Cardiorespiratory Responses to Scootering in Comparison with Walking, Running and Cycling

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Abstract: Physiological responses to riding a scooter (scootering) are compared with walking, running and cycling at three different treadmill speeds (80, 110 and 140 m min⁻¹) and slopes (0 %, 4 % and 8 %). Five healthy male college students performed all exercises at different intensities in four trials a day, one or two days a week. Each experiment comprised of a 5–20 minute resting period, followed by 3 minutes of exercise and 10–50 minute recovery time. Apart from stationary cycling to measure maximal oxygen uptake, all exercises were performed on a treadmill. Heart rate (HR), oxygen uptake (VO₂), carbon dioxide production (VCO₂), pulmonary ventilation (VE), respiration rate (RR) and respiratory exchange ratio (RER) were measured every 15 seconds, and averaged using a computerized breath-by-breath expired gas monitor. From these measurements, the ventilation equivalent for CO₂ (VE/VCO₂) was calculated. No significant differences in the HR-VO₂ relation with exercise intensity were observed among the different types of exercise. The slopes of the regression lines for VE-VO₂ and RER-VO₂ in scootering were steeper than those in other exercises (p<0.05). A significant correlation was noted between stroke frequency and RR in scootering (R=0.727, p<0.001). Measurement of the changes in VE/VCO₂ during scootering at 73, 80 and 90% VO₂max revealed a notably (p<0.05) larger ‘short period of depression’ (undershooting) with a peak around 30 seconds after exercise, which was rarely observed with the other exercises examined. These results suggest that the cardiorespiratory responses to scootering differ from those to walking, running and cycling, due to the unique locomotion pattern of this vehicle.

Key words: scootering, stroke frequency, walking, running, cycling, ventilatory equivalent for carbon dioxide

Introduction

A scooter is a small vehicle comprising a narrow board, two wheels and a steering apparatus. This form of transport has become increasingly popular with the younger generation since the new chrome version appeared in the market three years ago. The

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scooter is not only used as recreational or exercise equipment, but also as a transportation vehicle. Although the popularity of the scooter is on the increase, little is known about the physiological aspects of riding this vehicle (scootering) to date.

One of the peculiar aspects of scootering is its non-symmetrical movement, such that the rider continues to kick the ground with one foot while keeping the other foot on the board, although in some cases, the rider may alternate the foot that kicks the ground. This style of locomotion is different from walking, running and cycling, which mainly involve symmetrical movements. Therefore, it is reasonable to assume that scootering induces unique cardiorespiratory responses due to its non-symmetrical pattern of locomotion.

Since walking, running and cycling are often replaced by scootering, it is important to understand the differences between the physiological impacts of scooter riding and these other forms of locomotion. Although numerous studies in the literature have examined the differences between walking and running\(^1-^6\), running and cycling\(^7-^9\), running and in-line skating\(^10,^11\), running and roller skiing\(^12\), in-line skating and roller skiing\(^13,^14\), this report is the first investigation on scootering.

The study was conducted to compare cardiorespiratory parameters during and after scootering, walking, running and cycling.

Methods

Subjects
Five healthy male college students participated in this study. Subjects were informed of all the test procedures and written consent was obtained. This study was approved by the Departmental Ethics Committee of Kanto Gakuin University. The mean (SD) age, height and body weight was 21.0 (1.2) years, 166.6 (7.0) cm, and 61.1 (13.3) kg, respectively. All subjects were physically active, but their experience in scootering varied between two and six months. Subjects were familiarized with the experimental procedures in the laboratory.

Experimental procedures
All exercises were performed on a motor-driven treadmill (Tread-mill\(^\text{\textsuperscript{R}}\), Nishikawa Iron Works, Tokyo, Japan) for determining maximal oxygen uptake (\(\dot{V}O_2\)), except the bicycle test. The treadmill speed and angle were calibrated either before or immediately after each test.

Cardiorespiratory responses to scootering were compared to walking, running and cycling. In our experiments, a scooter (Micro\(^\text{\textsuperscript{R}}\), Micro Mobility Systems, Kusnacht, Switzerland) comprising two wheels of 100 mm in diameter with a narrow board of 100 mm width and 565 mm length between the wheel centers and a 850 mm high steering apparatus (total weight of 2.8 kg) was used. For cycling, a bicycle (Bridgestone\(^\text{\textsuperscript{R}}\), Tokyo, Japan) with two wheels of 660 mm diameter (weight: 19.0 kg) was employed. Scootering and walking/running were compared at three different treadmill speeds (80, 110 and 140 m min\(^{-1}\)) and slope angles (0 %, 4 % and 8 %). Physiological responses to scootering and cycling were compared at a fixed speed of 140 m min\(^{-1}\). Subjects performed all the trials listed in Table 1. The order of the trials was set randomly. Each student performed four trials per day, and measurements were taken one or two days per week. The temperature and relative humidity in the laboratory was maintained at a constant 20.0°C (SD, 0.1), and 62.0% (SD,
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Table 1. Each mode of exercise was performed at three different speeds and grades on a treadmill. Maximal bicycle ergometer test was performed in a different week.

<table>
<thead>
<tr>
<th>Speed</th>
<th>Grade</th>
<th>0 %</th>
<th>4 %</th>
<th>8 %</th>
</tr>
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<tbody>
<tr>
<td>80m per min</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>W</td>
<td></td>
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<tr>
<td>110m per min</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>140m per min</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td></td>
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<tr>
<td></td>
<td>R</td>
<td>R</td>
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<td>C</td>
<td>C</td>
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</table>

Maximal bicycle ergometer test

A computer-controlled cycle ergometer (Combi 232-C®, Combi, Tokyo, Japan) was used for the maximal bicycle test to determine $\dot{V}O_2_{max}$. The load was increased to 20 watts per minute, and subjects were required to continuously pedal at 50 rpm until volitional exhaustion. This procedure was similar to methods described by Caiozzo et al15) and Yen et al16).

Measurements

Oxygen uptake ($\dot{V}O_2$), minute ventilation ($\dot{V}E$), carbon dioxide production ($\dot{V}CO_2$), respiratory exchange ratio (RER) and respiration rate (RR) were measured using a gas monitor system (model AE 280®, Minato Medical Science, Osaka, Japan) for all trials, as shown in Table 1. The respiratory equivalents for $O_2$ ($\dot{V}E/\dot{V}O_2$) and $CO_2$ ($\dot{V}E/\dot{V}CO_2$) were calculated from these data. The system consisted of a microcomputer, a hot-wire flowmeter, and $O_2$ and $CO_2$ analyzers (Zr element-based $O_2$ analyzer and infrared $CO_2$ analyzer) with a pump that propelled gas to the analyzer at a rate of 220 ml min$^{-1}$. Data were obtained by a computerized breath-by-breath method, and averaged every 15 seconds. The system was calibrated before and after each trial using standard gas, according to manufacturer’s instructions.

Ventilation threshold (VT) during the maximal bicycle ergometer test was determined by the $\dot{V}O_2$ at which minimum $\dot{V}E/\dot{V}O_2$ values of the fifth-order polynomial for the relationship between $\dot{V}E/\dot{V}O_2$ and $\dot{V}O_2$ data were obtained17).

Heart rate (HR) was additionally monitored with a heart rate telemeter (Cardio Super model 2E32AR, San-ei, Tokyo, Japan) in all trials. Stroke frequency (scootering), pedal frequency (cycling) and step frequency (walking and running) were evaluated with a pushing counter, when constant movement was achieved during exercise.
Statistical analyses

Two-way ANOVA and student's t-test were used to compare stroke frequency in scootering at different speeds and grades. The relationships between \( \dot{V}O_2 \), HR, \( \dot{V}E \) and RER were determined with linear regression analysis. Slopes and y-intercepts were compared between exercises by regression coefficient calculation. RR and stroke frequency in scootering, and RR and \( \dot{V}O_2 \) relationships in each exercise mode were calculated by a second or fourth-order polynomial regression equation. Statistical significance was set at \( p<0.05 \).

Results

Maximal tests

The mean (SD) HRmax, \( \dot{V}E \)max, absolute \( \dot{V}O_2 \)max, relative \( \dot{V}O_2 \) max, \( \dot{V}CO_2 \)max and peak RER values during the incremental maximal bicycle ergometer test were 196.2 (6.2) beats min\(^{-1}\), 100 (16.3) 1 min\(^{-1}\), 2.70 (0.43) ml min\(^{-1}\), 44.75 (2.55) ml kg\(^{-1}\) min\(^{-1}\), 2.98 (0.46) l min\(^{-1}\) and 1.11 (0.03), respectively. The VT value in the cycling test was 42.0 ± 9.7% \( \dot{V}O_2 \)max.

Comparison between scootering and walking, running or bicycling

The relationships between \( \dot{V}O_2 \) and HR during exercise are indicated by regression lines (Fig. 1). No significant differences were observed in the regression coefficient of the slope

![Graph showing the relationship between heart rate (HR) and oxygen uptake (\( \dot{V}O_2 \)). Solid line: scootering, Shaded line: cycling, Dotted line: running, Small dotted line: walking.](

Fig. 1. The relationship between heart rate (HR) and oxygen uptake (\( \dot{V}O_2 \)). Solid line: scootering, Shaded line: cycling, Dotted line: running, Small dotted line: walking.
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Fig. 2. The relationship between ventilation (\(\dot{V}E\)) and oxygen uptake (\(\dot{V}O_2\)). Solid line: scootering, Shaded line: cycling, Dotted line: running, Small dotted line: walking. The slope of scootering was significantly steeper than that of cycling and running (\(p<0.05\)).

Fig. 3. The relationship between respiration rate and stroke frequency during scootering. A significant correlation was observed between these two parameters in scootering (\(p<0.001\)).

among the exercises examined. As shown in Fig. 2 and 5, the slopes of the \(\dot{V}O_2\)-\(\dot{V}E\) and the \(\dot{V}O_2\)-RER regression lines of scootering were significantly steeper (\(p<0.05\)) than those of running and cycling. Due to large differences in the range of treadmill speeds used for walking and scootering, comparisons between these two exercises were not possible. They intercept of the \(\dot{V}O_2\)-RER regression line varied between cycling and running, although
Fig. 4. The relationship between respiration rate (RR) and oxygen uptake (\(\dot{V}O_2\)) during scootering (a), cycling (b), and walking and running (c). Considerable correlation was noted between RR and \(\dot{V}O_2\) in scootering (\(p<0.001\)) and in cycling (\(p<0.05\)). However, no significant (NS) correlation was evident in scootering and in walking or running.

The slope angle was identical (Fig. 5). At any level of \(\dot{V}O_2\), the RER in cycling was 0.068 ±0.052 higher than that in running.

Table 2 displays mean (SD) stroke frequency in scootering at different speeds and slope angles. A significant \((p<0.05)\) difference in stroke frequency was observed between the slope angles for all speeds and between speeds at a stroke angle of 8%. The stroke frequencies of subject YH exhibiting a typical pattern in walking and running are compared in Table 3. Compared to walking and running at the same speed and slope angle, stroke frequency during scootering was higher. The relationship between RR and stroke frequency during scootering is shown in Fig. 3. A significant \((p<0.001)\) correlation was evident.
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Fig. 5. The relationship between respiratory exchange ratio (RER) and oxygen uptake (\(\dot{V}O_2\)). Solid line: scootering, Shaded line: cycling, Dotted line: running, Small dotted line: walking. The slope of scootering was significantly steeper than that of cycling and running (\(p<0.05\)).

Table 2. Mean (SD) stroke frequency in five subjects during scootering (times per min).

<table>
<thead>
<tr>
<th>Speed</th>
<th>Grade</th>
<th>0 %</th>
<th>4 %</th>
<th>8 %</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>80m per min</td>
<td>0 %</td>
<td>24.4 (8.0)</td>
<td>39.8 (12.0)</td>
<td>41.8 (6.9)</td>
<td>*</td>
</tr>
<tr>
<td>110m per min</td>
<td>0 %</td>
<td>31.2 (8.8)</td>
<td>41.2 (6.5)</td>
<td>57.6 (5.0)</td>
<td>***</td>
</tr>
<tr>
<td>140m per min</td>
<td>0 %</td>
<td>30.2 (13.3)</td>
<td>49.4 (6.2)</td>
<td>67.0 (8.1)</td>
<td>***</td>
</tr>
<tr>
<td>ANOVA</td>
<td>NS</td>
<td>NS</td>
<td>***</td>
<td></td>
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</tr>
</tbody>
</table>

* ; p<0.05, *** ; p<0.001, NS ; non significant.

Table 3. Stroke frequency of a subject (YH) during walking, running (normal numerals) and scootering (gothic numerals) in times per min.

<table>
<thead>
<tr>
<th>Speed</th>
<th>Grade</th>
<th>0 %</th>
<th>4 %</th>
<th>8 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>80m/min(Walk) (Scooter)</td>
<td>0 %</td>
<td>36</td>
<td>20</td>
<td>37</td>
</tr>
<tr>
<td>110m/min(Run) (Scooter)</td>
<td>0 %</td>
<td>51</td>
<td>27</td>
<td>52</td>
</tr>
<tr>
<td>140m/min(Run) (Scooter)</td>
<td>0 %</td>
<td>53</td>
<td>21</td>
<td>54</td>
</tr>
</tbody>
</table>

between the two values, as calculated from the following equation of the second degree:

\[ y = 30.459 - 0.249x + 0.007x^2 \] (\(R=0.727\)).

Fig. 4 shows the relationship between RR and \(\dot{V}O_2\) during scootering, cycling, walking and running. Significant correlation was noted between scootering (\(R=0.918\), \(p<0.001\)) and cycling (\(R=0.780\), \(p<0.05\)), but not with walking or running. \(\dot{V}E/\dot{V}CO_2\) values were calculated every 15 seconds from the commencement of exercise to recovery (Fig. 6). Comparisons between scootering and other exercises were made at similar levels of \(\dot{V}O_2\) (40-
Fig. 6. Changes in the ventilatory equivalent for carbon dioxide ($\dot{V}E \, \dot{V}CO_2^{-1}$) every 15 seconds from the commencement of exercise to recovery. Scootering (lower panels) was compared with other forms of locomotion (upper panels) at four different intensities of exercise (40%, 70%, 80% and 90% $\dot{V}O_2$).

At levels under the ventilatory threshold (42% $\dot{V}O_2$max), no undershooting (i.e. a state where the minimum value during recovery phase is lower than that during exercise) was observed for either walking or scootering. However, at levels higher than the ventilatory threshold (73%, 80% and 89% $\dot{V}O_2$max), undershooting was clearly noted in scootering, but not cycling or running. At the highest intensity of scootering (140 m min$^{-1}$, 8 %, $\dot{V}E/\dot{V}CO_2$ during the latter half of exercise was greatly elevated and immediately following exercise, undershooting was observed for 30 seconds.

**Discussion**

$\dot{V}O_2$max of the five subjects determined by the maximal bicycle test in this study were not statistically different from the mean value in Japanese male adults (18-31 years, n=33) reported by Yamaji$^{18}$. Therefore, the data in the present study represent the aerobic capacity of young adults in general.

**The relationship between HR and %$\dot{V}O_2$max**

Many researchers have investigated the relationship between HR and %$\dot{V}O_2$max (HR-$\dot{V}O_2$ relationship) for different exercise modes. No significant differences in the HR-$\dot{V}O_2$ relationship among various modes of exercise were revealed$^{8, 11-14, 19-21}$, although some analyses$^{19, 22, 23}$ reported differences dependent on gender. Cardiorespiratory responses during in-line ska-
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ting\textsuperscript{10,11}, roller skiing\textsuperscript{12} and Nordic skiing\textsuperscript{24} have been compared with those in running and/or cycling. Synder et al.\textsuperscript{10} reported a variation in the slope of the regression line between in-line skating and running or cycling. However, most other studies\textsuperscript{8,11-14,19-21} show that the HR-\ Voy relationship is not affected by the type of exercise in terms of regression line and slope. We observed no significant differences in the HR-\ Voy relationship between scootering and running or cycling (Fig. 1). This suggests that \ Voy during scootering can be estimated by HR, similar to other exercises.

The relationship between \( \dot{VE} \) and \( \dot{VO}_2 \)

Previous studies\textsuperscript{10} showed no significant differences between the slope of the \( \dot{VE}-\dot{VO}_2 \) regression line in running and cycling. However, the slope of the \( \dot{VE}-\dot{VO}_2 \) regression line for scootering was significantly steeper than that of other exercises (Fig. 2). The steeper slope may be due to the non-symmetric movement patterns in scootering. We noted that in scooter riding, the higher the intensity, the higher the stroke frequency and RR (Fig. 3). High-intensity scootering with higher stroke frequency increased RR and caused hyperventilation. Previous studies\textsuperscript{3,4,7,25} demonstrated that increase in \( \dot{VCO}_2 \) in high intensity exercises and elevated RR during fast repeated movements increases \( \dot{VE} \). For instance, in a graded cycling experiment, Takano\textsuperscript{26} observed that a higher frequency of pedaling rate resulted in higher RR and larger \( \dot{VE} \) at the same \( \dot{VCO}_2 \) level. In the present study, the pedaling rate was consistently 32 rpm at different slope angles when cycling was performed at a specific speed with a fixed gear of the bicycle. In contrast, the number of steps per minute in running were higher than those in walking (Table 3). However, this was not the case for scootering (Table 3).

The relationship between respiration rate and \( \dot{VO}_2 \)

In scootering, the higher the intensity of exercise, the higher the RR (Fig. 4a). In contrast, no correlation between \( \dot{VO}_2 \) and RR was detected for either walking or running. In cycling, RR was not increased upon high exercise intensity at 78% \( \dot{VO}_2 \) max. The difference between scootering and other exercises was probably due to the variations in exercise modality.

Relationship between RER and \( \dot{VO}_2 \)

As shown previously, the regression lines of RER-\( \dot{VO}_2 \) were parallel for cycling and running, with cycling being higher than that of walking (Fig. 5).\textsuperscript{10} The RER-\( \dot{VO}_2 \) regression line for scootering was steeper than that for running or cycling (Fig. 5). This suggests that \( CO_2 \) produced during scootering is greater than that produced during cycling or running at the same \( \dot{VO}_2 \) levels. The smaller number of muscles involved in scootering compared to other exercises may explain this observation.

The oxygen requirement for pedaling is greater when using one leg compared to two legs, and \( \dot{VE} \) is higher for one-leg exercise\textsuperscript{27,28}. In scootering, one leg kicking the ground is mainly used for propelling the vehicle, while the other leg plays a role in supporting the rider's weight and balance. Therefore, it is likely that the kicking leg requires a significantly greater amount of oxygen than the other. If this is the case, the differences in the physiological aspects of scootering and running would be explained by the distinct requirements of one versus two-leg exercise, as shown by Bassey and Goldsmith.\textsuperscript{28}.
may also explain why the RER-\(\dot{V}O_2\) regression line of scootering is steeper than that in other exercises.

\(\dot{V}E/\dot{V}CO_2\) during and after exercise

As shown in Figure 6, when exercise intensity was less than VT level (around 42\% \(\dot{V}O_2\max\)), \(\dot{V}E/\dot{V}CO_2\) did not decrease after the cessation of exercise. However, after scootering at a higher intensity than VT, a rapid but significant decrease in \(\dot{V}E/\dot{V}CO_2\) [so-called undershooting\(^{29}\)] was noted immediately after scootering, with the largest decrease at around 30 seconds following exercise (Fig. 6). We observed that the higher the intensity of scootering, the larger the undershooting (Fig. 6). In fact, during scootering at 90\% \(\dot{V}O_2\max\), considerable hyperventilation (104.3 ± 2.8 L min\(^{-1}\)) occurred as soon as exercise commenced. \(\dot{V}E/\dot{V}CO_2\) began to decrease as soon as exercise was stopped, reached minimal levels 30 seconds later and gradually recovered back to resting levels (Fig. 6).

On the other hand, undershooting was observed only slightly at 80\% \(\dot{V}O_2\max\) of running, and more significantly at 90\% \(\dot{V}O_2\max\). Undershooting was not evident at all under the 70\% \(\dot{V}O_2\max\) level and at 80\% \(\dot{V}O_2\max\) in cycling. This reflects the difference in time constant in \(\dot{V}E\) and \(\dot{V}CO_2\), especially a rapid decrease in \(\dot{V}E\) or slow recovery of \(\dot{V}CO_2\). It appears that high-intensity exercise results in undershooting of \(\dot{V}E/\dot{V}CO_2\). However, scootering causes undershooting after exercise even at low intensity. \(\dot{V}E/\dot{V}CO_2\) during scootering at increased VT levels was higher than that of cycling. This indicates that \(\dot{V}E\) during scootering is relatively high compared to \(\dot{V}CO_2\), and that the relative metabolic rate may not be a factor in determining gas exchange kinetics. The higher \(\dot{V}E/\dot{V}CO_2\) value during scootering is one of the factors causing undershooting following exercise.

The atypical aspects of the gas exchange kinetics in scootering may be associated with non-symmetrical movements in this form of locomotion.

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