Metabolic cost of walking with and without a shoe-lift on the contralateral foot of an immobilised extended knee

Tommy Boone
The College of St Scholastica, Duluth, Minnesota USA

The purpose of the present study was to determine the metabolic cost of walking with and without a shoe-lift on the contralateral foot of an immobilised extended knee. Eight male subjects were randomly allocated and participated in both the treatment (walking with a 2.5cm shoe-lift) and control (walking without a shoe-lift) conditions. Cardiac output (Q) and related cardiovascular measurements were analysed to determine the effect of a shoe-lift on central (heart rate (HR); stroke volume (SV)) and peripheral (arteriovenous oxygen difference (a-vO₂ diff)) components of oxygen consumption (VO₂). A metabolic analyser was used to determine VO₂ (ml·kg⁻¹·min⁻¹), which was converted to oxygen cost (ml·kg⁻¹·m⁻¹). The shoe-lift had no significant (p > 0.05) effect on VO₂ or oxygen cost. There were no significant differences in Q, HR, SV, a-vO₂ diff, systemic vascular resistance, carbon dioxide production, respiratory exchange ratio, expired ventilation, tidal volume and respiratory rate between the two walking conditions with and without a shoe-lift. These findings demonstrate that a shoe-lift added to the contralateral foot of an immobilised extended knee does not produce clinically important effects on oxygen cost or efficiency during walking.


Key words: Cardiac Output; Metabolism; Oxygen Consumption; Ventilation

Introduction

The most common form of exercise is walking. It requires energy that can be determined by measuring either VO₂ (ml·kg⁻¹·min⁻¹) or oxygen cost (ml·kg⁻¹·m⁻¹). The latter energy unit is used to determine the energy expenditure of interruption of the normal gait cycle due to a gait disability (Waters 1992).

Investigators have reported 18-23% increases in oxygen cost when the knee is immobilised in full extension compared with normal walking (Abdulhadi et al 1996, Inman et al 1981, Mattsson and Brostrom 1990, Perry 1992). Since the increased oxygen cost of walking may limit ambulation, it is not uncommon for physiatrists to prescribe a shoe-lift for the contralateral extremity. However, this practice is not universally accepted (Abdulhadi et al 1996) and may not be supported by the scientific literature (Birnbaum and Hedlund 1998).

There are only two previous studies of the effect of a shoe-lift added to the contralateral foot of an immobilised extended knee (Abdulhadi et al 1996, Birnbaum and Hedlund 1998). In the Abdulhadi et al (1996) report, oxygen cost was lower when a shoe-lift was added to the contralateral foot. But the improvement appears to be in reference to normal walking only. Whether there was an improvement between walking with and without a shoe-lift added to the contralateral foot of the immobilised extended knee is unclear. In the Birnbaum and Hedlund (1998) report, the investigators concluded that a shoe-lift on the contralateral foot of an immobilised extended knee did not improve walking efficiency as measured by oxygen cost.

Since energy cost of walking can limit people with disabilities, further study is necessary to better understand the conflicting findings. The purpose of the present study is to determine the oxygen cost of walking with and without a shoe-lift on the contralateral foot of an immobilised extended knee. The findings should clarify whether there is a practical significance as well as a statistical significance when wearing a shoe-lift to improve walking efficiency. In addition, the present study is designed to determine the effect of a shoe-lift on central (HR; SV) and peripheral (a-vO₂ diff) components of VO₂.
Methods

Eight male undergraduate students volunteered to participate in this study. None of the subjects was on any medication or had any known gait or cardiovascular disorder. The study was approved by the Human Subjects Committee of the Department of Exercise Physiology at the College of St Scholastica, and informed consent was obtained from each subject. The average (SD) age of the subjects was 23 (4) years, the average height was 162 (8) centimetres, and the average weight was 84 (6) kilograms. This study consisted of two exercise conditions, the order of which was randomised for each subject. In one walking session, the subjects walked wearing an external knee immobiliser applied unilaterally to keep the right knee in full extension throughout the gait cycle. In another walking session, subjects wore a 2.5cm shoe-lift made of rubber that was strapped to the sole of the left shoe with athletic tape.

Subjects walked on a Biodex treadmill at 5.63 km·h⁻¹ at 0% grade for 10 minutes during both walking sessions. During each session, the subjects were connected to a Medical Graphics CPX/D metabolic analyser(a) to measure steady-state VO₂ and related respiratory measures from the fifth to the ninth minute. The heart rate of the subjects was monitored during the last 10 seconds of each minute of data collection, using the Physio-Control LifePak 9(b) with a 3-lead electrocardiographic configuration. The HR data were averaged across five minutes from the fifth to the ninth minute. The subjects were previously familiarised with the treadmill, and all agreed prior to data collection that 5.63 km·h⁻¹ was the most comfortable walking speed. The comfortable walking speed of 93.8 m·min⁻¹ was within the functional range of adult walking speeds (40 m·min⁻¹ to 100 m·min⁻¹; Waters et al 1988).

To calculate steady-state oxygen cost in ml·kg⁻¹·min⁻¹ during walking, VO₂ expressed in ml·min⁻¹ was normalised by the subject’s body weight to ml·kg⁻¹·min⁻¹ then divided by the distance travelled (m·min⁻¹) (Perry 1992). The same steps were used to calculate steady-state VCO₂. Respiratory exchange ratio was determined by dividing VCO₂ by VO₂. Expired ventilation, TV and respiratory rate (RR) were also recorded by the metabolic analyser from the fifth to the ninth minute.

<table>
<thead>
<tr>
<th>Variable</th>
<th>With shoe-lift</th>
<th>Without shoe-lift</th>
<th>Mean difference</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO₂</td>
<td>1.24 (0.12)</td>
<td>1.19 (0.17)</td>
<td>0.06</td>
<td>-0.04 - 0.15</td>
</tr>
<tr>
<td>VO₂</td>
<td>14.5 (1.2)</td>
<td>14.2 (2.1)</td>
<td>0.3</td>
<td>0.96 - 1.60</td>
</tr>
<tr>
<td>VO₂</td>
<td>0.159 (0.017)</td>
<td>0.151 (0.012)</td>
<td>0.008</td>
<td>-0.003 - 0.019</td>
</tr>
<tr>
<td>VO₂</td>
<td>1.13 (0.09)</td>
<td>1.01 (0.16)</td>
<td>0.016</td>
<td>-0.089 - 0.057</td>
</tr>
<tr>
<td>VO₂</td>
<td>13.4 (1.1)</td>
<td>13.6 (1.9)</td>
<td>-0.2</td>
<td>-1.1 - 0.7</td>
</tr>
<tr>
<td>RER</td>
<td>0.90 (0.06)</td>
<td>0.96 (0.04)</td>
<td>0.05</td>
<td>-0.11 - 0.01</td>
</tr>
<tr>
<td>VE</td>
<td>30 (3)</td>
<td>31 (5)</td>
<td>-1</td>
<td>-4 - 2</td>
</tr>
<tr>
<td>TV</td>
<td>1171 (207)</td>
<td>1133 (214)</td>
<td>39</td>
<td>-41 - 118</td>
</tr>
<tr>
<td>RR</td>
<td>28 (5)</td>
<td>30 (7)</td>
<td>-2</td>
<td>-4 - 1</td>
</tr>
</tbody>
</table>
Cardiac output was determined during minute 10 of both walking sessions using the indirect CO₂ rebreathing technique (Heigenhauser and Jones 1989). Arterial CO₂ (PₐCO₂) was derived from the end-tidal pulmonary CO₂ (PₑCO₂). Mixed venous pulmonary CO₂ (PᵥCO₂) was derived from the CO₂ rebreathing (bag) procedure. Arterial CO₂ and mixed venous contents were calculated from arterial CO₂ tension and PᵥCO₂, respectively, using a standard oxygenated CO₂ dissociation curve (Collier 1956, Jones and Rebuck 1973). The metabolic analyser displayed the CO₂ signal graphically to ensure the PᵥCO₂ equilibrium.

Following the rebreathing procedure, systolic and diastolic blood pressures were measured by auscultation of the left brachial artery using a standard mercury sphygmomanometer. Systolic blood pressure (SBP) was determined as the point of appearance of Korotkoff sounds, while the point of disappearance of these sounds was considered to be the diastolic blood pressure (DBP). Mean arterial pressure (MAP) was calculated by adding one-third of the pulse pressure (the difference between SBP and DBP) to the diastolic pressure. Systemic vascular resistance (SVR) was estimated by dividing MAP by Q. Stroke volume (SV) was calculated by dividing Q by HR. Arteriovenous oxygen difference was calculated by dividing VO₂ by Q (Robergs and Roberts 1997).

To compare the two walking sessions with and without a shoe-lift, a paired samples t-test was performed at a level of significance of α = 0.05. A 95% confidence interval estimate of the each mean was also computer-generated. Results are given as mean ± SD (Tables 1 and 2).

Results

Cardiorespiratory responses while walking with and without a 2.5cm shoe-lift to the contralateral foot of the immobilised extended knee are presented in Tables 1 and 2. The shoe-lift had no significant (p > 0.05) effect on VO₂ (l·min⁻¹ or ml·kg⁻¹·min⁻¹) or oxygen cost (ml·kg⁻¹·m⁻¹). There were no significant differences in VCO₂, respiratory exchange ratio (RER), expired ventilation (V̇ₑ), TV, and RR (Table 1). Similarly, there were no significant differences in HR, SV, Q, a-vO₂ diff, and SVR (Table 2). In addition, since the 95% confidence intervals for the mean differences for each dependent variable were quite narrow, it is possible to rule out even quite small effects of the shoe-lift.

Discussion

The results of this experiment indicate that a shoe-lift added to the contralateral foot of an immobilised extended knee had no effect on oxygen cost during walking. Walking efficiency was not improved. This finding appears to disagree with the report by Abdulhadi et al (1996). However, it is unclear whether they addressed the oxygen cost difference between the walking sessions with and without a shoe-lift added to the contralateral foot of an immobilised extended knee. Instead, they discussed...
the benefits of a lower oxygen cost when walking with a 1.27cm and a 2.5cm shoe-lift to the contralateral foot of the immobilised extended knee to normal walking. As an example, Abdulhadi et al. (1996) reported that when the subjects’ knees were immobilised unilaterally in full extension, oxygen cost for walking was significantly less (12% versus 20% above that of normal walking) with the 2.5cm shoe-lift added to the contralateral foot of the immobilised extended knee.

For people with disabilities, the research question is not whether a shoe-lift results in a lower oxygen cost compared with normal walking. Rather, does a shoe-lift added to the contralateral foot of an immobilised extended knee improve walking efficiency versus when not wearing a shoe-lift? This is the question addressed in the present study, and by Birnbaum and Hedlund (1998).

Walking with and without the shoe-lift on the contralateral foot of the immobilised knee resulted in an extremely small difference in oxygen cost (0.159 ml·kg⁻¹·m⁻¹ versus 0.151 ml·kg⁻¹·m⁻¹), respectively. By comparing the oxygen cost values with the mean for normal walking (0.151 ml·kg⁻¹·m⁻¹; Waters and Yakura 1990), the physiologic efficiency of gait can be determined. Gait efficiency for walking with the shoe-lift averaged 95%. The physiologic efficiency for the subjects’ gait pattern without the shoe-lift averaged 97%. The fact that gait efficiency is only slightly different is consistent with the non-significant finding that the shoe-lift did not result in major changes in the subjects’ gait pattern.

The shoe-lift had no effect on $V_E$, which corresponds to the non-significant change in the rate of $O_2$ consumed or carbon dioxide production ($CO_2$). Neither rate nor tidal volume (TV) of breathing was changed. Likewise, the non-significant change in $VO_2$ [where $VO_2$ is the product of $O_2$ transport ($Q = HR \times SV$) and $O_2$ utilisation (a-$O_2$ diff)] was a function of the non-significant changes in the subjects’ central and peripheral adjustments. The Q response was due to the non-significant differences in HR and SV. These findings are in agreement with Birnbaum and Hedlund (1998).

While the present study and the report by Birnbaum and Hedlund (1998) are in agreement that a shoe-lift does not decrease oxygen cost, there are several interesting points that should be mentioned. First, the present study evaluated eight male subjects for 10 minutes on a treadmill while Birnbaum and Hedlund (1998) reported on six females and one male who walked for 20 minutes on a treadmill. Both studies walked the subjects at 5.63 km·h⁻¹ mph at 0% grade. Hence, the physiologic findings indicate that both male and female subjects respond similarly to the shoe-lift. Second, while $VO_2$ for the female subjects at the fixed walking pace is similar to the values in the present study, oxygen cost is higher in the female subjects. This finding is consistent with the higher HR responses with the female subjects. Third, the female subjects relied more on HR and less on SV (which was reversed in the male subjects) to produce the Q response. The additional 10 minutes of walking may also have been a factor in the physiologic response of the female subjects and, thus their apparent central adjustment to $VO_2$.

Statistical power The small number of subjects used in this study should be considered when concluding clinical significance (or lack thereof) of the effect of a shoe-lift on metabolic cost of walking (Dawson-Saunders and Trapp 1994). The question is: is the present study capable of detecting a given difference of a given size if the difference really exists? One answer is found in the 95% confidence intervals, which do not include clinically important effects. Hence, the reader can be 95% confident that walking with a shoe-lift added to the contralateral foot of an immobilised extended knee does not produce clinically important reductions in metabolic cost compared with walking without a shoe-lift. It should also be pointed out that the number of subjects in the present study ($n = 8$) approximates the number of subjects ($n = 7$) reported in Birnbaum and Hedlund (1998) and the number of subjects ($n = 10$) reported in Abdulhadi et al (1996). The investigators from the two studies did not report having determined the power of their study.

Conclusions

The data from this study provide contradictory evidence to the report by Abdulhadi et al. (1996). The present data show that adding a 2.5cm shoe-lift to the contralateral foot of an immobilised extended knee does not lower oxygen cost of walking and therefore does not improve walking efficiency. Further study is warranted before concluding that patients with knee fusion and knee immobilisation, either temporary or permanent, will benefit from a contralateral shoe-lift.
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Footnotes
(a) Medical Graphics Corporation, 350 Oak Grove Parkway, St. Paul, MN 55127-8599, USA
(b) Physio-Control LifePak 9, 11811 Willows Road Northeast, Box 97006, Redmond, WA 98073-9706, USA.

Author
Tommy Boone, Professor and Chair, Department of Exercise Physiology, Director, Exercise Physiology Laboratories, The College of St. Scholastica, 1200 Kenwood Avenue, Duluth, MN 55811, USA. E-mail: tboone2@css.edu (for correspondence).

References


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