowed to stop at any point or use the side-railings for support during the climb. If they did, the trial was repeated later. For each subject, both the SS and DS pattern trials were performed in the same session, but the order of the climbing patterns was randomized among all the subjects tested during that session. A compulsory minimum rest of 15 min was instituted between the two climbing pattern trials for each subject. Subjects were made to sit quietly after their first climbing pattern trial and the next climbing pattern trial commenced only after their HR had returned to less than 90

<table>
<thead>
<tr>
<th>Table 1 Subjects’ characteristics</th>
<th>Men (N=10)</th>
<th>Women (N=20)</th>
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<tbody>
<tr>
<td>Age (yrs.)</td>
<td>39.5 ± 12.3</td>
<td>30.1 ± 9.7</td>
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<tr>
<td>Body mass (kg)</td>
<td>64.4 ± 9.9</td>
<td>55.4 ± 7.9</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.70 ± 0.04</td>
<td>1.59 ± 0.07</td>
</tr>
<tr>
<td>VO2max (L·min⁻¹)</td>
<td>3.14 ± 0.76</td>
<td>2.38 ± 0.46</td>
</tr>
<tr>
<td>VO2max (ml·kg⁻¹·min⁻¹)</td>
<td>49.2 ± 11.4</td>
<td>43.2 ± 6.9</td>
</tr>
<tr>
<td>HRmax (beats·min⁻¹)</td>
<td>188 ± 16</td>
<td>188 ± 10</td>
</tr>
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VO2max=maximal oxygen uptake; HRmax=maximal heart rate
beats · min$^{-1}$ for at least 2 min.

During all climbing trials, an investigator carrying a digital metronome (MX-338, Wave, Taiwan) that emitted loud audible “beeps” accompanied each subject, to ensure that the subject stepped according to the dictated pace. In all trials, the subject was equipped with a portable respiratory gas analyzer system (K4, Cosmed, Rome, Italy) to measure his or her physiological responses throughout the climb. The K4 system had previously been validated (Hausswirth et al., 1999) and comprises an analyzer unit, battery pack and face-mask together with a HR telemetry (Sports Tester, Polar Oy, Kempele, Finland). The complete system weighs $\sim$800 g and was strapped onto a harness that the subject wore over his or her attire. The gas analyzers were calibrated according to the manufacturer’s instructions prior to each trial. The equipment did not hinder or obstruct the movement or vision of the subject. Ventilation ($V_E$), oxygen uptake ($VO_2$), respiratory exchange ratio (RER) and heart rate (HR) data were recorded every 15 s throughout the climb, but only measurements taken during the last 30 s of the ascent were used in the statistical analysis. Previous studies on ascending a similar public staircase have shown that climbers’ physiological responses tend to level-off or achieve steady-state after $\sim$90 s (Boreham et al., 2000; Teh and Aziz, 2002). The relative humidity and ambient air temperature, which was determined every 30 min during the field measurements, ranged from 26–30°C and 66–85%, respectively, throughout the study.

### Statistical Analysis

The Statistical Package for Social Sciences (SPSS 10.0 for Windows) was used for all statistical analysis. A Student paired t-test was used to determine if there are any significant differences in the variables measured during ascending between the SS and DS patterns. The level of significance was set at $p<0.05$.

### Results

The mean duration of ascent for the SS and DS patterns was $135\pm8$ and $163\pm11$ s, respectively. These are actual climb times for both step patterns, taking into account the time taken to traverse all the eleven 2-m landing areas between the flights of stairs. Table 2 summarizes the physiological responses during the last 30 s of descending with either the SS or the DS pattern. There were significant differences in all the physiological variables measured between the SS and DS pattern, although these differences were clearly small in magnitude.

### Discussion

In this study, the SS pattern elicited mean HR and mean $VO_2$ responses of 82% and 75% of the subjects’ respective $HR_{max}$ and $VO_2_{max}$ values. The DS pattern attained slightly lower values of mean HR and mean $VO_2$ of 79% and 72% of the respective maximal values. These data indicate that both the SS and DS step patterns surpassed the minimum threshold of exercise intensity required for the positive promotion of cardiovascular benefits and aerobic fitness adaptations (American College of Sports Medicine Position Stand, 1998). These findings provided further support to our previous investigations that had established that stair-climbing was a useful activity for cardiovascular benefits (Teh and Aziz, 2002).

The primary purpose of the present investigation however was to assess if there were differences in the physiological responses and energy expended between the SS and DS patterns. These two ascending patterns were commonly adopted by the exercising public when using such a staircase (Teh and Aziz, 2000; Teh and Aziz, 2002). Table 2 shows that all the variables measured were significantly higher in the SS than in the DS pattern. It is noteworthy that 77% of the 30 subjects were found to have greater $V_E$, $VO_2$ and HR responses during the SS pattern as compared to the DS pattern. The data indicates that the SS pattern elicited higher physiological responses than the DS pattern. However the magnitude of the differences in these variables between the two step patterns were less than 10%, suggesting that these differences may be of minimal or no clinical significance, at least in the present study’s population.

The present study’s protocol was not designed to examine the underlying mechanism(s) for the higher responses observed in SS, but several plausible explanations can be put forth for the greater cardiorespiratory and metabolic effects observed in the SS compared to the DS pattern. It has been established that faster speed of muscular shortening increases the energy turnover during contractions (Kang et al., 2004). For example, the oxygen uptake and consequent energy turnover was greater during cycle ergometry exercise at higher compared to lower cycling rates (Ferguson et al., 2001; Gaesser and Brooks, 1975). This could have been the case in the present study where the subject would have taken 90 more steps with the SS pattern as compared to the DS pattern. Secondly, it may be argued that the “internal work” in the SS pattern was greater than during the DS pattern. In human movement analysis, “internal work” is defined as the work needed to overcome gravity and the inertia of the limbs (Cavagna and Kaneko, 1977; Wells et al., 1986) during

<table>
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<tr>
<th>Table 2</th>
<th>Physiological responses during the last 30 s of the single-step (SS) and double-step (DS) patterns. ($N=30$)</th>
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<tbody>
<tr>
<td></td>
<td>Single step (SS)</td>
</tr>
<tr>
<td>$V_E$ (L · min$^{-1}$)</td>
<td>46.4±7.2</td>
</tr>
<tr>
<td>$VO_2$ (L · min$^{-1}$)</td>
<td>2.08±0.42</td>
</tr>
<tr>
<td>RER</td>
<td>0.89±0.11</td>
</tr>
<tr>
<td>HR (beats · min$^{-1}$)</td>
<td>154±16</td>
</tr>
</tbody>
</table>

$V_E$=minute ventilation, $VO_2$=oxygen uptake, RER=respiratory exchange ratio, HR=heart rate
movements. Because of the greater number of steps made, the working muscles in the SS pattern have had to work relatively harder (i.e., with higher internal work) to overcome the inherent inertia of the subject’s body mass and lower limbs (Marsh et al., 2004) as well as the increase in intramuscular friction (Donovan and Brooks, 1977). This view is partly supported by a recent human movement analysis study demonstrating that the major determinant of the metabolic cost of walking was the mechanical work needed during the step-to-step transition between strides (Donelan et al., 2002). Further evidence of this can be obtained from other human locomotion analyses where it was noted that internal work during fast cycling was significantly greater than slow cycling, even when the power output during both cycling rates was similar (Ferguson et al., 2001; Widricks et al., 1992).

Stepping faster also means the individual had to step harder, possibly leading to a greater recruitment of the less economical fast-twitch muscle fibres (Hagan et al., 1992; Wendt and Gibbs, 1974), particularly during the push-off step phase. It has been demonstrated that a greater activation of the fast-twitch fibres caused a higher energy turnover and oxygen uptake during fast contractions (Gaesser and Brooks, 1975; Ivy et al., 1987); and since the metabolic cost during exercise is borne virtually entirely by the working skeletal muscles (Armstrong et al., 1987), it is foreseeable that this might be the case during the SS pattern in comparison to the DS pattern. This is further supported by a previous study that showed that a relatively faster step-rate led to a significantly greater vertical impact force, albeit during a bench-stepping exercise (Scharff-Olson et al., 1997). This latter hypothesis is an attractive option in explaining the greater oxygen uptake observed during the SS compared to the DS pattern because there is now accumulating evidence suggesting that the rate of the force exerted against the ground determines the metabolic cost during human locomotion (Roberts et al., 1998; Taylor, 1985; Weyand et al., 2000; Wright and Weyand, 2001).

The significantly higher HR and $V^\prime_{\text{E}}$ responses during the SS pattern as compared to the DS pattern could possibly be a consequence of the enhanced sympathetic nervous system activity as a result of the influence in the sensory feedback arising from the mechanoreceptors of the additionally recruited exercising muscles (Rowell and O’Leary, 1990). Although the subjects’ physiological responses in the SS were significantly higher, more importantly, the mean oxygen uptake during the SS pattern was only 0.1 L · min$^{-1}$ (or 1.6 ml · kg$^{-1}$ · min$^{-1}$) greater than in the DS pattern. The calculated energy expenditure (assuming 5 kcal per liter of oxygen consumed) difference between the SS and DS patterns was very small, amounting to only $\approx 0.5$ kcal · min$^{-1}$. It was estimated that the SS ascending pattern would consume an additional 5% caloric expenditure or $\approx 15$ kcal when extended to a typical 30 min exercise session, when compared to the DS pattern. Thus, in terms of overall energy expenditure, the additional calories expended when adopting the SS pattern seem to be of little practical significance.

This was a field-based investigation and therefore possessed several limitations. It may be argued that the landings could have caused the differences observed. However, we ensured that all subjects walked across the landing area using only four strides during both the SS and DS step patterns, with the difference being only the tempo of the strides. Also, walking horizontally causes minimal vertical elevation in the body’s center of mass and thus it is unlikely that there would be any substantial difference in the energy cost during these landings between either step patterns. Secondly, the present comparison between the SS and DS step patterns was based solely on the energy cost of the two activities. It would have been ideal if other measures such as electromyographic recording of the muscles’ level of activation and/or actual force plate measurement had been taken to directly assess the differences between the SS and DS step patterns. It is recommended that future studies adopt these measurement techniques to provide a better understanding of the muscular and physiological demands of each step pattern.

**Conclusion**

Ascending a public staircase with the SS (0.15 m per step) pattern at a rhythmic tempo of 100 steps · min$^{-1}$ led to marginally higher physiological responses and oxygen uptake than ascending with the DS (0.30 m per step) pattern at a pace of 50 steps · min$^{-1}$. Considering the small differences in caloric expenditure between the SS and DS patterns, individuals can choose either step pattern when ascending the stairs.

**Acknowledgements** The expert assistance of Ms Lee Hong Choo in the study’s data collection is greatly appreciated.

**References**


Received: July 26, 2004
Accepted: March 18, 2005
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