Abstract  The purpose of this study is to examine the cardiovascular and metabolic responses between dynamic and static exercise when a leg press exercise is performed. Seven participants (20–21 yrs) were recruited for the experiment. Four modes of dynamic or static leg press exercise were assigned in two combined conditions: a unilateral or a bilateral condition and two exercise intensities with 20% and 40% of maximal voluntary contraction (20% MVC, 40% MVC). The duration of the dynamic exercise and the static exercise at 20% MVC was six minutes, and the static exercise at 40% MVC was three minutes. In the dynamic exercise, ventilation (V ˙E), O2 uptake (V˙O2), heart rate (HR), and systolic and diastolic blood pressures (SBP , DBP) reached the steady-state after 3 min exercise, while in the static leg press, these responses continued to increase at the end of exercise. The alteration in V˙O2 mostly depended on both exercise intensity and the one- or two-leg condition during the dynamic leg press, whereas no significant difference in V˙O2 during the static leg press was found in the four modes. The alterations in rate-pressure product (RPP) depended solely on exercise intensity and leg condition. These findings suggest that the static leg press causes a greater rise in HR, SBP, and DBP. In addition, RPP appears particularly sensitive to experimental modes. J Physiol Anthropol Appl Human Sci 24(4): 277–283, 2005 http://www.jstage.jst.go.jp/browse/jpa

Keywords: leg press, blood pressure, O2 uptake, heart rate, ventilation

Introduction

The leg press is popular in weight training and the squat is performed as a training event, as well as being common in certain types of ordinary behavior. Included therein is the kind of static muscle contraction lasting for more than a few minutes that is often needed when people operate a sailboat. The wall squat is administrated as a muscle endurance test (Bull, 2000) and is also performed as part of training. Thus, research promoting an extended understanding of these activities is important, and it is beneficial to compare the cardiorespiratory responses to dynamic and static exercise at a given work rate or force performed for a few minutes.

It has been generalized that in comparison with dynamic activity, static activity involving less than 20% maximal voluntary contraction (MVC) of the involved muscle group evokes a modest increase in systolic, diastolic blood pressure (SBP, DBP), and heart rate (HR), but during contractions greater than 20% MVC, HR increases corresponding to the tension exerted and there is an abrupt and precipitous increase in SBP, while the stroke volume (SV) remains essentially unchanged except at higher MVC (>50% MVC) (Paven and Potts, 1998; Franklin, 2001). Asmussen (1981) also reported that blood pressure is surprisingly increased even with moderate increases in oxygen uptake (V˙O2) during static exercises.

Regarding leg press exercise, greatly increased blood pressure during high intensity static exercises has been found (McArdle and Foglia, 1969; MacDougall et al., 1985), and during the concentric contraction phase of dynamic exercises with a heavy load (MacDougall et al., 1985). However, there have not been many studies dealing with cardiorespiratory response to leg press exercise, especially to investigate leg press exercise at relatively low intensity. Sharkey (1966) investigated cardiorespiratory response to the leg press at approximately 10% to 40% MVC, where it was concluded that V˙O2, HR, and BP in static exercises exceeded those in dynamic exercises. However, his phasic and static exercises were, in summary, the ones performed with the left and then the right leg alternating for 15 and 30 seconds. Such a static exercise is essentially the same as “rhythmic isometric exercise” (Asmussen, 1981). During static, one-legged knee extension at 20%, 40%, and 60% MVC, continuously increasing HR and BP were observed, where the exercise duration at 20% MVC was the longest (4.6 min on average) (Smolander et al., 1998).

The purpose of this study, then, is to examine the cardiorespiratory responses to the leg press performed...
unilaterally or bilaterally for 3 or 6 minutes, comparing the
difference between the cases in both a dynamic and a static
mode with two different intensities, 20% MVC and 40%
MVC.

Methods

Subjects

Seven healthy male college students (20–21 yrs) who
regularly participate in yacht racing were recruited for this
study (Table 1). A periodical health check done by a school
doctor was conducted and all subjects showed no signs of
health problems. Subjects were informed of all the test
procedures and their written consent was obtained. The study
was approved by the Departmental Ethics Committee of
Kanto-Gakuin University.

Maximal voluntary contraction

To determine MVC, each subject performed a maximal
isometric contraction voluntarily five times keeping the same
posture and with the same action as in the experimental
exercise, using a dynamometer. The subjects underwent the
test using one leg more skillfully than the other, thus revealing
that all the subjects were left-legged persons. Two values, the
highest and the lowest among the five maximal trials, were
excluded, and the mean of the remaining values was used to
determine the MVC.

Maximal bicycle ergometer test

A computer-controlled cycle ergometer (Combi 232-C®,
Combi, Tokyo, Japan) was used for the maximal bicycle test to
determine the maximal oxygen uptake (VO₂ max) of each
subject. The load was increased to 20 watts per minute, and the
subjects were required to continuously pedal at 50 rpm until
volitional exhaustion. The procedure was similar to the
methods described by Cariozzo et al. (1982) and Yen et al.
(1983).

Exercise apparatus and protocols

The leg press apparatus used in this experiment was
developed by Kijima, one of the authors (Fig. 1). The
apparatus was designed for the unilateral and the bilateral leg
press. Resistance is set by adding weight to the horn at the
edge of a metal arm attached to the foot-plate.

Loods corresponding to 20% MVC and 40% MVC were set
in this experiment. Subjects conducted eight modes of the
exercise. That is, the dynamic leg press exercises consisted of a
unilateral exercise at 20% MVC (U20d), a bilateral exercise at
20% MVC (B20d), a unilateral exercise at 40% MVC (U40d),
and a bilateral exercise at 40% MVC (B40d), and the static
exercises consisted of the same modes as the dynamic ones,
indicated as U20s, B20s, U40s, and B40s respectively.

Each subject rested for at least thirty minutes before the
exercise. After the rest, the subject sat on the seat of the
apparatus, was secured with a wide belt around the abdomen,
and remained still for a few minutes before starting the
exercise. Once seated, the subject kept the upper body upright
and kept both the trochanter major and the lateral malleolus at
approximately the same height. The subject was instructed not
to plantar flex the foot when pressing up.

During the dynamic leg press, the subject was assigned to
press the load up and down about 40 cm, which corresponds to
moving the knee angle from 90 to 180 degrees. Repetitions
were conducted at a rate of 30 per minute, controlled with a
metronome. The subjects were instructed not to sustain the
weight after the weight reached the top so as to avoid an
eccentric muscle contraction when they flexed the knee back to
the starting position. For the static exercise, the subjects were
required to keep the knee angle at 90 degrees. All the subjects
used their left leg for the unilateral exercise.

Measurements

Oxygen uptake (VO₂), minute ventilation (VE), carbon
dioxide production (VCO₂), and respiratory exchange ratio (R)
were measured using a gas monitor system (model AE-300S®,
Minato Medical Science, Osaka, Japan). The system consisted
of a microcomputer, a hot-wire flowmeter, and O₂ and CO₂
analyzers (Zr element-based O₂ analyzer and infrared CO₂
analyzer) with a pump that propelled gas to the analyzer at a
rate of 220 ml/min. Data were obtained by a computerized
breath-by-breath method, and averaged every 15 seconds. The
system was calibrated before and after each trial in accordance

<table>
<thead>
<tr>
<th>Subj.</th>
<th>Age (yrs)</th>
<th>Height (m)</th>
<th>Weight (kg)</th>
<th>VO₂max (ml/kg/min)</th>
<th>MVC (kgW)</th>
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<tr>
<td>1</td>
<td>20</td>
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</tr>
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<td>Mean</td>
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<td>1.73</td>
<td>64.7</td>
<td>41.5</td>
<td>75.4</td>
</tr>
<tr>
<td>SD</td>
<td>0.58</td>
<td>0.66</td>
<td>8.90</td>
<td>6.37</td>
<td>13.92</td>
</tr>
</tbody>
</table>
with the manufacturer’s instructions.

Heart rate (HR) was measured by a heart rate telemeter (Cardio Super model 2E32AR, NEC San-ei, Tokyo, Japan). Systolic and diastolic blood pressure (SBP, DBP) were measured at the index finger of the right hand by a servo-pulse plethysmograph (Finapres, Ohmedia, 2300 NIBP monitor, Englewood, Colorado, USA) which provided data every 6 seconds. Rate-pressure product (RPP) was calculated using the equation, HR×SBP/100 (Franklin, 2001; McArdle et al., 2000).

**Statistical analysis**

A two-way ANOVA was applied to test if steady states in the cardiorespiratory parameters measured had occurred from the 3rd minute to the end of the exercise and if significant differences appeared in physiological responses among the different modes of the dynamic and static exercises. Benferroni’s method was used when a significant F-value was obtained. A paired t-test was applied to test the difference in magnitude of the responses between every dynamic and static mode of the correspondent workload, and also between one-legged and two-legged exercises. Statistical significance was set at p<0.05.

**Results**

Changes in $\dot{V}E$, $\dot{V}O_2$, HR, SBP, and DBP during and after the dynamic and the static exercises at 20% and 40% MVC are shown comparatively in Fig. 2. Each value at the 3rd and the 6th minute was tested statistically, and there were two patterns that are specific to the dynamic leg press and the static leg press, respectively. That is, $\dot{V}E$, $\dot{V}O_2$, HR, SBP, and DBP in the dynamic leg press started to increase as the exercise started and reached steady-state conditions in 3 minutes while in the static leg press, all except SBP in the bilateral case, they continued to increase up to the end of the exercises.

The following are the magnitudes of the responses in comparison between the dynamic leg press and the static leg press. $\dot{V}E$ between the dynamic and the static leg press in bilateral cases was significantly different both at 20 and 40% MVC. $\dot{V}E$ at 40% MVC in the static leg press both in the unilateral and bilateral cases did not decrease even 1 minute after the exercises. At 40% MVC, $\dot{V}O_2$ in the dynamic and the static leg press of the unilateral case was at the same level, but in the bilateral case, a significant difference appeared between the dynamic leg press and the static leg press ($p<0.001$). The values of $\dot{V}O_2$ in the dynamic leg press from the 3rd to the 6th minute range between $7.3\pm1.03$ ml/kg/min ($17.7\pm3.49\%$ of $\dot{V}O_{2max}$) in U20 and $20.9\pm3.13$ ml/kg/min ($51.6\pm11.0\%$ $\dot{V}O_{2max}$) in B40, and show that $\dot{V}O_2$ and the work performed have a linear relationship ($r=0.883$, $p<0.001$).

At 20% MVC, HR in the static leg press was significantly higher than in the dynamic leg press at the sixth minute. At 40% MVC in the bilateral case, HR in the static leg press was significantly higher than in the dynamic leg press ($p<0.05$).

Both SBP and DBP in the static leg press were significantly higher ($p<0.05–0.001$) than in the dynamic leg press except SBP in the bilateral case at 20% MVC.

Fig. 3 shows fluctuations of $\dot{V}E/\dot{V}O_2$ in the dynamic leg press and the static leg press of the bilateral cases acquired in this experiment. It appeared that in the dynamic leg press, $\dot{V}E/\dot{V}O_2$ rapidly decreased to below 30 and was fluctuating around that level until the end of the exercises, while in the static leg press, $\dot{V}E/\dot{V}O_2$ gradually decreased slightly, but began increasing before the end of the exercises.

Table 2 shows the results obtained through the t-test on the response between each mode of the dynamic exercise and the corresponding static exercise. Each value in the table is the mean value of the response to the exercise from the beginning to the 3rd minute.

There is no difference in the amount of $\dot{V}O_2$, HR, SBP, and DBP between the bilateral leg press at 20% MVC and the unilateral leg press at 40% MVC, regardless of it being dynamic or static. The higher the weight load, the higher the $\dot{V}O_2$ and HR in both the dynamic and the static exercises ($p<0.05$), but a significant difference in blood pressure is found only in the DBP of the static exercises (Fig. 4).

**Discussion**

A distinguishing pattern between the dynamic and the static exercise was the steady-state condition of cardiorespiratory parameters in the dynamic exercise and the continuously increasing parameters in the static contraction (Fig. 2). Examining the rates during the first 3 minutes (Table 2), our data mostly agree with the general tendency that says static contractions elicit marked increases in both SBP and DBP while the rise in HR is less pronounced (Lind and McNicol 1967; Asmussen, 1981; Paven and Potts, 1998; Franklin, 2001). However, increasing the magnitude of the response in the static leg press, at the 6th minute, $\dot{V}E$ and HR in the static leg press exceeded those in the dynamic leg press, and $\dot{V}O_2$ in the static leg press reached the same level as that in the dynamic leg press, which have rarely been mentioned. RPP in the static leg press tends to be higher than in the dynamic leg press (Fig. 4) and at the 6th minute the difference became even greater.

While maintaining static contractions, the blood flow may be hampered or completely blocked during the whole contraction period. It was reported that the mean % MVC that would stop muscle blood flow is 50% MVC in the musculus rectus femoris and 64% MVC in the musculus vastus lateralis (Sadamoto, 1983). Shepard (1983) suggested that isometric contractions that develop less than 15% to 30% MVC, depending on the muscle groups, produce moderate increase in blood flow during contractions. This might suggest that the blood flow in the static leg press at 20% MVC in this study was not very restricted, but at 40% MVC, flow might be close to being impaired.

Under these conditions, it is assumed that the increasing $\dot{V}E$
and HR in the static leg press in this study were induced to adjust to the energetic requirement, but the adjusting speed was apparently slower than in the dynamic leg press. In fact, $\dot{V}O_2$ and $V_{\dot{E}}/\dot{V}O_2$ were gradually changing. $V_{\dot{E}}/\dot{V}O_2$ in this study (Fig. 3) suggested that the respiratory efficiency in the dynamic leg press was well adjusted during the whole exercise period, but the one in the static leg press was not.

Before discussing the effect of exercising muscle mass on...
the cardiorespiratory response, we examine whether \( \dot{V}O_2 \) and \( \dot{V}E \) per limb during one-legged exercise are greater than those during two-legged exercise when the relative work rates are the same. This issue has often been discussed (Davis and Sargeant, 1974; Bassey and Goldsmith, 1975; Sargent and Davis, 1977; Neary and Wenger, 1986; Ogita et al., 2000, Koga et al., 2001). Despite only a simple setting, there were no differences in the present study. It was clearer when the values were compared

### Table 2

<table>
<thead>
<tr>
<th></th>
<th>U20(d-s)</th>
<th>B20(d-s)</th>
<th>U40(d-s)</th>
<th>B40(d-s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VE</td>
<td>14.3±1.7/11.5±1.5</td>
<td>20.9±3.5/17.8±2.8</td>
<td>19.8±2.5/17.3±4.1</td>
<td>33.7±6.2/22.6±4.9</td>
</tr>
<tr>
<td>( \dot{V}O_2 )</td>
<td>7.0±0.9/5.4±0.7</td>
<td>10.8±1.4/8.1±1.5</td>
<td>10.4±1.2/8.0±1.4</td>
<td>18.1±2.5/9.8±1.2</td>
</tr>
<tr>
<td>HR</td>
<td>86±7.9/87±5.1</td>
<td>99±8.1/106±12.9</td>
<td>103±10.2/110±8.5</td>
<td>126±9.9/124±11.5</td>
</tr>
<tr>
<td>SBP</td>
<td>132±6.2/145±8.0</td>
<td>149±7.5/155±16.1</td>
<td>149±9.8/168±13.0</td>
<td>158±16.7/177±13.6</td>
</tr>
<tr>
<td>DBP</td>
<td>86±10.9/91±5.7</td>
<td>88±6.2/104±9.3</td>
<td>94±9.7/110±13.9</td>
<td>100±5.4/125±12.1</td>
</tr>
<tr>
<td>RPP</td>
<td>113±11.7/126±10.4</td>
<td>144±8.0/166±32.8</td>
<td>153±14.0/186±25.0</td>
<td>198±17.2/218±14.2</td>
</tr>
</tbody>
</table>

Note: In every column, the values indicate mean±SD of the dynamic (left) and static (right) exercises. + or – comes from calculation subtracting the static value from the dynamic one. *, **, and *** indicate the significance levels, 0.05, 0.01, and 0.001, respectively.

### Fig. 3

Change of ventilatory equivalent for O\(_2\) (\(\dot{V}E/\dot{V}O_2\)) with dynamic and static leg press at 20% and 40% MVC. The responses to the two types of muscular contraction are significantly different (\(p<0.001\)). In labels, B, 20, 40, d, and s indicate bilateral, 20% MVC, 40% MVC, dynamic, and static, respectively. B1–B3 on the time course indicate resting time before exercise.

### Fig. 4

Oxygen uptake (Mean±SD) and RPP (\(SBP \cdot EHR/100\)) (Mean±SD) during the first 3 minutes in leg press. In labels, U, B, 20, 40, d, and s indicate unilateral, bilateral, 20% MVC, 40% MVC, dynamic, and static, respectively. All the differences in VO\(_2\) and in RPP between the corresponding dynamic and static exercises are significant (\(p<0.05–0.001\)) except the difference in RPP between B20d and B20s.
after subtracting the resting value although it was suggested that some inhibited circulatory responses might appear in two-legged exercises (Ogita et al., 2000).

If we exclude the effect of the one- or two-legged issue which determines the blood pressure and HR responses to static contraction, the size of active muscle mass or the percentage of MVC should be considered here. Many studies have discussed this issue comparing the responses in different parts of the body or only in small muscle masses (Lind and McNicol, 1967; McCloskey and Streetfield, 1975; Mitchel et al, 1980; Seal et al, 1983). However, based on this research, it should be recognized that the magnitude of \( V̇O_2 \) and HR depend on the percentage of MVC when the active muscle mass is the same and vice versa.

In conclusion, the static leg press continued to increase in HR, SBP, and DBP even at 40% MVC. The dynamic leg press resulted in an alteration in \( V̇O_2 \) which depended on both exercise intensity and leg condition; the static leg press did not show this change. The alterations in RPP depended on exercise intensity and leg condition. These findings suggest that the static leg press causes a greater rise in HR, SBP, and DBP. In addition, RPP appears particularly sensitive to experimental modes.

Acknowledgements This work was supported by both the Academic Association of Yokohama College of Commerce and Kanto-Gakuin University.

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Accepted: May 23, 2005
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