Effects of Room Temperature and Body Position Change on Cerebral Blood Volume and Center-of-foot Pressure in Healthy Young Adults

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Abstract This study aimed to examine the effects of room temperature and body position changes on cerebral blood volume, blood pressure and center-of-foot pressure (COP). Cerebral oxygenation kinetics and blood pressure were measured by near infrared spectroscopy (NIRS) and volume-compensation, respectively, in 9 males and 9 females after rapid standing from sitting and supine positions in low (12°C) or normal (22°C) room temperatures. COP was also measured in a static standing posture for 90 s after rapid standing. The total hemoglobin (Hb) decreased just after standing. Blood pressure after standing at normal temperature tended to decrease immediately but at low temperature tended to decrease slightly and then to increase greatly. The decreasing ratio of total Hb and blood pressure upon standing from a supine position at normal room temperatures was the largest of any condition. Total Hb recovered to a fixed level approximately 25 sec after standing from a sitting position and approximately 35 sec after standing from a supine position. All COP parameters after standing tended to change markedly in the supine position compared to the sitting position, especially at normal temperatures. The COP parameters after standing in any condition were not significantly related to the decreasing ratio of total Hb but were related to the recovery time of total Hb after standing. In conclusion, decreasing ratios of total Hb and blood pressure after standing from a supine position at normal temperatures were large and may affect body sway. *J Physiol Anthropol 27(2): 63–70, 2008* http://www.jstage.jst. go.jp/browse/jpa2 [DOI: 10.2214/jpa2.27.63]

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Introduction

When healthy people quickly stand up from sitting or supine positions, approximately 500–700 ml of blood moves to the lower body (i.e., lower limbs or abdomen) from the heart, despite the concomitant action of blood pressure regulatory mechanisms (Steinberg, 1980; Andre et al., 1989; Wieling and Shepherd, 1992). Blood pressure is regulated mainly by the baroreceptor reflex, the renin-angiotensin system, and aldosterone release. In particularly, baroreceptors in various organs can detect rapid changes in blood pressure and prevent orthostatic hypotension and fainting. If this blood pressure regulation is not sufficient, systolic pressure temporarily decreases as circulating blood volume diminishes due to pooling of venous blood, and cerebral symptoms such as dizziness and lightheadedness may occur (Mehanoul-Schipper et al., 2001).

Orthostatic hypotension occurs generally when the heart rate increases and the blood pressure decreases (systolic pressure: over 30 mmHg, and diastolic pressure: over 15 mmHg) (Halar and Bell, 1998; Mukai and Lipsitz, 2002). Temporary decreases in oxygen supplied to the cerebrum during orthostatic hypotension may decrease body control while standing.

Continuous cerebral oxygenation monitoring with noninvasive near-infrared spectroscopy (NIRS) can be an indicator of cerebral blood volume changes. Moreover, time-series recording of the center-of-foot pressure (COP) by a force plate (stabilimeter) allows for accurate and objective body sway monitoring. Variations in cerebral blood volume and blood pressure during posture changes have been examined by many researchers (Harms et al., 2000; Kusano et al., 2000; Kawaguchi et al., 2001) with an emphasis on people with orthostatic symptoms and the elderly. However, few have examined the relationship between cerebral blood volume and

body sway observed immediately after postural changes. Moreover, even in healthy young people, physiological variations, such as cerebral blood volume, blood pressure and autonomic nervous function, occur temporarily during postural changes (Mehagnoul-Schipper et al., 2000; Kawaguchi et al., 2001). Tanaka et al. (1994) observed changes in orthostatic hypotension in Japanese and Swedish people and reported that the diastolic pressure in the supine position and the systolic pressure while standing were significantly lower in Japanese than in Swedish people. In addition, they inferred that the Japanese have less body stability during standing as a result of orthostatic hypotension.

We hypothesized that standing from a supine or sitting position produces a temporary reduction in cerebral perfusion and a subsequent increase in body sway even in healthy young people. Furthermore, if the temporary reduction in cerebral perfusion after postural changes increases body sway, it is assumed that a significant postural change will further exacerbate body sway. Moreover, orthostatic dizziness is mainly attributed to decreased blood pressure from a temporary decrease in venous return. Blood pressure regulation increases the peripheral vascular resistance with an increase in heart rate leading to stabilization of blood pressure. Therefore, we hypothesized that the decrease of cerebral perfusion is restrained in low ambient temperatures because vasoconstriction caused by cold temperatures will lead to lower reductions of blood pressure.

This study aimed to compare variations in cerebral oxygenation, blood pressure, and COP after standing from the sitting and supine positions at normal and low room temperatures for healthy young Japanese adults.

Methods

Subjects

The subjects were 18 healthy young adults (9 males, M age=20.6years, SD=1.4, M height=176.1 cm, SD=8.1, M weight=70.3 kg, SD=9.3 kg, 9 females, M age=20.2years, SD=1.2, M height=164.6 cm, SD=3.5, M weight=56.7 kg, SD=4.5). Subjects did not habitually use any systemic medicines. Written informed consent was obtained from all subjects and their parents after a full explanation of the experimental purpose and protocol. This experimental protocol was approved by the ethics committee at Kanazawa University.

Materials
1) Stabilimeter

An Anima's stabilimeter (G5500, Japan) was used for the measurement of the COP. This instrument calculates the COP of vertical loads from three vertical load sensors placed at the peak of an isosceles triangle on a level surface. Data were recorded at a sampling frequency of 20 Hz. Eleven COP parameters with high trial-to-trial and day-to-day reliabilities (Demura et al., 2001; Yamaji et al., 2001) were selected from the following 4 domains: distance (mean path length, root

mean square), velocity (mean velocity of X- and Y-axis, root mean square of sway velocity), area (area surrounding mean path length, area surrounding maximal amplitude rectangle for each axis), and amplitude distribution (standard deviation of X- and Y-axis, standard deviation of X- and Y-axis velocity).

2) Cerebral tissue oxygenation monitor

Near-infrared spectroscopic (NIRS) instruments (NIRO-300, Hamamatsu Photonics, Japan) measured cerebral tissue oxygenation (total hemoglobin (Total Hb), the tissue oxygen saturation index (TOI), the oxygenated hemoglobin (Oxy-Hb), and the deoxygenated hemoglobin (Deoxy-Hb) during posture changes. Changes in total Hb volume indicate changes in cerebral blood volume. The probe of the NIRO-300 contains a light source filtered at 775, 813, 850, and 913 nm and three optical detectors placed 5 cm from the light source. The changing volumes of oxy-/deoxy Hb and oxidized/reduced-cytochrome aa3 are determined and analyzed with an algorithm incorporating the modified Beer-Lambert law (Hamaoka et al., 1996, 2003). The slope of light attenuation versus distance is determined by estimating the relative absorption coefficients of tissue, i.e., the non-scattered light. Scattered light is delivered via two fiber-optic light detectors to a photomultiplier at 0.5 sec intervals. It is hypothesized that the oxygenation kinetics determined by the NIRO-300 are measured at a depth of about 25 mm from the skin, because the mean path length is half the distance between the light source and the detector. The total absorbance of light incident by the tissue was the sum of the absorbance by Oxy-Hb and Deoxy-Hb in the blood and other tissues.

3) Blood pressure

Arterial pressure in the finger was measured with the volume-compensation method (Radia press RBP-100, KANDS, Japan). Averages of systolic and diastolic blood pressure values measured by noninvasive continuous blood pressure monitoring devices were calculated every second. The measurement principle of this instrument is almost the same as the commonly used Portapres (Finapres Medical System) although the algorithms of pressure correction are different. This instrument determines absolute values of arterial blood pressure from light volume variation corrected by calibration, the ratio of pressure pulse wave (standard values) to photoelectric volume pulse wave. After measuring blood pressure at the upper arm during rest by the oscillometric method, this device detects variations of blood hemoglobin with blood flow volume by optical wavelength irradiation (640 nm) to the skin from an emission sensor attached to the ear lobule while providing light pressure (about 100 mmHg). Because the variations of blood hemoglobin are relative, the blood pressure is corrected with the ratio of the value during rest as measured by the oscillometric method. The photoelectric volume pulse wave data is corrected with this value. Absolute blood pressure values were determined with a prepared algorithm for blood pressure computation. Emission sensors consist of a photoelectronic sensor and a body motion sensor. The former detects reflected light volume variation in

the blood vessel from optical wavelength irradiation (640 nm), and the latter detects reflected light volume variation on a surface by the photoelectronic sensor. It is designed to eliminate measurement errors that result from changes in the photoelectric volume pulse wave by body motion.

Nakada et al. (2007) reported a high trial-to-trial reliability of blood pressure measured by this instrument and close agreement with the Portapres during exercise.

Experimental procedure

The experimental design was a cross-over design where the subjects participated in all of the experimental conditions (room temperatures: normal (22°C) and low (12°C); body position during rest: sitting and supine). Each subject was measured on the same day with an interval of 30 min between trials, and the trials were randomized in terms of the order of the conditions. The humidity was kept at 30% for all conditions. The NIRS probe was attached to the subject's frontal plane, and cerebral oxygenation was measured for 1 min while sitting in a normal temperature room. The NIRS probe remained attached until the end of all experimental conditions. In all conditions, the mean value of cerebral oxygenation while sitting in a normal temperature room was set as the criteria value (100%). The changes in continuous blood pressure were measured at the ear lobule with the Radia press RBP-100. During standing with the measurement of COP, cerebral oxygenation was continually measured. The subjects entered the experimental room which was maintained at a low or normal temperature, and remained quiet in either a sitting or a supine position for 10 min in order to adapt to the room environment. Then, they stood up and the COP was measured in an upright posture for 90 sec. They were instructed to respire naturally and to stabilize their body posture quickly. Moreover, to reduce the influence of muscle contractions, they were instructed not to overstrain their muscles. Following this procedure, each experimental condition (room temperature and body position during resting conditions) was repeated three times. The switch was set to the lateral region of the thigh in order to respond to standing. The sensor was switched when the subject stood vertically on the floor, and the COP was measured. The event signal was entered into the NIRS recorder at the same time.

Data analysis

The cerebral oxygenation by NIRS in each condition was compared to the mean value at a sitting position in the normal temperature room. The trial-to-trial reliabilities of the COP and the changing ratio of the cerebral oxygenation before and after standing were examined using an intra-class correlation coefficient (ICC). The reliability of the time-series change of cerebral oxygenation and blood pressure were examined by the cross correlation coefficient. The mean differences in COP after standing and the changing ratio of cerebral oxygenation before and after standing between conditions (room temperature and body position during rest) were examined

using the two-way ANOVA. For the multivariate comparison, Tukey's HSD test was used. The recovery time from the temporary decrease of total Hb after standing was calculated in each condition, and the relationship between this time and the COP parameters was examined using Pearson's correlation coefficient. A probability level of 0.05 was indicative of statistical significance.

Results

The ICC of the COP between trials was over 0.75 (ICC= 0.76–0.83) in all conditions. Moreover, the cross-correlation coefficient of the time-series change of cerebral oxygenation and blood pressure was over 0.8 (r_{xy}=0.80–0.94). Therefore, the data of the third trial, exposure for a long time, was used in the subsequent analysis.

Figure 1 shows the time series change in the parameters regarding total Hb in the frontal head plane, a cerebral blood volume indicator, and blood pressure in each body position and room temperature. Total Hb time-series values were calculated relative to the value at rest while sitting at 22°C. The total Hb just after standing decreased significantly more from the supine position under normal room temperature conditions compared with the other conditions. Average blood pressure after standing at normal temperature tended to decrease immediately but that at low temperature tended to decrease slightly and then increase greatly.

Figure 2 shows the result of the two-way ANOVA (room temperature×body position during rest) for a changing ratio of cerebral oxygenation kinetics before and after standing. There were no significant interaction factors for any of the parameters, and the changing ratio for the supine position in normal temperature conditions was the largest of any of the conditions. The decreasing ratio of these parameters at sitting and supine positions in low-temperature conditions tended to be smaller than that in normal temperature conditions.

Table 1 shows the results of the two-way ANOVA (room temperature×body position during rest) for the COP parameters after standing. There were significant differences in the main factors (body position during rest) in all of the parameters, except for the standard deviation of the Y-axis. The body sways for supine positions at normal and low temperatures were significantly larger than those for the sitting position.

In both temperature rooms, the recovery of total Hb after standing from a sitting position took about 25 sec, but that from a supine position took about 35 sec. The two-way ANOVA of the recovery time (room temperature×body position during rest) revealed significant differences in the main factors (body position during rest); the recovery times at a supine position were significantly longer than those at a sitting position. Table 2 shows the correlations between COP parameters and decreasing ratio and recovery time of total Hb upon standing. The COP parameters after standing in any condition were not significantly related to the decreasing ratio
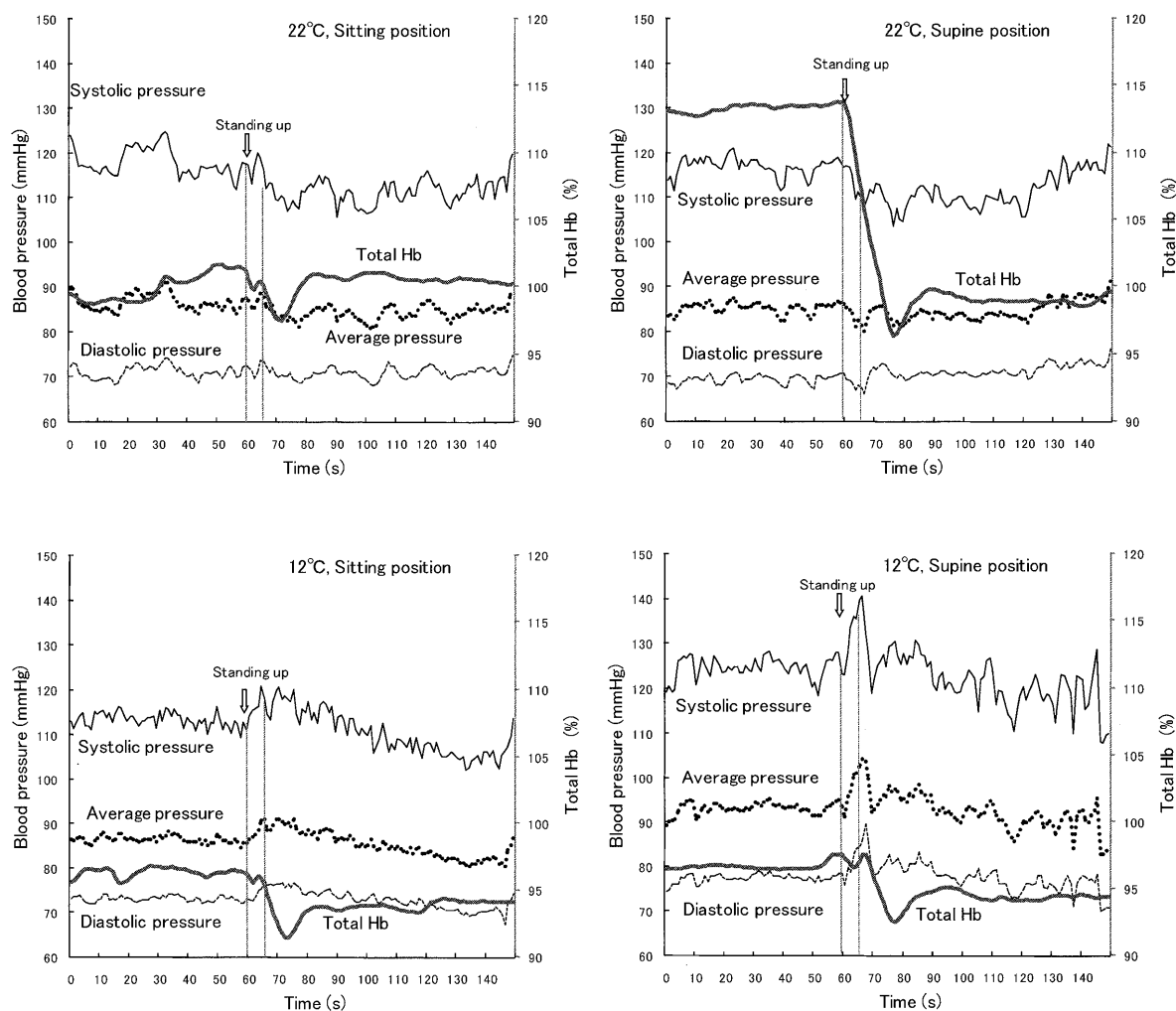
Fig. 1 Changes in total hemoglobin and blood pressure in each body position and room temperature. Values are expressed as the mean for each sampling time. Total Hb values were calculated relative to the value at rest while sitting at 22°C.

of total Hb but showed significant correlations with the recovery time of total Hb after standing (e.g., root mean square or standard deviation of Y-axis; r=0.47–0.76, p<0.05).

Discussion

Healthy people do not experience large changes of body posture or syncope because of blood pressure regulation (Steinberg, 1980). However, they often feel symptoms such as dizziness or lightheadedness caused by the temporary decrease of blood pressure (Mehanoul-Schipper et al., 2001). Orthostatic hypotension resulting from impaired blood pressure regulation causes a temporarily-diminished oxygen supply to the brain (Kawaguchi et al., 2001). We hypothesized that when the outside air temperature is low, orthostatic hypotension is controlled by vasopressor adaptation. Moreover, since the movement of circulating blood to the lower body after standing from a supine position is larger than that from a sitting position, this symptom may become more marked.

1) Cerebral oxygenation kinetics after standing

The time-series changes of blood pressure in this study may support this hypothesis which the changing volume corresponds to a significant posture change because the blood flow volume from the head to the lower limbs increases as a result of gravity when standing up from a supine position rather than sitting position. Therefore, if the decline in blood supply causes cerebral symptoms, this symptom may occur more readily when standing up from a supine position than from a sitting position. Few have studied the influence on body sway of the temporary decline in the cerebral blood volume after standing. The findings of previous studies regarding the physiological response, such as the cerebral oxygenation available after changing posture, may be summarized as follows: after standing, the blood pressure and heart rate increase, and the oxy-Hb and total Hb decrease, whereas deoxy-Hb increases (Colier et al., 1997; Mehagnoul-Schipper, 2000; Kawaguchi et al., 2001; Tanaka et al., 2003). Moreover, since Total-Hb and Oxy-Hb decrease after standing, it is inferred that the cerebral blood volume decreases during the
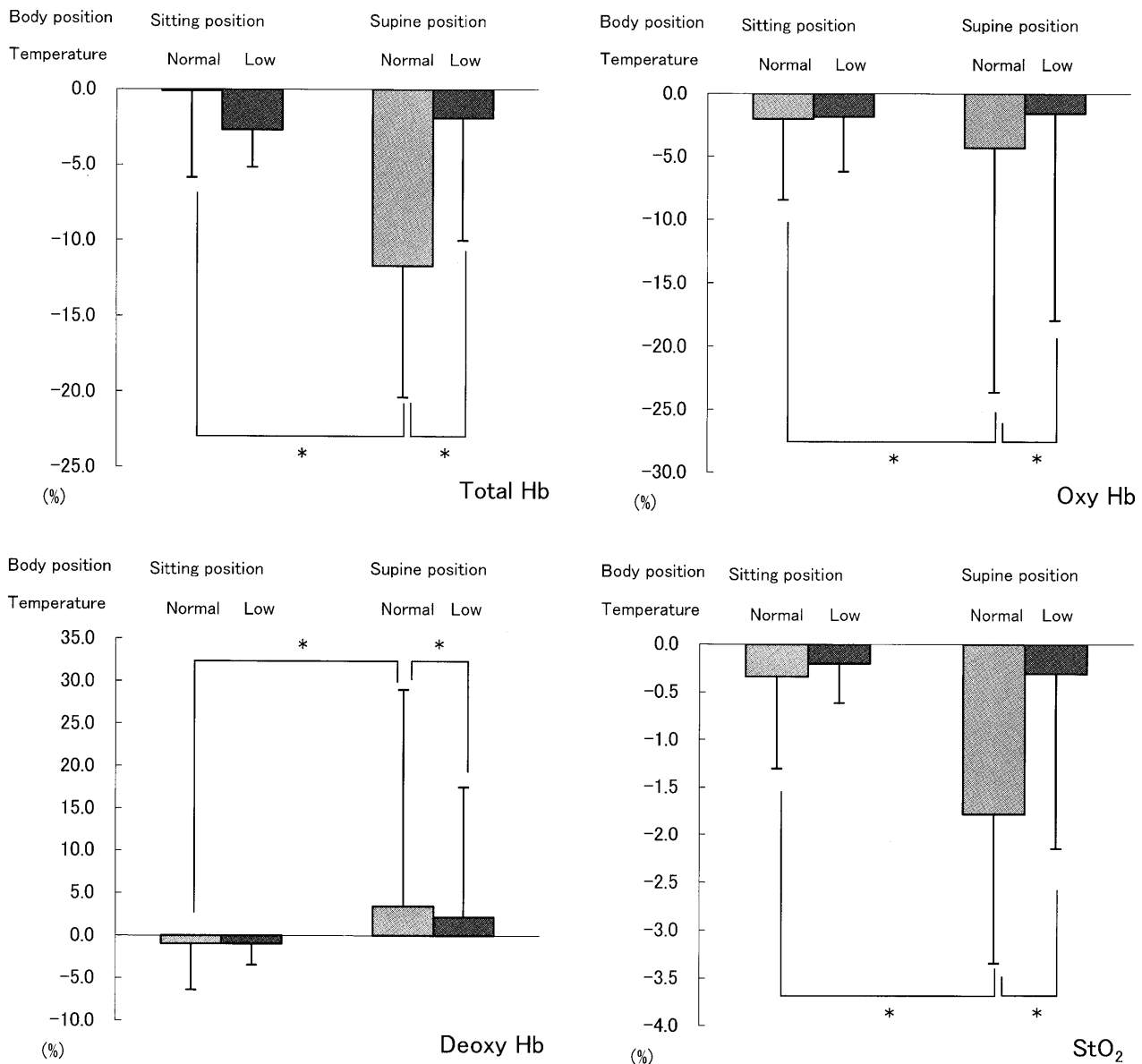
Fig. 2 The changing ratio of cerebral hemodynamics before and after standing. Two way ANOVA (Temperature×Body position during rest) and post-hoc (Tukey's HSD) reveal the differences in the changing ratio. *: $p < 0.05$.

rapid posture change.

The results of this study regarding the changing tendency of Oxy-Hb, total Hb, TOI and Deoxy-Hb agreed with those of previous studies (Colier et al., 1997; Madsen et al., 1998; Kusano et al., 2000; Kawaguchi et al., 2001; Tanaka et al., 2002). The circumvascular vessels change in response to the room temperature and become smaller under low-temperature conditions. The circulating blood volume is lower because the circumvascular vessels are smaller. Moreover, the blood supply to the cerebrum with the decline in blood pressure may be small under low temperatures, because the change of cerebral oxygenation parameters after standing was smaller than that under normal temperatures. In other words, the temperature of the room may exert a greater influence on cerebral oxygenation

compared to the body position change (sitting to standing or supine to standing).

2) *COP changes after standing*

Body sway after standing may be influenced by the resting position, that is, standing from a supine position rather than from a sitting position, regardless of the outside air temperature. As stated above, although the decrease of total Hb at low temperatures was small compared with that at normal temperatures, there were no significant differences in COP parameters between both room temperatures. Therefore, in healthy people, the temporary decrease in the volume of cerebral blood after standing, or the temporary decrease in blood pressure, may not be the main body sway factor that interrupts body posture.

Table 1   The results of two way ANOVA (temperature×Body position during rest) and post-hoc for each COP parameter

Parameters	unit	Normal temperature				Low temperature				Two way ANOVA						Post-hoc (HSD)	
		Sitting		Supine		Sitting		Supine		Temperature $(df=1, 17)$		Body position $(df=1, 17)$		Interaction $(df=1, 17)$		Body position	
		Mean	±SD	Mean	±SD	Mean	±SD	Mean	±SD	F	p	F	p	F	p	Normal	Low
1 Mean path length	(cm/s)	1.16	0.27	1.31	0.34	1.10	0.23	1.23	0.23	3.21	0.09	10.48	0.00 *	0.00	1.00	Sit<Sup	Sit<Sup
2 Root mean square	(cm)	0.94	0.26	1.05	0.25	0.88	0.19	1.00	0.14	1.08	0.31	5.73	0.03 *	0.01	0.94	Sit<Sup	Sit<Sup
3 Standard deviation of X-axis	(cm)	0.50	0.11	0.56	0.14	0.47	0.09	0.57	0.11	0.08	0.78	6.45	0.02 *	0.81	0.38	Sit<Sup	
4 Standard deviation of Y-axis	(cm)	0.78	0.18	0.88	0.23	0.74	0.18	0.80	0.16	2.06	0.17	2.85	0.11	0.17	0.69		
5 Standard deviation of X-axis velocity	(cm/s)	1.24	0.31	1.49	0.37	1.17	0.25	1.38	0.32	1.99	0.18	11.76	0.00 *	0.10	0.76	Sit<Sup	Sit<Sup
6 Standard deviation of Y-axis velocity	(cm/s)	1.27	0.28	1.56	0.32	1.19	0.24	1.51	0.26	1.11	0.31	21.49	0.00 *	0.25	0.62	Sit<Sup	Sit<Su
7 Area surrounding mean path length	(1/cm)	16.27	4.78	12.89	5.07	17.12	3.13	12.66	4.17	0.19	0.67	21.08	0.00 *	0.51	0.48	Sit > Sup	Sit > Sup
8 Area surrounding maximal amplitude rectangle	(cm²)	21.35	8.25	34.31	13.70	16.93	6.11	32.48	10.17	1.36	0.26	33.70	0.00 *	0.12	0.73	Sit<Sup	Sit<Sup
9 Mean velocity of X-axis	(cm/s)	0.69	0.18	0.75	0.22	0.64	0.15	0.70	0.14	1.23	0.28	4.45	0.05 *	0.01	0.91	Sit<Sup	
10 Mean velocity of Y-axis	(cm/s)	0.70	0.16	0.80	0.19	0.66	0.14	0.76	0.16	3.59	0.08	12.01	0.00 *	0.00	1.00	Sit<Sup	Sit<Sup
11 Root mean square of sway velocity	(cm/s)	1.79	0.39	2.16	0.48	1.68	0.33	2.06	0.38	1.95	0.18	24.76	0.00 *	0.01	0.93	Sit<Sup	Sit<Sup

Note) * $p < .05$, Sit: Sitting position during rest, Sup: Supine position during rest.

Table 2 Correlations between decreasing ratio of total Hb and COP parameters

| Parameters | unit | Decreasing ratio of total Hb | | | | Recovery time of total Hb after standing | | | |
| | | Normal temperature | | Low temperature | | Normal temperature | | Low temperature | |
		Sitting	Supine	Sitting	Supine	Sitting	Supine	Sitting	Supine
1 Mean path length	(cm/s)	0.09	0.19	0.09	−0.08	0.27	0.44	0.25	0.51*
2 Root mean square	(cm)	0.02	0.36	0.06	−0.22	0.32	0.56*	0.47*	0.33
3 Standard deviation of X-axis	(cm)	0.01	0.36	−0.24	0.11	0.43	0.40	0.23	0.24
4 Standard deviation of Y-axis	(cm)	0.04	0.33	0.13	−0.32	0.46	0.76*	0.47*	0.44
5 Standard deviation of X-axis velocity	(cm/s)	0.11	0.28	0.05	0.03	0.21	0.23	0.21	0.21
6 Standard deviation of Y-axis velocity	(cm/s)	0.23	0.38	0.15	−0.30	0.32	0.54*	0.11	0.02
7 Area surrounding mean path length	(1/cm)	−0.03	−0.46	0.15	0.30	−0.33	−0.34	−0.32	−0.23
8 Area surrounding maximal amplitude rectangle	(cm²)	0.16	0.40	−0.24	−0.31	0.21	0.21	0.21	0.22
9 Mean velocity of X-axis	(cm/s)	0.06	0.13	0.12	0.10	0.04	0.10	0.12	0.25
10 Mean velocity of Y-axis	(cm/s)	0.14	0.25	0.06	−0.13	0.21	0.30	0.00	0.42
11 Root mean square of sway velocity	(cm/s)	0.17	0.36	0.12	−0.17	0.03	0.43	0.50*	0.34

Note) The correlations with an asterisk were significant value ($p < 0.05$).

3) The relationships among cerebral oxygenation, blood pressure changes, and body sway after standing

It has been reported that blood pressure regulation in healthy people leads to blood pressure recovery approximately 20–30 sec after rapid standing (van Lieshout et al., 2001). This study supports these findings. Moreover, the total Hb in the cerebrum recovered approximately 20–30 sec after a temporary decrease with standing. This recovery corresponded to blood pressure recovery. There is a significant difference between recovery times in resting positions (i.e., sitting and supine positions), and was significantly longer in the supine position. Moreover, the total Hb markedly decreased after standing, and did not recover to the resting level after 1 min, except in the case of sitting at normal temperature conditions (Fig. 1). Tanaka et al. (2003) reported that patients with orthostatic intolerance did not recover their total Hb and oxy-Hb of cerebral blood after standing. Further, they suggested that the delay in the recovery of the cerebral oxygenation kinetics is closely related to chronic fatigue. The present results also showed the relationship between the recovery time of total Hb in the cerebrum and body sway parameters. Therefore, it is possible that the delay of blood pressure regulation influences body sway and largely depends on differences of the resting position (sitting and supine positions) rather than the outside air temperature.

4) Conclusion

In conclusion, cerebral oxygenation decreases temporarily just after standing in any condition, but may be affected by room temperature more than body position change. Body sway is related to the recovery time of total Hb after a temporary decrease with standing.

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