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Oxygen uptake and heart rate kinetics of body mass-based squat exercise in children and adults

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Abstract

This study aims to clarify oxygen uptake ($V\text{O}_2$) and heart rate (HR) kinetics of body mass-based squat exercise (SQBM) with relation to age. Fourteen healthy adults and 19 healthy children performed SQBM 200 times as well as an incremental loaded bicycle test to determine maximal $V\text{O}_2$ and HR. The $V\text{O}_2$ and HR during SQBM were normalized to maximal $V\text{O}_2$ (%$V\text{O}_2$peak) and HR (%HRmax), respectively. Electromyograms (EMGs) were recorded from the vastus lateralis, rectus femoris, vastus medialis, and biceps femoris muscles from the right leg. In the $V\text{O}_2$ and HR during SQBM, the time constant in children was faster than adults, whereas the physiological load (%$V\text{O}_2$peak and %HRmax) was almost the same between children and adults. In both groups, %$V\text{O}_2$peak was significantly related to %HRmax during SQBM. The slope of the %$V\text{O}_2$peak-%HRmax relationship was 0.92 for children, and 0.73 for adults.

The current results demonstrate that, compared to adults, the rise in $V\text{O}_2$ and HR after initiation of SQBM is faster in children, and the physiological load during SQBM partially depends on individual maximal aerobic capacity.

Keywords: cardiorespiratory response to exercise, time constant, electromyogram, aerobic metabolism

Introduction

For children, some earlier studies have demonstrated that training modality with body mass-based exercise can be effective for improving force capability and physical fitness in a school day with no temporal and spatial restrictions¹-⁵. Mackay and colleagues revealed that 10- to 12-minute body mass-based jump training improved body composition and jump performance¹-⁵. Body mass-based squat exercise training is also feasible and effective for increasing muscle size, increasing the muscular strength of force-generating capacity in the lower extremities, and as physical fitness for children⁴,⁵. Concerning these findings, body mass-based exercise training can be considered feasible for strengthening anaerobic capacity in children.

From the viewpoint of aerobic metabolism in resistance exercise, cardiorespiratory response to resistance exercise at anaerobic threshold intensity, corresponding to approximately 25% of one repetition maximum, has been shown to be stable after 3 to 6 min from task onset for adults⁶. Furthermore, oxygen uptake ($V\text{O}_2$) and heart rate (HR) during body mass-based squat exercise (SQBM) is equivalent to that at the anaerobic threshold during an incremental load bicycle test. This finding implies that squat exercise at anaerobic threshold intensity is predominantly aerobic in nature. During SQBM, the percentage of $V\text{O}_2$ relative to maximal $V\text{O}_2$ depends on maximal $V\text{O}_2$ in young healthy men⁷.

The kinetics of cardiorespiratory parameters in moderate-intensity exercise have been characterized by three phases⁸-¹¹. Cardiodynamic phase (phase I) is the rapid increase in $V\text{O}_2$ within 15-20 s of exercise onset because of the increase in pulmonary blood flow due to the sudden increase in venous return from contracting muscle. Primary component phase (phase II) is the exponential rise in $V\text{O}_2$ culminating in the steady-state $V\text{O}_2$ (phase III). The rise in $V\text{O}_2$ during phase II has been shown to correlate with the exponential rise in $V\text{O}_2$ at contracting muscle¹²,¹³. Faster $V\text{O}_2$ kinetics in bicycle exercise depends on the percentage of type I fibers in agonist muscles¹⁴. Children have a greater percentage of slow twitch fibers in muscle compared to adults¹⁵,¹⁶. Low- or moderate-intensity exercise in children may predominantly rely on aerobic energy supply due to the muscle enzyme of aerobic metabolism (e.g. carnitine palmitoyltransferase and 2-oxoglutarate dehydrogenase)¹⁷ and fiber type profiles¹⁸,¹⁹. Taken together, it is reasonable to assume that, compared to adults, children would have faster kinetics of $V\text{O}_2$ during SQBM, regardless of the same relative exercise intensity. However, the earlier findings concerning the age-related differences in the dynamic kinetics of low- and moderate-intensity exercises in phase II are contradictory⁸-¹¹.

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For adults, the muscular activity level of the quadriceps femoris muscles during SQBM is negatively related to maximal voluntary knee extension torque relative to body mass. Furthermore, an increase in relative load during the incremental loaded bicycle test linearly elevates oxygen uptake and muscular activity. Considering the earlier finding that maximal voluntary torque (MVC) relative to body mass is lower in children than in adults, we expected that an age-related difference in relative physiological load during SQBM would be due to MVC relative to body mass in children and adults.

To the best of our knowledge, information concerning VO2 and HR kinetics of SQBM is scarce for children. According to the American College of Sports Medicine (ACSM) exercise guidelines, an exercise intensity of 40-85% VO2max or 55-85% HRmax can improve the endurance capacity of the whole body. Furthermore, a training program consisting of many repetitions with low load has been shown to be an effective maneuver for developing systemic and local muscular endurance. Elucidating VO2 and HR kinetics of SQBM in children will be useful for designing a body mass-based training program for improving aerobic capacity. Therefore, this study aimed to clarify VO2 and HR kinetics of SQBM with relation to age. We hypothesized that VO2 and HR kinetics during SQBM would be faster in children than adults, and the level of VO2 and HR during SQBM depends on individual maximal aerobic capacity.

Methods

Participants. Fourteen healthy adults (age, 24.3 ± 5.0 years) and 19 healthy children (age, 10.7 ± 0.9 years) participated in this study. None of the participants were engaged in regular resistance training. They were free of the long-term use of oral steroids or other medications that can influence weight gain, multiple food allergies, moderate or substantial physical or developmental disability, or infection. They refrained from eating, smoking, or drinking tea or coffee for 2 h prior to the test. This study was approved by the ethical committee of the National Institute of Fitness and Sports in Kanoya (No 3-14). Prior to the experiment, all participants were informed on the purpose and procedures of the study and possible risks. Written informed consent was obtained from all subjects and the parents of the children.

Experimental protocol. All participants were involved in two experimental sessions with an interval of 2 days. An incremental loaded bicycle test was conducted to determine peak VO2 (VO2peak) and maximal HR (HRmax) in the first session. In the second session, subjects continuously performed SQBM 200 times. Respiratory gas, heart rate, knee joint angle, and muscular activity were measured during both tasks. Prior to each experiment, participants exerted maximal voluntary isometric contractions (MVCs) of knee extension and flexion.

Incremental loaded bicycle test. An incremental loaded bicycle test was conducted with an electrically braked bicycle ergometer (COMBI, AEROBIKE75XLIII, Tokyo, Japan) to determine HRpeak and VO2peak. For adults, the test was performed in accordance with the procedure used by Thompson et al. After a 5-min rest, they pedaled the bicycle with an initial load of 75 W. The load was increased by 25 W every 3 min until exhaustion. After a 5-min rest, they pedaled the bicycle with pedaling frequency held constant at 60 rpm with the aid of an audible metronome. For children, the task was conducted according to the protocol of Thompson et al. After a 3-min rest, they pedaled the bicycle with pedaling frequency of 50 to 60 rpm. The initial test load was 12.5 W for children with 120 to 140 cm height, and 25 W for children with over 140 cm height. The load was increased by 25 W every 2 min until exhaustion. We set the following criteria to judge termination of the test: (1) oxygen uptake was at a steady state, (2) rating of perceived exhaustion (RPE) was 19 or 20, (3) subjects were unable to maintain a pedaling rate of 60 rpm, (4) respiratory exchange ratio (RQ) > 1.15, and (5) heart rate was at steady state (estimated value ± 15 bpm). The test was finished when three out of five of these criteria were met.

Body mass-based squat exercise (SQBM). According to the protocol of Haramura et al., participants continuously performed SQBM 200 repetitions at a tempo of 45 rpm (2 beats/time). Participants stood with their legs at shoulder width and squatted with the knee joint flexed at 90° from standing position, and then returned to initial position. A box was put behind them to control range of motion during SQBM. Participants were asked to pull their hips back, not lean their trunks or knees forward, and stop motion when changing from ascending (descending) to descending (ascending) phases during the task.

Heart rate (HR). HR was monitored every 1 s using telemetry (Polar RC3 GPS, Polar Electro OY, Kempele, Finland). HR was normalized to HRpeak and expressed as relative value (%HRpeak).

Respiratory gas. During both tasks, respiratory gas was collected continuously to determine VO2, carbon dioxide production, minute ventilation, and respiratory exchange ratio (RER). Before the experiment commenced, flow volume calibration and oxygen gas calibration were performed using an automated breath-by-breath system that was previously calibrated (Vmax Spectra 229, Sensor Medics Corp., Yorba Linda, CA, USA). During SQBM, respiratory gas data was averaged for each 10 s epoch. VO2 during both tasks was normalized to body mass.

Electromyograms (EMGs). Surface EMGs (ME6000T, MEGA Electronics, Finland) with Ag-AgCl electrodes

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(diameter 10 mm; interelectrode distance 20 mm) (N-00-S, Blue Sensor M, Ambu, Denmark) were recorded from the vastus lateralis (VL), rectus femoris (RF), vastus medialis (VM), and biceps femoris (BF) muscles from the right leg. After the skin surface was shaved, rubbed with sandpaper, and cleaned with alcohol, the electrodes were attached to the skin over the muscle belly in the direction of fascicles at the same location for both days, according to the method reported by Tillin et al.29. The electrode locations were at 55% for VL, 50% for RF, 90% for VM, and 45% for BF of the distance between the greater trochanter and the lateral femoral condyle. The location of each electrode was marked on the skin surface with a permanent marker. A ground electrode (preamplifier) was attached near the two electrodes. EMG signals were collected at a sampling frequency of 2 kHz and stored on a personal computer.

For EMG normalization, participants exerted MVC torque of knee extension and flexion with a dynamometer (Biodex System 2, Biodex Medical Systems, NY, USA). Participants were fixed on an adjustable chair with hip and knee joints flexed at 90°. To prevent the joint angle from changing during the tasks, the trunk and hips were fixed using non-elastic belts. They gradually exerted each torque from baseline to maximum and then sustained at maximum for approximately 2 s. Two trials were performed with a 3-min interval between trials. An additional trial was conducted if the difference in the peak values between the trials was more than 10%. The trial with the highest peak force was adopted for further analysis. The torque signal was stored in a personal computer via A/D converter (PowerLab 16/35, AD Instruments, Australia). MVC torque was normalized to body mass (KET/BM and KFT/BM). The repeatability of MVC measurements in this study is confirmed in a previous study7).

**Knee joint angle.** To determine the ascending and descending phases during SQBM, knee joint angles were recorded using an electronic goniometer (SG150, Biometics, Gwent, UK). The goniometer was attached to the lateral side of the thigh and lower leg with adhesive tape. Joint angle signals were recorded and stored via an A/D converter (PowerLab 16/35, AD Instruments, Australia) to a personal computer at a sampling frequency of 2 kHz.

**Data analysis.** In the incremental loaded test, VO2peak was averaged over the last 30s of the final stage25. Ventilatory threshold (VT) was determined as the highest exercise level at which the ventilatory equivalent (VE) stopped increasing linearly with relation to VO2.20. For SQBM, we detected the outlier according to earlier studies29,30. To remove non-physiological data resulting from coughing and sneezing, etc., any breaths more than four standard deviations away from the mean of the surrounding 6 breaths (3 before and 3 after) were deleted. The corrected data were aligned with the onset of the exercise and then linearly interpolated between each breath to yield data at 1-s intervals. The interpolated data were averaged every 15s over the exercise.

After data processing, time constant (τ) of VO2 was determined by fitting a mono-exponential equation using least squares non-linear regression analysis 3 min from the onset of the exercise until the end of the exercise, which included a delay term, δ, to a fitting window constrained to start after the end of the cardiodynamic phase (t > 15 s)11). To confirm whether the slow component existed, τ was estimated by fitting the model for one duration from 15 s to 180 s after the onset of SQBM, and another from 15 s after the onset of SQBM to the end of the exercise. The results demonstrated that no significant difference in τ was found in either group (50 ± 18 s vs. 44 ± 9 s for children, and 61 ± 20 s vs. 68 ± 20 s for adults), but the mean value of the τ derived from a fitted model for the latter period tended to be higher than that for the former period in adults. Since it is possible that a slow component exists in the VO2 kinetics of adults, we adopted the fitted model for one duration from 15 s to 180 s after the onset of SQBM, and analyzed the slow component by using the method described later. Furthermore, adjusted Coefficient of determination (β) was higher in the former model than in the latter one (0.79 ± 0.13 vs. 0.63 ± 0.18 for children, and 0.88 ± 0.09 vs. 0.83 ± 0.11 for adults). In this study, we fitted the model for the duration from 15 s to 180 s after the onset of SQBM.

$$\Delta V\text{O}_2(t) = \Delta V\text{O}_2 \cdot (1 - e^{\delta \cdot t})$$

where ΔVO2 (t) is the increase in VO2 at time t above the baseline; ΔVO2 is the incremental change in VO2 from baseline to steady-state; τ and δ are the time constant and delay term of the response respectively. Fig. 1 presents a typical example of ΔVO2 kinetics with the fitted model in children and adults.

The magnitude of the VO2 slow component was taken as the difference between the amplitude of the averaged for the last 30s (VO2, last 30s) of SQBM and the asymptote (absolute VO2 amplitude) in phase II, calculated from the sum of VO2 at baseline and ΔVO2. The percentage of contribution of the slow component to the total response of VO2 was derived from the following equation:

$$\text{\%VO2slow component} = \frac{\text{VO2, last 30s} - \text{absolute VO2 amplitude}}{\Delta \text{VO2} \times 100}$$

The obtained HR were averaged every 15s. After the data processing, we analyzed the entire response to SQBM with the following equation; ΔHR(t) = ΔHR(ss)(1 – e45t)11). The VO2 and HR at steady state during SQBM were normalized to VO2peak and HRpeak, respectively, and expressed to relative values (%VO2peak and %HRpeak).

To quantify the EMG amplitudes of each muscle during both tasks, root-mean-square (RMS) was calculated during the MVC and SQBM, respectively. In the MVC
task, the RMS value was determined over a 1-s window centered at the time at which peak torque was attained (EMG MVC). For SQ BM, the RMS value was calculated over each cycle from descending to ascending phases, and averaged over 1-min. intervals. The RMS value during SQBM was normalized to EMG MVC and expressed as a relative value (%EMG MVC).

**Statistical analysis.** Values are expressed as means and SDs. To test the age-related differences in the independent variables, an unpaired t test was used. We also calculated Cohen’s d as indices of effect sizes (ES), and interpreted Cohen’s d as large: ≥0.80, medium: 0.50-0.79, small: 0.20-0.49, or trivial: <0.20. Analysis of covariance (ANCOVA) was tested to assess the age-related differences in the VO2 and HR parameters when adjusting the corresponding value at baseline as covariate, and a Bonferroni post hoc test was used for comparison between groups. Pearson’s product-moment correlation coefficients (Pearson’s r) were calculated to determine the relationships between the parameters of VO2 and HR kinetics during SQ, and aerobic capacities (VO2peak, %VO2peak and %HRpeak at VT), MVC/BM and %EMGmax of QF and BF. Correlation coefficients were interpreted as being trivial (r < 0.1), small (0.1 < r < 0.3), moderate (0.3 < r < 0.5), large (0.5 < r < 0.7), very large (0.7 < r < 0.9) or nearly perfect (r > 0.9). Statistical significance was set at p < 0.05. Stepwise multiple regression analysis was performed with the %VO2max as the dependent variable and BM, BMI, VO2peak, MVC/BM, %EMGmax of QF and BF as independent variables in each group. For every independent variable selected, the product of the standardized partial regression coefficient (β) in the multiple regression analysis and the Pearson’s r in the relationship with the %VO2peak during SQBM, and expressed as a percentage, were calculated as an index of %VO2peak during SQBM. All data analyses were conducted by using statistical software (IBM SPSS 25 for Windows).

**Results**

Table 1 presents the physical characteristics of the participants. Height, body mass and BMI were higher in adults than children. In the incremental loaded test, VO2peak and VO2 at VT were lower in children than in adults. MVC torques relative to body mass in knee exten-
sion and flexion were significantly lower in children than adults. There were no significant age-related differences in other parameters.

Fig. 2 shows the kinetics of \( \dot{V}O_2 \) and \%\( \dot{V}O_2 \)peak during SQBM in children and adults. Table 2 provides the information on age-related differences in the parameters of \( \dot{V}O_2 \) kinetics during SQBM. \( \dot{V}O_2 \) at baseline and steady state during SQBM were lower in children than in adults. There were no significant age-related differences in \%\( \dot{V}O_2 \)peak at steady state during SQBM. The \( \tau \) of \( \dot{V}O_2 \) during SQBM tended to be faster in children than adults, but was not significant (\( p = 0.099 \), ES = 0.62). The percentage of contribution of the slow component to total response of \( \dot{V}O_2 \) was higher in adults than in children.

### Table 1. Comparison of physical characteristics between children and adults.

<table>
<thead>
<tr>
<th></th>
<th>Children (N = 19)</th>
<th>Adults (N = 14)</th>
<th>ES (d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height, cm</td>
<td>141.0 ± 10.2</td>
<td>171.7 ± 4.9</td>
<td>* 3.76</td>
</tr>
<tr>
<td>Body mass, kg</td>
<td>34.5 ± 7.9</td>
<td>65.6 ± 7.7</td>
<td>* 4.12</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>17.2 ± 2.4</td>
<td>22.2 ± 2.3</td>
<td>* 2.23</td>
</tr>
<tr>
<td>( \dot{V}O_2 ) peak, ml/min/kg(^{2/3})</td>
<td>149.5 ± 26.5</td>
<td>200.4 ± 26.3</td>
<td>* 1.98</td>
</tr>
<tr>
<td>( \dot{V}O_2 ) at VT, ml/min/kg(^{2/3})</td>
<td>93.6 ± 21.5</td>
<td>118.6 ± 19.9</td>
<td>* 1.24</td>
</tr>
<tr>
<td>%( \dot{V}O_2 )peak at VT, %</td>
<td>65.4 ± 11.2</td>
<td>59.5 ± 8.7</td>
<td>0.60</td>
</tr>
<tr>
<td>HRpeak, bpm</td>
<td>184.2 ± 9.9</td>
<td>184.3 ± 7.4</td>
<td>0.02</td>
</tr>
<tr>
<td>HR at VT, bpm</td>
<td>136.0 ± 25.1</td>
<td>140.9 ± 15.5</td>
<td>0.24</td>
</tr>
<tr>
<td>%HRpeak at VT, %</td>
<td>73.8 ± 13.0</td>
<td>76.0 ± 6.9</td>
<td>0.21</td>
</tr>
<tr>
<td>KET/BM, Nm/kg</td>
<td>2.22 ± 0.57</td>
<td>3.08 ± 0.89</td>
<td>* 1.22</td>
</tr>
<tr>
<td>KFT/BM, Nm/kg</td>
<td>0.91 ± 0.28</td>
<td>1.25 ± 0.23</td>
<td>* 1.32</td>
</tr>
</tbody>
</table>

Values are means and SDs.
BMI, body mass index; \( \dot{V}O_2 \) peak, peak oxygen uptake; VT, ventilatory threshold; \%\( \dot{V}O_2 \)peak, percentage of \( \dot{V}O_2 \) at VT in \( \dot{V}O_2 \)peak; HR, heart rate; HRpeak, peak heart rate; \%HRpeak, percentage of HR at VT in HRpeak; KET/BM, knee extension torque relative to body mass; KFT/BM, knee flexion torque relative to body mass

*, significantly different from children

Fig. 2 Time course of 15 s averaged \( \dot{V}O_2 \) and \%\( \dot{V}O_2 \)peak of body mass-based squat exercise in children (filled circle) and adults (open circle).
Fig. 3 presents the kinetics of HR and %HRpeak during SQBM in children and adults. Table 3 provides the information on age-related differences in the parameters of HR kinetics during SQBM. ΔHR and HRs at baseline and steady state were higher in adults than in children. There were no significant age-related differences in the %HRpeak at steady state during SQBM. The %EMGmax of BF was higher in children than in adults, whereas no significant age-related difference in the %EMGmax of QF was found. ANCOVA results revealed that a combination of the measured variables remained significant.

Regardless of age, %VO2peak was significantly related to %HRpeak at steady state (Fig. 4, r = 0.711 for children, and r = 0.803 for adults, p < 0.05). No significant age-related difference in the regression slope was found.

Fig. 5 presents the relationship between %VO2peak at

| Table 2. Comparison of cardiorespiratory response to body mass-based squat between children and adults. |
|--------------------------------------------------|--------------------------------------------------|--------|
| Children (N = 19)                                | Adults (N = 14)                                  | ES (d) |
| V̇O2 at baseline, ml/min                         | 217.5 ± 77.8                                     | 267.9 ± 47.7       | * 0.78 |
| V̇O2/BM at baseline, ml/kg/min2/3                | 20.4 ± 6.2                                       | 16.5 ± 2.8        | * 1.39 |
| V̇O2 at steady state, ml/min                     | 729.6 ± 232.8                                    | 1463.0 ± 259.0    | * 3.10 |
| V̇O2/BM at steady state, ml/min/kg2/3            | 67.9 ± 12.4                                      | 89.9 ± 13.2       | * 1.79 |
| %VO2max, %                                       | 46.7 ± 11.5                                      | 45.6 ± 8.3        | 0.10  |
| ΔV̇O2, ml/min                                    | 512.3 ± 191.3                                    | 1195.3 ± 251.0    | * 3.23 |
| ΔV̇O2/BM, ml/kg/min2/3                           | 62.3 ± 10.7                                      | 83.2 ± 12.5       | * 1.82 |
| τ of V̇O2, s                                     | 49.9 ± 17.7                                      | 61.3 ± 20.4       | 0.62  |
| V̇O2 at the last 30 s, ml/min                    | 695.6 ± 222.9                                    | 1544.9 ± 321.7    | * 3.26 |
| V̇O2/BM at the last 30 s, ml/kg/min2/3           | 44.3 ± 13.1                                      | 78.4 ± 17.2       | * 2.28 |
| % of SC, %                                       | -6.5 ± 16.4                                      | 6.8 ± 12.6        | * 0.92 |

Values are means and SDs.
BM, body mass; V̇O2, oxygen uptake at steady state during the squat; %VO2max, percentage of V̇O2 at steady state during the squat in maximal V̇O2; ΔV̇O2, difference between V̇O2 at steady state during the squat and that at baseline; τ of V̇O2, constant time of V̇O2 during the squat; % of SC, percentage of contribution of the slow component to the total response of V̇O2
* significantly different from children
steady state during SQBM and VO₂peak. The %VO₂peak during SQBM was negatively related to VO₂peak in children (r = -0.660, p < 0.05) and adults (r = -0.724, p < 0.05). The τ of VO₂ (r = -0.538, p < 0.05) was related to the VO₂peak in children (r = 0.485, p < 0.05). The τ of HR was negatively related to the VO₂peak in adults (r = -0.613, p < 0.05). For adults, the %EMG of QF during SQBM was negatively related to KET/BM (r = -0.544, p < 0.05). In children, BM was significantly related to the parameters of VO₂ and HR kinetics (r = 0.545 to 0.928, p < 0.05), respectively, except for τ of VO₂ and HR, and % of slow component of VO₂.

Multiple regression analysis demonstrated that, for %VO₂peak during SQBM, the VO₂peak and BM were selected as explanatory variables in children (Table 4), and, in adults, only the VO₂peak was selected (Table 4). The contribution of the VO₂peak was 45% for children and 52% for adults. In children, the contribution of BM was 31%.

**Discussion**

The main findings of this study were that the time constants of VO₂ and HR kinetics during SQBM were lower

<table>
<thead>
<tr>
<th>Table 3. Comparison of heart rate and muscular activity level of body mass-based squat between children and adults.</th>
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<tbody>
<tr>
<td><strong>Children (N = 19)</strong></td>
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<tr>
<td>-----------------------</td>
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<tr>
<td>HR at baseline, bpm</td>
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<tr>
<td>HR at steady state, bpm</td>
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<td>ΔHR, bpm</td>
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<td>τ of HR, s</td>
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<td>%HRpeak, %</td>
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<tr>
<td>QF %EMGmax, %</td>
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<td>BF %EMGmax, %</td>
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</table>

Values are means and SDs.

HR, heart rate during the squat; ΔHR, difference between HR at steady state during the squat and that at baseline; %HRpeak, percentage of HR at steady state during the squat in peak HR; τ of HR, constant time of HR during the squat; QF, quadriceps femoris muscles; BF, biceps femoris muscle; %EMGmax, muscular activity level during the squat

*: significantly different from children

Fig. 4 Association of %VO₂peak with %HRpeak at steady state during body mass-based squat exercise in children (filled circle) and adults (open circle).

Fig. 5 Association of %VO₂peak at steady state during body mass-based squat exercise with VO₂peak in children (filled circle) and adults (open circle).
in children than in adults, whereas %VO₂peak and %HRpeak values in children were similar to those in adults. Furthermore, the %VO₂peak during SQBM depended on maximal aerobic capacity, regardless of age. These findings indicate that, for children, VO₂ and HR kinetics of SQBM may reach steady state faster compared to adults, and the magnitude of %VO₂peak during exercise may depend on individual maximal aerobic capacity.

For VO₂ and HR, the time constant in children was faster than in adults. In low- or moderate-intensity exercise (e.g. cycling), earlier findings concerning age-related differences in the time constant were inconsistent⁸⁻¹¹. The current finding supports the earlier finding reported by Fawkner et al.⁹, in which the mathematical model adopted for dynamic kinetics is the same as this study. Concerning physiological factors, the rise in VO₂ during phase II has been shown to correlate with the exponential rise in VO₂ in contracting muscle¹²⁻¹³. Faster VO₂ kinetics in bicycle exercise depends on the percentage of type I fibers in agonist muscles⁴. Children have a greater percentage of slow twitch fibers in a given muscle compared to adults¹⁵⁻¹⁶. Furthermore, anaerobic (e.g. lactate dehydrogenase, creatine kinase, adenylate kinase) and aerobic (e.g. citric acid cycle) enzyme activity in children is different from in adults, indicating that children have a lower anaerobic and lactate generation capacity, compared to adults⁷⁻¹⁸. Another potential factor is the age-related difference in VO₂peak. The time constant is negatively related to VO₂max for adults²⁶⁻²⁷. In this study, however, the corresponding relationship in children was not significant, although there was an age-related difference in VO₂peak. Taken together, it is considered that, for children, the faster time constants of VO₂ during SQBM might be due to the age-related difference in muscle enzyme and fiber type profiles⁷⁻¹⁸.

During SQBM, the physiological load in children (46.7%VO₂peak and 67.8%HRpeak) did not differ from that of adults (45.6%VO₂peak and 71.0%HRpeak). Furthermore, the %VO₂peak during SQBM was lower than at VT, obtained from the incremental loaded test, and %HRpeak was similar at corresponding points. This indicates that the physiological load during SQBM may be equivalent to exercise below the anaerobic threshold for children. It may also be considered that the percentage of contribution of the slow component is a negative value in children (Table 2). Low- or moderate-intensity exercise can be maintained for a relatively long time, because blood lactate concentration is an equilibrium between rate of lactate appearance into and disappearance from the blood during exercise²⁸⁻³⁰, indicating that energy for SQBM in children might be supplied largely via aerobic metabolism³¹.

In this study, the %VO₂peak was strongly related to %HRpeak during SQBM, regardless of age. The slopes of the regression equation were 0.73 for adults and 0.92 for children, being slightly lower in adults compared to children. In earlier findings on incremental loaded tests, the slopes of %VO₂max-%HRmax relationships were 1.18-1.41, obtained from low resistance exercises such as cycling and running³². On the other hand, the slope was 0.58 in moderate- and high-intensity resistance exercises³³. Considering these findings, the corresponding relationship in SQBM may be similar to that of low-intensity exercises for children; but, in adults, the corresponding relationship may be closer to that of moderate- and high-intensity resistance exercise.

For children, the %VO₂peak and %HRpeak at steady state during SQBM were negatively related to VO₂peak; but no association of MVC torque with the %VO₂peak at steady state during SQBM was found. Higher aerobic power may be attributed to greater mitochondrial numbers, greater mitochondrial density, and higher oxidation ability in active muscle³⁴. Taken together, the current findings indicate that physiological load during SQBM may depend on maximal aerobic power, and not on maximal force-generating capacity. Multiple regression analysis also supports these findings, in which the VO₂peak and BM were selected as explainable variables for predicting the %VO₂peak at steady state during SQBM.

The %EMG MVC of QF during SQBM was approximately

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>β</th>
<th>Contribution (%)</th>
<th>R²</th>
<th>Adjusted R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Children</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VO₂peak</td>
<td>-0.687</td>
<td>45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BM</td>
<td>0.577</td>
<td>31</td>
<td>0.768</td>
<td>0.739</td>
</tr>
<tr>
<td>Adults</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VO₂peak</td>
<td>-0.724</td>
<td>52</td>
<td>0.524</td>
<td>0.484</td>
</tr>
</tbody>
</table>

%VO₂peak, peak oxygen uptake during the squat; BM, body mass; %BM, body mass

Contribution (%), product of Pearson’s correlation coefficient and standard partial regression coefficient (β) in the relationship between the %VO₂peak during the body mass-based squat and each of independent variable.
35% across the participants. This is consistent with the reported value that the muscular activity level of the vastus lateralis muscle during body mass-based parallel squat exercise was 33% of that during maximal voluntary contraction. For adults, the %EMG MVC of QF during SQBM was negatively related to KET/BM, being consistent with the earlier findings on the corresponding relationship in SQBM. For children, however, the corresponding relationship was not significant in this study. This finding implies that the muscular activity level may be independent of maximal voluntary torque in the lower extremities. An increase in relative load during the incremental loaded bicycle test linearly elevates oxygen uptake and integrated EMG activity, and we expect that %VO2peak during SQBM depends on the muscular activity level of QF. However, the corresponding relationships were not significant in this study.

**Practical Application**

In this study, the physiological load during SQBM was 46.7%VO2peak and 67.8%HRRpeak in children. This load might be favorable for improving their muscle endurance and whole-body endurance capacity, according to ACSM exercise guidelines. Furthermore, VO2 kinetics in children presented a faster time constant and steady state of VO2 kinetics. This indicates that SQBM may be performed for a long time without accumulating blood lactate via a predominant aerobic metabolism. Considering the finding that a training program consisting of many repetitions with low load is an effective maneuver for developing local muscular endurance. If the earlier findings can be applied to children, the body mass-based squat exercise might prove to be useful in improving both muscle endurance and whole-body endurance when children perform the exercise.

**Conclusion**

The current results indicate that the time constants of oxygen uptake and heart rate kinetics of body mass-based squat exercise were faster in children than adults, whereas the physiological load was almost the same in both children and adults. Furthermore, the physiological load during body mass-based squat exercise may depend on maximal aerobic power, regardless of age.

**Conflict of Interests**

The authors declare that they have no competing interests.

**Author Contributions**

MH participated in the study design, data analysis, and drafting of the manuscript. YT participated in study design, coordination of research activities, and drafting of the manuscript. Both authors read and approved the final manuscript.

**References**


