INFLUENCE OF ANAEROBIC AND AEROBIC EXERCISES ON THE CENTER OF PRESSURE DURING AN UPRIGHT POSTURE

Shinichi Demura1, Masanobu Uchiyama2

1Kanazawa University, Graduate School of Natural Science and Technology, Kakuma, Kanazawa, Ishikawa, JAPAN
2Research and Education Center for Comprehensive Science, Akita Prefectural University, Kaidobata-Nishi, Shimoshinjo-Nakano, Akita, JAPAN

This study was designed to examine the influence of anaerobic and aerobic exercise, using a cycle ergometer, on upright standing postural control in addition to physiological and psychological responses. During an upright standing posture, 15 healthy male participants were measured for center of pressure (COP), physiological parameters (heart rate, systolic and diastolic blood pressures, and blood lactate concentration), and the ratio of perceived exertion before and after the exercises. They performed a maximal voluntary pedaling exercise for 10 seconds two times under anaerobic exercise conditions and then at 50% of maximal aerobic power for 60 minutes at 60 rpm under aerobic exercise conditions. Measurements were conducted before, immediately after and at 5, 10 and 15 minutes after the exercises. Body sway was recorded by a COP measurement device GS500 (ANIMA, Japan) with three vertical load sensors. COP sway was assessed by mean position of COP sway in the anteroposterior and mediolateral directions as well as the sway area and path length. Three COP parameters regarding sway area and velocity were significantly higher immediately after the exercises than at the other times. In conclusion, the influence of the two exercise protocols on postural control is detected by sway area and velocity. However, the exercise-induced increase of sway velocity recovers earlier than the physiological parameters (heart rate, systolic blood pressure, and blood lactate concentration). It would appear that both prolonged aerobic exercise and high-intensity anaerobic exercise have a relatively small influence on upright standing postural control in healthy young males. [J Exerc Sci Fit • Vol 7 • No 1 • 39–47 • 2009]

Keywords: body sway, ergometer exercise, postural control

Introduction

To maintain a bipedal upright standing posture without falling, human beings sustain and control the position and momentum of the center of gravity of the whole body within a small support base during standing (Horak et al. 1989). People maintain a stable standing posture by integrating vestibular, visual, and somatosensory information in the central nervous system (Soames & Atha 1980). Humans cannot efficiently perform various movements without having a stable posture. Thus, people require postural control to constantly obtain a stable posture in the context of performing adequate movements under all conditions.

It has been reported that the center of pressure (COP) sway is affected by various stimuli from the external environment or internal to the body, such as a temporal mental task (calculation) (Aizawa et al. 1994), holding a bag with one hand (Demura et al. 2005), and a difference in visual acuity (Uchiyama...
et al. 2006). Physical activities also become a considerable stimulus to the internal body. The abovementioned postural control has an important role not only in daily activities, but also in sports activities (Adlerton et al. 2003). Thus, it is of interest to study the immediate effects of cycling exercise using a bicycle ergometer, which is used as a loading device in studies of nervous and physiological responses during exercise, on upright standing postural control (Vuillerme & Hintzy 2007).

In previous studies on the influence of cycling exercise on postural control, changes in COP have been reported to be induced by various physiological causes, such as dehydration due to sweating (Gauchard et al. 2002; Derave et al. 1998) or fatigue in skeletal muscles (Vuillerme & Hintzy 2007). Although the intensity and duration of the cycling exercise in each previous study are different, results from these studies mainly suggested that postural stability decreases in the anteroposterior (AP) direction after cycling exercise (Vuillerme & Hintzy 2007).

However, even with the same exercise mode, the influence of the cycling exercise on the body differs depending on its intensity or duration. In high-intensity and short-term anaerobic exercise, an increase in blood lactate concentration occurs, and the oxygen utilization of the muscles is limited due to an increase in the muscle internal pressure. Then the fatigue level of the fast-twitch fibers with low fatigue tolerance may increase. Moreover, minute ventilation and respiratory rate increase because of the oxygen debt. In contrast, under continuous moderate exercise, the above physiological changes may not be observed. However, people may sweat due to elevated temperature (Derave et al. 1998). Furthermore, depletion of glycogen by aerobic exercise results in a decrease in blood glucose level, which may induce central fatigue (Ishikawa & Takemiya 1994). It is thought that each of these differences in generalized physiological responses has a different influence on postural control after exercise. Various sports have a specific pattern of energy consumption depending on the types of physical activities in each sport event. However, there are few studies examining the influence of exercise on postural control in humans over time. Furthermore, there is no report comparing the exercise-induced influence of anaerobic and aerobic exercise. By broadly classifying various physical activities and sports events into anaerobic and aerobic exercises, the results obtained in this study can suggest the influence of each exercise type on postural control.

This study aimed to examine the effect of aerobic versus anaerobic cycling on upright postural control over time.

**Methods**

**Subjects**

Fifteen healthy males (mean age, 19.9±1.0 years; mean height, 1.72±0.05 m; mean body mass, 67.3±5.2 kg) voluntarily participated in this study. Their physical characteristics were almost the same as the age-matched national standard value (Laboratory of Physical Education, Tokyo Metropolitan University 2000). Before the measurements, the purpose and procedure of this study were explained in detail and informed consent was obtained from all participants. This experimental protocol was approved by the Ethics Committee (Kanazawa University Health and Science Ethics Committee). None of the participants had any history of musculoskeletal, neurological or vestibular problems.

**Assessment of cycling load**

**Anaerobic exercise condition**

The subjects were previously measured for maximal anaerobic power (Watt) to determine the exercise intensity in the anaerobic exercise condition. Maximal anaerobic power was measured by an electronically braked bicycle ergometer Powermax V (COMBI, Tokyo, Japan). This was calculated based on three kinds of load on the Powermax V (the first trial: 4 Kp; the second trial: 7 Kp; the last trial: 10 Kp) and the pedaling rates at maximum exertion with each load. This protocol was conducted in accordance with an existing program incorporated into the ergometer.

**Aerobic exercise condition**

The subjects were previously measured for maximal aerobic capacity (power output at exhaustion) (Watt) to determine exercise intensity in the aerobic exercise condition. Maximal aerobic power was measured by an electronically braked bicycle ergometer Powermax V (COMBI, Tokyo, Japan). This was calculated based on three kinds of load on the Powermax V (the first trial: 4 Kp; the second trial: 7 Kp; the last trial: 10 Kp) and the pedaling rates at maximum exertion with each load. This protocol was conducted in accordance with an existing program incorporated into the ergometer.
1989). First, \( \text{VO}_2 \) was calculated using equation (1) and peak \( \text{VO}_2 \) was calculated using equation (2). Then, incremental ratio of exercise load was determined by assigning these estimated values to equation (3).

\[
\text{VO}_2 \text{ with unloaded pedaling} \ (\text{mL/min})
= 150 + (6 \times \text{Weight}) \\
\text{Peak of } \text{VO}_2 \ (\text{mL/min}) = (\text{Height} – \text{Age}) \times 20 \tag{2}
\]

Incremental ratio of exercise load (Watts/min)
\[
= (\text{peak of } \text{VO}_2 – \text{VO}_2)/100 \tag{3}
\]

**Balance assessment**

The output of the postural control system can be observed as the center of mass (COM) and/or the COP under the plantar surface of both feet. Acceleration of the COM is induced by both excess and deficient ankle torque to achieve maintenance of posture during standing upright. Therefore, there is a slight discrepancy between COP and COM, i.e. the high frequency components of COP sway (Masani & Abe 2005; Winter et al. 1998). However, in many studies on postural control and in many clinical settings, COP sway is recorded as an output of the postural control system (Masani & Abe 2005).

A stabilometer (G5500; Anima, Tokyo, Japan) was used as a COP measurement device. This can calculate the COP of vertical loads from the values of three vertical load sensors, which are put on the corner of an isosceles triangle on a level surface. Data were sampled at 20.0 Hz and transferred to a personal computer following A/D conversion.

COP measurements were carried out in accordance with the standard procedure of the committee for standardization of stabilometric methods and presentation (Kapteyn et al. 1983). In the COP measurements, subjects stood upright and barefoot with feet together on a platform with their arms by their sides (Kapteyn et al. 1983). They were asked to look at a 3-cm diameter red circle target placed at eye level about 3.0 m in front of them. The measurement time of each trial was 60 seconds. In the Pre Test, two trials of COP measurement were conducted and the means of the two trials were used as representative values. In the other tests (Post Tests 1, 2, 3 and 4), each subject underwent one trial.

Body sway was assessed by mean position, root mean square (RMS), RMS of sway velocity, power spectrum distribution of COP sway in the AP and mediolateral (ML) directions, independent of COP sway area and path length per second (Table 1) (Kitabayashi et al. 2002).

**Physiological assessment**

To assess physiological responses, we measured heart rate (HR) with an electrocardiograph device (ML1200; Fukuda Denshi, Tokyo, Japan), systolic and diastolic blood pressures with a blood-pressure manometer (STBT780, COLIN, Komaki, Japan), and blood lactate concentration with a simplified blood lactate concentration measure (Lactate Pro LT-1710; Arkray, Kyoto, Japan). The ratio of perceived exertion (RPE) was assessed by Borg’s 6–20 Ratings of Perceived Exertion scale (Borg 1982). In the Pre Test, two trials were conducted and the mean values were used as representative values. In the other tests (Post Tests 1, 2, 3 and 4), each subject underwent one trial.

**Experimental design**

A crossover design, in which all subjects participated in both exercise conditions, was used in this study. First, each subject was assigned the order of participation in anaerobic and aerobic exercise conditions at random. Maximal power measurements, for determining the pedaling load of each subject in each exercise condition, were also conducted in this order with a 1-week interval. Each subject visited our laboratory 1–2 weeks prior to the experiment, at which time maximal anaerobic and aerobic power were measured as stated previously. Two weeks after each power measurement, subjects participated in the two exercise conditions (anaerobic and aerobic) over a 2–3-day interval, considering the influence of fatigue.

In the anaerobic exercise condition, subjects performed two trials (with a 1-minute rest) of maximal pedaling for 30 seconds at 120% (Kp) of the load (4, 7 or 10 Kp) with which the maximal anaerobic power (Watt) of each subject was obtained. Before and after this, COP and physiological parameters were measured. Subjects were instructed to maximally exert as much as possible within the time limit.

In the aerobic exercise condition, subjects pedaled at 60 rpm for 60 minutes with a 50% load of their maximal aerobic power (Watt). Before and after this, measurements of each evaluation parameter were conducted. No subject dropped out of these protocols due to physical problems caused by these protocols.

In each exercise condition, subjects were first measured twice for physiological parameters, followed by two trials of COP sway measurements during upright standing posture (Pre Test) after enough rest on a chair (about 10 minutes). After the Pre Test, subjects performed the pedaling exercise. COP sway and physiological parameters were measured immediately after...
the pedaling exercise (Post Test 1), after 5 minutes (Post Test 2), 10 minutes (Post Test 3), and 15 minutes (Post Test 4) for both exercise conditions. They rested on a chair between each post test (Figure 1).

**Statistical analysis**

As described in the above Experimental design section, all subjects participated in both exercise conditions. The change in their characteristics of postural control before and after the exercise protocols was assessed by 14 COP sway parameters. Various physiological and psychological changes were evaluated by HR, blood pressure (systolic and diastolic), blood lactate concentration, and RPE. COP sway parameters, physiological parameters, and RPE were analyzed using separate two-way (factor A: exercise type × factor B: time) analyses of variance (ANOVA) with repeated measures on both factors. Mean differences between each

<table>
<thead>
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<th>Table 1. Characteristics of center of pressure parameters</th>
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![Fig. 1 Experimental protocol and measurement items. In each test, the following items were measured (in the Pre Test, each item was measured twice): center of foot pressure, heart rate, systolic blood pressure, diastolic blood pressure, ratio of perceived exertion, and blood lactate concentration.](image)
cell were examined by Tukey’s honestly significant difference (HSD) method when a significant difference was found by ANOVA. Also, the level of significance was set at 0.05, and 36 body sway parameters were tested according to Bonferroni’s method ($\alpha' = 0.05/14 = 0.0036$).

Results

**Influence of anaerobic and aerobic exercises on physiological parameters and subjective exertion ratio**

Table 2 shows the results of analyses for physiological and psychological parameters. Significant differences were found in HR, blood lactate concentration, systolic blood pressure and RPE. HR was significantly higher in the anaerobic condition than in the aerobic condition immediately after exercise (Post Test 1). In both exercise conditions, HR was higher in Post Tests 1, 2, 3 and 4 than in the Pre Test, being highest in Post Test 1. Blood lactate concentration was higher in the anaerobic condition than in the aerobic condition in all post tests (Post Tests 1, 2, 3 and 4). Blood lactate concentration was higher in Post Tests 1, 2, 3 and 4 than in the Pre Test, being highest in Post Test 1. Systolic blood pressure was higher in the anaerobic condition than in the aerobic condition immediately after exercise (Post Test 1). Systolic blood pressure obtained in the anaerobic condition was significantly higher in Post Tests 1 and 2 than in the Pre Test. Systolic blood pressure obtained in the aerobic condition was significantly higher in Post Test 1 than in the Pre Test. RPE was higher in the anaerobic condition than in the aerobic condition in all post tests (1, 2, 3 and 4). In both exercise conditions, RPE was significantly higher in all post tests than in the Pre Test.

**Changes in COP parameters**

Figure 2 shows COP sway parameters (rectangle area, path length per second, velocity of sway in the AP direction, and standard deviation of velocity of sway in the AP sway) which showed significant differences. Significant interactions were found in the velocity of sway in the AP direction and in its standard deviation. These were significantly higher in the aerobic condition than in the anaerobic condition in Post Test 1. In both the aerobic and anaerobic conditions, these were significantly higher immediately after exercises (Post Test 1) than in the other tests. No significant main effect (time) was found for rectangle area and path length per second. Rectangle area obtained in the anaerobic condition was significantly larger in Post Test 2 than in the Pre Test. Path length per second obtained in both anaerobic and aerobic conditions was significantly longer in Post Test 1 than in the other tests. No significant main effect of exercise type was found in any COP parameters.

Discussion

The present study examined the influence of anaerobic and aerobic exercises on upright standing postural control in addition to physiological and psychological responses. The rest to exercise transition is characterized by an increase in HR, ventilation, cardiac output, body temperature, sympathetic nervous system activation and lactate production (acidosis) (Tarnopolsky 2004). When starting exercise, anaerobic energy pathways are initially applied, and then, as exercise is sustained, aerobic energy generation pathways predominate (Tarnopolsky 2004).

From the results of analyses for physiological parameters, it was shown that different energy-supplying mechanisms are used by the two exercise protocols in this study. Physiological parameters other than systolic blood pressure showed the influence of the exercises. Systolic blood pressure in both exercise conditions markedly increased immediately after exercise (up to 128.71% in the anaerobic condition and up to 113.57% in the aerobic condition) as compared with that before exercise (anaerobic condition, 125.3 mmHg; aerobic condition, 142.3 mmHg). Particularly, in the anaerobic exercise condition, a significant increase in blood pressure remained 5 minutes after exercise. In the anaerobic and aerobic exercise conditions, HR more than doubled immediately after each exercise (256.6% and 231.3% of HR at rest, respectively), which supported an increase in systolic blood pressure. Homeostasis acts to decrease the HR when systolic blood pressure increases, and to increase HR when systolic blood pressure decreases, but systolic and diastolic blood pressures increase together during exercise (Nakamachi et al. 1999).

Blood lactate concentration remained significantly increased until 15 minutes after anaerobic exercise. This suggests that an anaerobic energy metabolic pathway was extensively used. In the aerobic exercise condition, no changes in blood lactate concentration before and after exercise were found, which are consistent with Jorfeldt’s (1970) and Jorfeldt et al.’s (1978) results.
Table 2. Test results of two-way ANOVA and multiple comparisons for physiological parameters and ratio of perceived exertion (n = 15)

<table>
<thead>
<tr>
<th>Exercise condition</th>
<th>Pre Test</th>
<th>Post Test 1</th>
<th>Post Test 2</th>
<th>Post Test 3</th>
<th>Post Test 4</th>
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<th>Post hoc, HSD method</th>
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<td>SD</td>
<td>Mean</td>
<td>SD</td>
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<td>HR</td>
<td>Anaerobic</td>
<td>60.9</td>
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<td>155.7</td>
<td>15.89</td>
<td>96.0</td>
<td>11.74</td>
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<td>56.6</td>
<td>15.71</td>
<td>130.9</td>
<td>31.08</td>
<td>94.7</td>
<td>12.42</td>
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<td>F3 7.26</td>
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<td>La</td>
<td>Anaerobic</td>
<td>2.2</td>
<td>1.29</td>
<td>11.0</td>
<td>4.37</td>
<td>9.4</td>
<td>4.12</td>
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<td>Aerobic</td>
<td>2.2</td>
<td>0.98</td>
<td>3.2</td>
<td>1.18</td>
<td>2.5</td>
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<td></td>
<td>F3 24.55</td>
<td>0.00*</td>
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<tr>
<td>SBP</td>
<td>Anaerobic</td>
<td>121.9</td>
<td>12.20</td>
<td>156.9</td>
<td>23.96</td>
<td>133.4</td>
<td>15.45</td>
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<tr>
<td></td>
<td>Aerobic</td>
<td>125.3</td>
<td>14.20</td>
<td>142.9</td>
<td>21.84</td>
<td>123.9</td>
<td>17.94</td>
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<td>F3 4.28</td>
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<td>DBP</td>
<td>Anaerobic</td>
<td>67.7</td>
<td>8.98</td>
<td>67.8</td>
<td>11.76</td>
<td>67.9</td>
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<td>67.8</td>
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<td>73.3</td>
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<td>F3 1.11</td>
<td>0.36</td>
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<td>RPE</td>
<td>Anaerobic</td>
<td>6.0</td>
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<td>18.8</td>
<td>1.05</td>
<td>12.7</td>
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<td>6.0</td>
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<td>14.5</td>
<td>1.86</td>
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<td>F3 24.32</td>
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*p < 0.05. F1 = time; F2 = exercise condition; F3 = interaction; HR = heart rate; La = blood lactate concentration; SBP = systolic blood pressure; DBP = diastolic blood pressure; RPE = ratio of perceived exertion.
Thus, the selection of exercise intensity and duration in this study may have been appropriate. RPE was markedly higher in the anaerobic exercise condition than in the aerobic exercise condition from immediately after exercise to 15 minutes later. It is considered that this phenomenon occurred because the lactate acid generated in the glycolytic system induced a pH decrease (i.e. lactate acidosis) (Tarnopolsky 2004) and a power decrease in muscular contraction.

Both exercises which induced the above-stated physiological changes resulted in significant changes in COP sway. Many postural muscles (cervical, erector spinae, quadriceps femoris, anterior tibial, soleus muscle, etc.) relate to upright standing postural control. It has been reported that muscle fatigue alters muscle contractile efficacy (Duchateau & Hainaut 1985; Bigland-Ritchie & Woods 1984; Viitasalo & Komi 1981), and also proprioceptive information and cortical control (Gandevia 1998; Belhaj-Saif et al. 1996; Macefield et al. 1991). It may, therefore, affect movement and postural control (Chabran et al. 2002). From the present results, significant differences in upright standing postural control output, mainly before and after anaerobic and aerobic exercises, occurred only in COP sway area and velocity and were found to occur immediately after the exercises. Applying these findings to actual practices, the following possibility is suggested: high-intensity exercises, such as instant sprinting in sport events including soccer, basketball, baseball, and so on, has adverse effects on subsequent balance control during the sporting activities, which results in a decline in performance.

However, the duration of the influence of both exercises on body sway was shorter than the physiological parameters and subjective exertion ratio. It is inferred that the influence of exercise on the cardiovascular system and on energy metabolism is larger than on the postural control system. Even strenuous anaerobic exercise and aerobic exercise sustained for 1 hour has an influence for only about 10 minutes. Both the prolonged aerobic and very high intensity anaerobic cycling exercises are considered to have
little influence on postural control in healthy young males. Considering that the blood lactate concentration, among the physiological parameters, only showed a significant difference between each post test in the anaerobic condition, it is inferred that fatigue of leg muscles by hard pedaling influenced COP sway in the AP direction.

When observing COP sway in each direction, ML sway was not influenced by the pedaling exercise. The exercise-induced influence was found only in AP sway. Thus, it is inferred that ML sway, as compared to AP sway, is not sensitive to the fatigue of muscles involved in the pedaling exercise. Ericson et al. (1985) reported that muscles involved primarily in movements within the sagittal plane are recruited during the cycling exercise. Hence, it is considered that the muscles that become fatigued due to the cycling exercise increase AP sway but do not influence ML sway. Because an upright standing posture is mainly controlled by postural muscles involved in plantarflexion and dorsiflexion of the ankle and knee/hip flexion and extension, the cycling exercise largely influences postural sway, especially in the AP direction.

Although there are some factors relating to body sway frequency, such as dysfunction of sensory systems (vestibular, visual and proprioceptive systems) (Cherng et al. 2003; Palmieri et al. 2002; Giacomini et al. 1998) and subjects’ respiration (Schmid et al. 2004), it was reported that the respiratory effect on body sway is very small (Watanabe et al. 1975). Actually, according to Jeong (1999), it is necessary to double the respiratory rate in increasing body sway path length up to 120%. In this study, physiological parameters were measured immediately after both exercises, followed by COP sway measurements. During the former measurements, the respiratory rate may markedly decrease. It may be necessary to examine the influence of respiration immediately after exercises on sway frequency.

There were a few limitations in this study. First, the upright standing postural task with both feet was selected to examine the cycling exercise-induced fatigue on postural control over time. This posture has been examined in many previous studies (Vullerme et al. 2005; Ledin et al. 2004; Corbeil et al. 2003) on various disturbances of postural control. Therefore, the present results are comparable to those of previously published results. However, this stance (a bipedal upright posture) is a very easy task for healthy young adults compared with the one-legged stance or bipedal stance with eyes closed. Furthermore, people generally do not always stand upright on both feet during various sports events. Considering these factors, examining the exercise-induced influence when standing on one leg with eyes open or closed, which is harder to maintain than bipedal stance, remains as a future task. Second, cycling with an ergometer was selected as a whole body exercise in this study. However, the quadriceps femoris are the main muscles activated during the cycling exercise. Thus, the influence of cycling exercise-induced fatigue on postural control largely relates to fatigue in this muscle. This should be considered in interpreting the present results. Therefore, in may be impossible to generalize the present results to fatigue caused by running, jogging, walking, jumping, and weight-bearing exercises.

In conclusion, the influence of two exercise protocols on postural control is detected by sway area and velocity. However, the exercise-induced increase in sway velocity recovers earlier than that of the physiological parameters (HR, systolic blood pressure, and blood lactate concentration). It would appear that both a prolonged aerobic exercise and a high-intensity anaerobic exercise have a relatively small influence on upright standing postural control in healthy young males.

References


