Cardiorespiratory Changes When Balancing One's Whole Body on One Leg with Eyes Closed

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Abstract: Postural control system has been extensively studied in terms of somatic motor function, but little is known about its connection with human autonomic function. The purpose of this study was to determine the cardiorespiratory changes in response to the 3-min load that was performed by balancing one's whole body on one leg with eyes closed (SOLEC load) or eyes open (SOLEO load) in 11 healthy young subjects (5 males and 6 females, mean age 20.8 ± 1.9 year). Blood pressure (BP), heart rate (HR), respiratory rate (RR), inspiratory and expiratory duration (T_i and T_e), tidal volume (V_T), and oxygen uptake ($\dot{V}_{O_2}$) were measured before, during, and after the load. The SOLEC load produced significant increases in HR and systolic BP within 1 min.

There were further increases in systolic and diastolic BP during the late period of the load. Metabolic rate ($\dot{V}_{O_2}$) showed a gradual increase during the SOLEC load, indicating that the late responses would be partly due to metabolic alteration. The early responses are considered to be mediated neurally through the postural control system which receives the afferent inputs arising from vestibular system and from muscle proprioceptors of the leg. In contrast, SOLEO load caused small insignificant changes in BP, HR, V_T , and $\dot{V}_{O_2}$, suggesting that a visual input is essential for balancing a postural change. The balance test with eyes closed may have value in a clinical neurological rehabilitation setting. [Japanese Journal of Physiology, 46, 145–153, 1996]

Key words: blood pressure, balance test, vestibulosympathetic reflexes, muscle proprioceptor.

There is a great deal of information on the postural control system in relation to somatic motor function [1]. The stability of posture is controlled by a variety of neuronal structures such as the basal ganglia, the cerebellum, brain stem reticular formation, which generate a tonic contraction of antigravity muscles. The stability of posture is regulated by the visual system, vestibular signals from the otolith and the afferent inputs arising from muscle proprioceptor. On the other hand, the neuronal system controlling the stability of posture can affect the homeostasis of autonomic functions, as described in detail for the vestibulo-sympathetic reflex [2] and vestibulo-respiratory reflex [3, 4].

To evaluate postural control, the balance test which consists of the act of balancing of the whole body on one leg seems a most convenient method. This test is called "standing on one leg (SOL test)" in this paper.

The SOL test is basically used to evaluate physical ability rather than autonomic function. Surprisingly, there are no quantitative data available regarding human cardiorespiratory changes in response to the SOL test. This study was thus conducted to obtain human data concerning the effects of the SOL test on the cardiorespiratory and metabolic systems. Since the visual system plays an important role in compensating for a postural change, the SOL tests were performed on the subjects with or without eyes closed.

When examining the vestibular function, a caloric test or a head-tilt test is frequently used [5–8]. The caloric test is usually applied under laboratory conditions. A head-tilt test has been established in the field of space medicine and underwater physiology [9, 10]. Compared to the caloric and the head-tilt tests, the SOL test is very simple, because no specific equipment is needed. Furthermore, it takes only a few min-

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utes for an ordinary healthy subject to reach a performance limit, namely losing balance. Thus, it is expected that considerable changes in autonomic parameters can be evoked during the short period required for the SOL test, when balance is lost. The results in this study suggest that the SOL test may have potential value as an autonomic function test.

METHODS

Subjects. Eleven healthy subjects (5 males and 6 females), aged 18 to 24 (20.8 ± 1.9 years, mean $\pm$ SD), volunteered to participate in this study after having been informed of the experimental procedures.

Data collection. Each subject's blood pressure (BP), heart rate (HR), respiratory rate (RR), inspiratory duration (T_i), expiratory duration (T_e), tidal volume (V_T), and oxygen uptake ($\dot{V}_{O_2}$) were measured before, during, and after a balance test described later in the Experimental procedure section (Figs. 1 and 2).

Fig. 1. Experimental procedures. A: standing on one leg with eyes closed (SOLEC), B: standing on one leg with eyes open (SOLEO), C: standing on both legs with eyes closed (SEC).

Fig. 2. Schematic representation of measuring equipment. BP, blood pressure; HR, heart rate; ECG, electrocardiogram; RR, respiratory rate; V_T , tidal volume; T_i , inspiratory duration; T_e , expiratory duration; $\dot{V}_{O_2}$, oxygen uptake; EMG, electromyogram; EOG, electrooculogram.

Using a blood pressure monitor with oscillometric method (Nippon Colin, STBT-680), systolic and diastolic BP were measured by the attachment of a blood pressure cuff around the upper arm. The BP measurement was performed automatically at 1-min intervals. HR was continuously recorded using an electrocardiograph (Nihon Kohden, OEC-6501).

Ventilation and gas exchange responses were monitored continuously using a computerized system consisting of a respiratory flowmeter and O_2 and CO_2 analyzer (Minato Medical Science, Aeromonitor AE-280). Inspired and expired V_T (BTPS) and duration were measured using a hot-wire respiratory flowmeter. The expired O_2 and CO_2 concentrations were measured by an analyzer equipped with a zirconia element and an infrared gas analyzer, respectively. The gas analyzer was calibrated with precision-measured gas mixture (15.2% O_2 and 5.07% CO_2). The calculations for ventilation and gas exchange were performed on a breath-by-breath basis, but mean values were reported for 1-min periods. $\dot{V}_{O_2}$ (STPD) was calculated by determining the sample differences between inspired and expired gas volumes.

Electromyographic activity (EMG) was recorded from the soleus and the plantar muscle with a pair of Ag/AgCl surface electrodes. The electrodes were placed over the soleus muscle just proximal to and parallel to the Achilles tendon to evaluate the muscle activity of the foot when balancing the whole weight of the body on one leg. The plantar muscle EMG activity was measured by placing electrodes on the medial side of the thenar eminence to monitor the movement of the opposite foot being apart from the ground during standing on one leg.

To estimate the change in head position, electroocu-

lography (EOG) of vertical eye movements were recorded with bipolar electrodes, centered about 1 cm above and below the right eye. EMG and EOG were amplified using a multi-telemeter (Nihon Kohden, WEB-5000).

Experimental procedure. Subjects were required to stand with their eyes open for 3 min (control period). After the control period, they performed a balance test for 3 min (load period), followed by a 3-min recovery period (Fig. 1). The balance test consisted of three distinct types of load, i.e., standing on one leg with eyes closed (SOLEC), standing on one leg with eyes open (SOLEO), and standing with eyes closed (SEC). The three tests were performed in random sequence for each subject. The subject's eyes were covered with goggles colored with white paint while balancing his/her whole body on one leg, to stimulate afferent inputs other than visual input.

Data analysis. The experimental results are presented as mean $\pm$ SD every minute, but data obtained after subjects lost their balance were excluded. To statistically assess the effects of the balance tests on BP, HR, RR, T_i , T_e , V_T , and $\dot{V}_{O_2}$, data obtained before, during, and after each balance test was compared using ANOVA, i.e., analysis of variance for repeated measures. When the ANOVA results indicated a statistically significant difference, Scheffe's tests were used to analyze the differences among test periods and

loads. The accepted level of significance of all statistical tests was set at 5%.

RESULTS

In this study, 9 of 11 subjects could keep their balance during a 3-min SOLEC load, whereas the other 2 subjects lost their balance within 2 min. A typical response to SOLEC load is shown in Fig. 3. BP in the control period was 115/86 mmHg. This value was considered to be a normal BP at rest. BP obtained 1 min after the onset of the load increased; the systolic BP was higher than the value obtained in the control period, whereas diastolic BP decreased slightly in comparison with the control. Systolic BP at the 3-min marker during the load remained elevated, compared to the value obtained 1 min after the onset of the load. However, diastolic BP increased as compared with the value obtained at the 1-min marker during the load. BP recovered within 1 min following cessation of the load, and that value was almost equivalent to the control level before the load.

There was an increase in RR during the SOLEC load. RR increased from 20.7 breaths/min in the control period to 23.3 breaths/min at the 1-min marker during the load. RR at the 3-min marker during the load was 26.2 breaths/min. This value was higher than the control level and higher than the level obtained at

Fig. 3. Typical records of changes in the BP, ECG, respiratory flow, EMG, and EOG of vertical eye movements to the SOLEC load. These records were obtained before and after onset of the load (left panels) and cessation of the load (right panels).

the 1-min marker during the load. RR recovered within 1 min following cessation of the load.

As for respiratory flow, there was a change in the waveform of the expiratory flow after the onset of the load; the peak expiratory flow in the control period appeared in the early expiratory phase, whereas the peak expiratory flow after onset of the load occurred in the mid-expiratory phase. This change in expiratory flow suggests that active expiration occurs during the SOLEC load. There was a slight decrease in the amplitude of the respiratory flow immediately after onset of the SOLEC load. However, there was an increase in the amplitude of inspiratory and expiratory flows obtained during the late period of the load. A marked increase was noticed in inspiratory and expiratory flows during the first several breaths after cessation of the load. The respiratory flow returned gradually to the control level during the recovery period.

In the case shown in Fig. 3, $\dot{V}_{O_2}$ obtained in control period was 180 ml/min. The SOLEC load produced an increase in $\dot{V}_{O_2}$ (210 ml/min at 1 min after the onset of the load). $\dot{V}_{O_2}$ at the 3-min marker during the load was 304 ml/min. This value was higher than both the value in the control period and the value at the first 1-min marker during the load. Although there was a decrease in $\dot{V}_{O_2}$ at the 1-min marker following cessation of the

load (272 ml/min), the O_2 consumption remained higher than that at the first 1-min marker during the load.

EMG recordings from the soleus and the plantar muscles showed silent activity in the control period. SOLEC load evoked a recruitment of the EMG activity in the soleus, with continued activity noted until the end of the load. There was transient activity in the EMG of the plantar muscle at the onset of SOLEC load, indicating a postural change of standing on one leg. Recruitment of EMG activity in the plantar muscle was noticed after the end of the load, probably due to a compensatory mechanism for fatigue of the leg which supported the whole body.

EOG recording showed a slow vertical movement of the eye as well as spiky waves (blinks) in the control period. The slow vertical movement of the eye was reduced during the late period of the SOLEC load, accompanied by a decrease in the number of blinks.

Heart rate and blood pressure

Mean values of HR and BP measured before, during, and after the SOLEC, SOLEO, and SEC loads are shown in Fig. 4. The mean HR obtained at 3 min before the SOLEC load was 79.9 ± 11.1 bpm. No signifi-

Fig. 4. Responses of HR and BP measured before, during, and after SOLEC (top), SOLEO (middle), and SEC (bottom) loads. Values are means $\pm$ SD for 11 subjects. *Indicates a significant difference ($p < 0.05$) from the corresponding value at 3 min before the load (control). †Indicates a significant difference ($p < 0.05$) from the corresponding value during the SOLEO load. Shaded area, load period of 3-min duration.

cant variation was found between the control data measured at 1 min and 3 min prior to the load. SOLEC load produced an increase in HR compared to the control level. Mean HRs at the 2- and 3-min markers during the SOLEC load were 91.8 ± 13.9 and 88.7 ± 9.6 bpm, respectively. These values were significantly higher than the control ($p < 0.05$).

SOLEO load (middle panel in Fig. 4) produced a small increase in HR compared to the control and was statistically not significant ($p > 0.05$), but these values were significantly lower than mean HRs obtained during the SOLEC load ($p < 0.05$). HR remained unchanged throughout the SEC load (bottom panel in Fig. 4).

The mean BP obtained at 3 min before SOLEC load was 116/81 mmHg. Both systolic and diastolic mean BPs increased progressively during the load. Systolic mean BPs obtained at the 2- and 3-min markers during the SOLEC load were significantly higher than the control level ($p < 0.05$). There was a significant increase in diastolic mean BP only at the 3-min marker during the load. Both systolic and diastolic mean BPs returned to the control level within 1 min following cessation of the load.

Although SOLEO load produced much less significant increase in systolic BP compared to that observed during the SOLEC load, mean systolic BP obtained only at the 3-min marker during the SOLEO load was significantly lower than that during the SOLEC load ($p < 0.05$). No significant variations in BP were found during SEC load.

Respiratory rate

Figure 5 shows RR responses to SOLEC, SOLEO, and SEC loads. Mean RR obtained 3 min before the SOLEC load was 17.6 ± 3.6 breaths/min. There was no significant change in the mean RR during the control period. The mean RR significantly increased to 21.8 ± 2.7 breaths/min at the 1-min marker during the load ($p < 0.05$), and this elevation persisted until the end of the load. Mean RR declined after the load, but it remained higher than the control level.

The response of RR to SOLEO load was qualitatively analogous to the RR response observed during the SOLEC load. Mean RRs obtained at the 1- and 3-min markers during the load were significantly lower than those during the SOLEC load ($p < 0.05$). It was noticed that SOLEO load produced a significant increase in mean RR, compared to the control ($p < 0.05$). There was no measurable change in the mean RR during the SEC load.

Fig. 5. Responses of RR measured before, during, and after SOLEC (top), SOLEO (middle), and SEC (bottom) loads. Values are means $\pm$ SD for 11 subjects. * Indicates a significant difference ($p < 0.05$) from the corresponding value at 3 min before the load (control). † Indicates a significant difference ($p < 0.05$) from the corresponding value during the SOLEO load. Shaded area, load period of 3-min duration.

Inspiratory duration and expiratory duration

The mean values of T_i and T_e measured before, during, and after SOLEC, SOLEO, and SEC loads are shown in Fig. 6. The mean T_i and T_e obtained at the 3-min marker before the SOLEC load were 1.40 ± 0.26 and 2.11 ± 0.50 s, respectively. Both T_i and T_e did not show any significant change during the control period. The mean T_i and T_e obtained at the 1-min marker during SOLEC load were 1.13 ± 0.13 and 1.66 ± 0.22 s, respectively. Those values were significantly smaller than the control level ($p < 0.05$). Both T_i and T_e gradually returned to the control level during the recovery period.

SOLEO load produced a small decrease in mean T_i , compared to the control level, whereas mean T_e obtained at the 2- and 3-min markers during the load was significantly smaller than the control ($p < 0.05$). No significant differences in T_i and T_e were found during SEC load.

Fig. 6. Responses of T_l and T_e measured before, during, and after SOLEC (top), SOLEO (middle), and SEC (bottom) loads. Values are means $\pm$ SD for 11 subjects. * Indicates a significant difference ($p < 0.05$) from the corresponding value at 3 min before the load (control). Shaded area, load period of 3-min duration.

Fig. 7. Responses of V_t and $\dot{V}_{O_2}$ measured before, during, and after SOLEC (top), SOLEO (middle), and SEC (bottom) loads. Values are means $\pm$ SD for 11 subjects. * Indicates a significant difference ($p < 0.05$) from the corresponding value at 3 min before the load (control). † Indicates a significant difference ($p < 0.05$) from the corresponding value during the SOLEO load. Shaded area, load period of 3-min duration.

Tidal volume and oxygen uptake

Figure 7 shows mean values of $\dot{V}_T$ and $\dot{V}_{O_2}$ obtained before, during, and after the SOLEC, SOLEO, and SEC loads. The mean control level of $\dot{V}_T$ and $\dot{V}_{O_2}$ obtained at 3 min before SOLEC load was 576 ± 225 ml and 237 ± 77 ml/min, respectively. The mean $\dot{V}_T$ obtained at the 1-min marker after the onset of SOLEC load was 585 ± 175 ml, which was almost the same as the control level. $\dot{V}_T$ increased steadily during the SOLEC load. Of particular interest was that $\dot{V}_T$ showed a further increase even after cessation of the load. Note that the mean $\dot{V}_T$ obtained 1 min before the end of the load was 718 ± 194 ml, and the mean $\dot{V}_T$ obtained 1 min after the end of the load was 810 ± 232 ml. These values were significantly higher than the control ($p < 0.05$). $\dot{V}_T$ returned gradually to the control level during the recovery period.

Mean $\dot{V}_{O_2}$ obtained 1 min after the onset of SOLEC load (329 ± 112 ml/min) showed a small increase as compared to the control level. $\dot{V}_{O_2}$ during the load increased progressively, with continued increases noted until 1 min following cessation of the load. The means for $\dot{V}_{O_2}$ obtained 1 min before and 1 min after the end of the load (431 ± 84 and 442 ± 168 ml/min, respectively) were significantly higher than the control levels ($p < 0.05$). Note that mean $\dot{V}_{O_2}$ 1 min after the end of the load was higher than the control level.

SOLEO load produced a small increase in mean $\dot{V}_T$ and $\dot{V}_{O_2}$, compared to the control level, and these values obtained at 1 min before and after the end of the load were significantly lower than those during the SOLEC load ($p < 0.05$). There was no measurable change in mean $\dot{V}_T$ and $\dot{V}_{O_2}$ during the SEC load.

DISCUSSION

The present study demonstrated clear-cut cardiorespiratory changes in response to the 3-min load that was performed by balancing one's whole body on one leg with eyes closed. This load produced significant increases in HR and systolic BP within 1 min. There were further increases in systolic and diastolic BP during the late period of the load. The early responses would be mediated neurally, whereas the late response is considered secondary to augmented metabolic activity, due probably to static exercise during the SOLEC load.

There are several neural factors underlying the early cardiovascular changes observed during the load. Since the load was performed by having the subject balance their whole body on one leg, an important factor might be afferent inputs arising from muscle proprioceptor of the leg. Orani and Decandia [11]

demonstrated in animal (cat) experiments that electrical stimulation of group Ia afferent fibers from muscle proprioceptor of the leg elicited an increase in arterial pressure and an augmentation of pulmonary ventilation. Gautier *et al.* [12] reported that a succinylcholine-induced excitation of muscle spindles in cats produced increases in HR and pulmonary ventilation. There is also evidence in human studies to suggest that afferent inputs arising from muscle proprioceptor of the leg evoke increases in BP and HR [13, 14]. Ray *et al.* [14] reported that static leg exercise produced increases in muscle sympathetic nerve activity accompanied by rises in BP and HR. Therefore, afferent inputs arising from muscle proprioceptor can be considered one of the essential neural factors influencing the increases in BP and HR observed during the load in this study.

It is expected that the vestibular system would be stimulated during the load, because the balance test is performed by the subjects with their eyes closed. There is no direct observation showing that activation of the vestibular system evokes increases in HR and BP in humans. However, there are alternative studies indicating that afferent input from the vestibular system modulates cardiorespiratory control [2, 5, 15–17]. For example, Doba and Reis [5] demonstrated that bilateral transection of the vestibular nerves impaired the compensation for hypotension produced by head-up tilt in cats; analogous impairment was produced by a lesion of the fastigial nucleus, one of the deep nuclei of the cerebellum, which receives neural input from the vestibular apparatus. Yates *et al.* [17] showed that electrical stimulation of the vestibular neurons in the cat's medulla caused an excitation of the reticular neurons in the rostral ventrolateral medulla, i.e., an important source for excitatory inputs to sympathetic preganglionic neurons. There is evidence to suggest that a vestibulo-sympathetic reflex occurs in humans [6, 18]. Essandoh *et al.* [6] reported that head-down neck flexion in prone male subjects evoked a rapid decrease in blood flow to the forearm and calf. The rapidity of onset of changes in blood flow indicates that it was mediated neurally, presumably as a consequence of an increase in sympathetic nerve activity elicited by inputs from labyrinthine receptors. Thus, it is possible that the vestibulo-sympathetic reflex may be involved in the changes in HR and BP observed herein.

The vestibular system is considered to be strongly activated especially when a subject loses his/her balance. In this study, most subjects experienced a heavy swinging of their bodies during the late period of the load. Thus, we hypothesize that the vestibulo-sympa-

thetic reflex may occur especially during the late period of the load.

The balance test with eyes open elicited small insignificant increases in HR and BP. No subject lost their balance during the 3-min load with eyes open. This indicates that the visual system is essential for balancing a postural change, whereas the vestibular system plays only a minor role in postural control during the load with eyes open.

Since the balance test was exerted by voluntary or active contraction of antigravity muscles, the subject's motivation is necessary for accomplishment of the test. This indicated that the frontal association cortex and the primary motor cortex are also involved in the neuronal mechanisms underlying the balance test. Therefore, it is possible that the higher brain may cause the sympathetic excitation observed during the SOLEC load, presumably through the hypothalamus, i.e., the higher center of the sympathetic nervous system. However, further experimental evidence is necessary before discussing the details.

There is another important factor influencing the cardiovascular responses during the load both with and without eyes closed; that factor is the activation of the muscle pump which produces an increase in venous return and cardiac output. It is thought that static contraction of muscles of the standing leg during the load caused compression of the peripheral vein, which in turn increased venous return, and caused a rise in BP. In addition, the contraction of abdominal muscles as described later in detail, would induce the compression of abdominal veins which also contributes to the increase in venous return.

As for the respiratory changes, the present study revealed that the balance test produced a significant increase in RR accompanied by a decrease in both T_i and T_e within 1 min. These early changes may be explained in part by the excitation of sympathetic nerve activity as discussed above. In fact, Leitner and Dejours [19] demonstrated that a significant increase in ventilation occurred by vibrating triceps surae muscles of the hindlimbs that excite mainly the primary nerve endings from muscle spindles. Thus, the afferent inputs arising from muscle proprioceptor of the leg is considered to evoke the ventilatory excitation as well as the activation of sympathetic nerve activity.

It was also noticed that active expiration or contraction of abdominal muscles occurred during the load, as evidenced by the sustained, augmented expiratory flow. Note that the high expiratory flow was observed in the mid- to late expiratory phase. Abdominal muscles are known to play a significant role not only in respiratory control but also in postural control. The

tonic contraction of the abdominal muscle is essential for balancing the body on one leg. In addition, Yates *et al.* [3] reported that vestibular nerve stimulation caused predominantly an increase in abdominal nerve activity, indicating that the vestibulo-respiratory reflex may also cause abdominal muscle contraction. Such contraction of the abdominal muscle is considered to result in an increase in the coeliac pressure as described earlier and to impede the downward movement of the diaphragm. This activation of the expiratory (abdominal) muscle is thought to contribute to the change in the waveform of the expiratory flow.

The present results demonstrated a mild increase in metabolic rate ($\dot{V}_{O_2}$) which occurred progressively during the SOLEC load. This gradual increase in $\dot{V}_{O_2}$ may also account for the respiratory changes observed in the late period of the load. We would like to emphasize that this load caused a very small increase in the metabolic rate, less than those observed during an ordinal exercise test using a treadmill or an ergometer. Therefore, we suggest that this balance test with eyes closed can be utilized for the evaluation of the elderly and the disabled. In other words, this test is a convenient method to evaluate the autonomic function related to postural control system. It is possible that this test has value in the clinical neurological rehabilitation setting.

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REFERENCES

1. Allum JHJ, Allum-Mecklenburg DJ, Harris FP, and Probst R: Natural and artificial control of hearing and balance. In: Progress in Brain Research, ed. Allum JHJ, Allum-Mecklenburg DJ, Harris FP and Probst R, Elsevier, Amsterdam, Vol. 97, p 424, 1993
2. Yates BJ: Vestibular influences on the sympathetic nervous system. Brain Res Rev 17: 51-59, 1992
3. Yates BJ, Jakus J, and Miller AD: Vestibular effects on respiratory outflow in the decerebrate cat. Brain Res 629: 209-217, 1993
4. Miller AD, Yamaguchi T, Siniaia MS, and Yates BJ: Ventral respiratory group bulbospinal inspiratory neurons participate in vestibular-respiratory reflexes. J Neurophysiol 73: 1303-1307, 1995
5. Doba N and Reis DM: Role of the cerebellum and vestibular apparatus in regulation of orthostatic reflexes in the cat. Circulation Res 34: 9-18, 1974
6. Essandoh RHT, Denison DM, and Shepherd JT: Reflex constriction of human resistance vessels to head-down neck flexion. J Appl Physiol 64: 767-770, 1988
7. Scherer H and Clarke AH: The caloric vestibular reaction in space. Acta Otolaryngol 100: 328-336, 1985
8. Spiegel EA: Effect of labyrinthine reflexes on vegetative nervous system. Arch Otolaryngol 44: 61-72, 1946

9. Edholm OG: Effect of gravity on the blood pressure of the cat. *J Physiol (Lond)* 98: 79–96, 1940
10. Watanabe S: Vestibular function under weightlessness conditions. *J Physiol Soc Jpn* 50: 211–222, 1988
11. Orani GP and Decandia M: Group I afferent fibers: Effects on cardiorespiratory system. *J Appl Physiol* 68: 932–937, 1990
12. Gautier H, Lacaille A, and Dejourn P: Ventilatory response to muscle spindle stimulation by succinylcholine in cats. *Respir Physiol* 7: 383–388, 1969
13. Callister R, Ng AV, and Seals DR: Arm muscle sympathetic nerve activity during preparation for and initiation of leg-cycling exercise in human. *J Appl Physiol* 77: 1403–1410, 1994
14. Ray CA, Rea RF, Clary MP, and Mark AL: Muscle sympathetic nerve responses to static leg exercise. *J Appl Physiol* 73: 1523–1529, 1992
15. Cobbald AF, Megirian D, and Sherrey JH: Vestibular evoked activity in autonomic motor outflows. *Arch Ital Biol* 106: 113–123, 1968
16. Tang PC and Gernandt BE: Autonomic responses to vestibular stimulation. *Exp Neurol* 24: 558–578, 1969
17. Yates BJ, Yamagata Y, and Bolton PS: The ventrolateral medulla of the cat mediates vestibul sympathetic reflexes. *Brain Res* 552: 265–272, 1991
18. Mano T, Iwase S, Saito M, Koga K, Abe H, Inamura K, Matsukawa Y, and Hashiba M: Somatosensory-vestibular sympathetic interactions in man under weightlessness simulated by head-out water immersion. *In: Basic Aspects of Vestibular Functions*, ed. Hwang JC, Dauntton NG, and Wilson VJ, Hong Kong University Press, Hong Kong, pp193–203, 1988
19. Leitner LM and Dejourn P: Reflex increase in ventilation induced by vibrations applied to the triceps surae muscles in the cat. *Respir Physiol* 12: 199–204, 1971