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Original Article

Relationship between postural control and respiratory movement during one-leg standing in healthy males

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Abstract. [Purpose] The purpose of this study was to examine the relationship between postural control and respiratory movements after identifying the characteristics of respiratory movements in different postural holding tasks. [Participants and Methods] The total trajectory length was measured using a stabilometer (G-620; Anima Company, Tokyo, Japan), while respiratory movements were measured using an expiratory gas analyzer (PowerMetz; Anima Company, Tokyo, Japan) during closed-leg and one-leg standing. Respiratory movements were characterized as tidal volume (TV), respiratory rate (RR), minute volume (MV), and metabolic equivalents (METs). [Results] The total trajectory length, METs, RR, and MV were higher in one-leg standing than in closed-leg standing. The rate of change in the total trajectory length during one-leg standing was positively correlated with the rate of change in TV and negatively correlated with RR. [Conclusion] The results suggest that postural control of one-leg stance holding is associated with changes in respiratory motion.

Key words: Postural control, Respiratory movement, One-leg standing

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INTRODUCTION

Since the upper body's center of gravity exists in the thorax, it is considered that there is a close relationship between respiratory motion and the position of the body's center of gravity[1)]. Previous studies have also shown that the characteristics of the thoracic movement change in different postures[2, 3)]. It has also been reported that the diaphragm, intercostal muscles, and transversus abdominis muscles have a dual function of stabilizing the trunk and respiratory movement[4)]. Furthermore, during unilateral lower limb loading and one-leg standing, the external and internal abdominal oblique and rectus abdominis muscle are active, indicating the activity of muscle groups involved in the respiratory movement[5, 6)]. In other words, it is predicted that the thoracic cage and respiratory muscles related to respiratory movement affect the trunk's control and play an important role in postural control. We believe that developing physiotherapy considering the relationship between postural control and respiratory movement may effectively evaluate and treat respiratory diseases. However, the mechanism showing the relationship between postural control and respiratory motion has not been fully elucidated for its utilization in clinical situations. Caron et al. stated that the center of gravity sway in the upright posture is reduced in the apneic state compared to free breathing[7)]. Hernandez et al. reported that voluntary breathing exercises alter the center of pressure (COP) variability during standing holding[8)]. They also clarified the relationship with postural control by analyzing different breathing tasks[8)]. Hamaoui et al. reported a more pronounced tendency for postural disturbance in breathing exercises with thoracic breathing than with abdominal breathing[9)]. These are selected tasks for respiration, and the relationship with postural control is clarified. However, no scattered reports analyze the changes in respiratory motion by selecting a task for postural control. By analyzing the relationship with a respiratory motion from the viewpoint of postural control, we believe that the relationship

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between the two can be clarified more deeply. Therefore, in this study, we analyzed basic data showing the relationship between respiratory motion and postural control from the viewpoint of postural control in healthy participants.

Therefore, this study aimed to clarify the characteristics of respiratory motion in different postural holds and examine the relationship between postural control and respiratory motion during the one-leg standing posture.

PARTICIPANTS AND METHODS

The participants were 15 healthy males (age: 19.7 ± 0.9 years, height: 173.5 ± 5.5 cm, body mass: 63.1 ± 8.0 kg, body mass index: 20.9 ± 2.4 kg/mg^2; mean ± standard deviation). Participants had no history of smoking, respiratory diseases or traumas, anamneses of thoracotomy or laparotomy, or obvious spinal or thoracic deformations. This study was approved by the ethics committee of the Sendai Seiyo Gakuin College and was performed according to the Declaration of Helsinki revised in October 2013 (approval no. 0315).

The examiner explained the measurement procedure to each participant, who was barefoot, wearing comfortable clothes, and present in a noise-free room. This study measured the total trajectory length using a stabilometer (G-620, Anima Company, Tokyo, Japan) for postural control. Respiratory movements were measured by an expiratory gas analyzer (PowerMetz, Anima Company, Tokyo, Japan) by measuring tidal volume (TV), respiratory rate (RR), minute volume (MV), and metabolic equivalents (METs). The two task conditions were closed-leg standing and one-leg standing. In both conditions, participants were instructed to gaze at an object at the same height as their line of sight, 2 m in front of them[6)]. In addition, both upper limbs were crossed in front of the chest to unify the positions of the upper limbs during measurement[6)]. In the closed-leg standing posture, the pelvis was kept horizontal at 0 cm between the medial edges of the feet[6)]. For one-leg standing, the limb to be measured was selected arbitrarily[10)]. The hip and knee joints of the free leg were slightly flexed, and the pelvis was kept horizontal[6)]. The order of the measurements was randomized, and the total trajectory length and respiratory motion were measured simultaneously for 60 s under each condition. The participants were placed in a resting standing position (distance between the medial edges of both feet: 20 cm) for 60 s while wearing the mask of the exhaled gas analyzer. The reason for the 60 s resting position was to ensure a consistent breathing condition prior to the task. The participants were then given a cue to begin the task posture (closed-leg or one-leg standing position). Measurements were started 5 s after the start signal to avoid the effects of initial shaking. The total trajectory length per minute and average values of TV, RR, MV, and METs were calculated. Failure to maintain a closed-leg or one-leg standing posture for 60 s was considered a failure, and the measurement was repeated. This study calculated the rate of change to capture the change in respiratory motion between the closed-leg and one-leg standing positions. The total trajectory lengths, TV, RR, and MV during one-leg standing were normalized to the total trajectory lengths, TV, RR, and MV during closed-leg standing. The percent change from the respiratory parameters during closed-leg standing to those in one-leg standing was calculated. The formula used was (parameters in one-leg standing position/parameters in closed-leg standing position) ×100 (%). The calculated data were defined as the total trajectory length and TV, RR, and MV change rates. A value greater than 100% indicated that the parameters increased in the one-leg standing position compared with the closed-leg standing position.

Statistical analysis was performed using the Wilcoxon signed-rank test to compare the total trajectory length, TV, RR, MV, and METs in the closed-leg and one-leg standing positions. In this study, the mean and 95% confidence intervals (95% CIs) of the total trajectory length, TV, RR, and MV change rates were also calculated to capture changes in the parameters in the one-leg standing position compared with the closed-leg standing position. Pearson's correlation coefficient was used to analyze the relationship between the total trajectory length change rate and the TV, RR, and MV change rates in the one-leg standing posture. The significance level was set at $p<0.05$. SPSS Statistics for Windows (version 24.0; IBM Corp., Armonk, NY, USA) was used to evaluate and analyze the data.

RESULTS

The total trajectory length, TV, RR, MV, and METs in the closed-leg and one-leg standing positions are shown in Table 1. The total trajectory length, RR, MV, and METs were significantly higher in the one-leg standing posture than in the closed-leg standing posture. There was no significant difference in the TV. Total trajectory length rate of change was 406.2 ± 119.4% (95% CI: 472.2–340.2), TV rate of change was 102.6 ± 11.2% (95% CI: 96.4–108.8), RR rate of change was 118.7 ± 20.6% (95% CI: 107.3–130.0), and MV rate of change was 120.4 ± 16.2% (95% CI: 111.5–129.4). A positive correlation was also observed between the total trajectory length and TV change rates ($r=0.67$, $p<0.01$) during one-leg standing. A negative correlation was observed between the rate of change in total trajectory length and that in RR during one-leg standing ($r=-0.55$, $p<0.05$). No significant correlation was found between the rates of change of total trajectory length and MV during one-leg standing.

DISCUSSION

This study clarified the differences in the characteristics of respiratory motion during postural control in the closed-leg standing and one-leg standing postures. Furthermore, the relationship between postural control and respiratory movement in

Table 1. Respiratory data in closed-leg and one-leg standing positions

	Closed-leg standing	One-leg standing
TV (L)	0.62 ± 0.20	0.62 ± 0.17
RR (breaths/min)	17.61 ± 3.91	20.48 ± 3.81**
MV (L/min)	10.28 ± 2.80	12.11 ± 2.70**
METs	1.71 ± 0.38	2.11 ± 0.44**
Total trajectory length (mm)	58.80 ± 13.74	226.89 ± 41.37**

Values are mean ± SD, n=15.
TV: tidal volume; RR: respiratory rate; MV: minute volume; METs: metabolic equivalents.
**Significant difference the closed-leg standing, p<0.01.

the one-leg standing posture was clarified. This study showed that total trajectory length, RR, MV, and METs increased in the one-legged standing position compared to the closed-leg standing position. Because of the reduction of the basal plane of support, the one-leg standing task is more difficult and requires a high degree of standing balance ability. As exercise intensity increases, TV and RR increase, oxygen uptake and carbon dioxide emissions also gradually increase. Compared to the closed-leg standing posture, the METs increased in the one-leg standing posture, suggesting that the exercise intensity was higher. Therefore, it is considered that the RR increased in the one-leg standing posture because the one-leg standing posture requires more oxygen uptake and carbon dioxide release than the closed-leg standing posture. It is suggested that the increase in RR affected the increase in MV. However, there was no significant difference between the closed-leg and one-leg standing positions for TV. Increasing the thoracic movement and muscle activity of the respiratory muscles is necessary to increase the TV. Nevertheless, the center of gravity shift also becomes larger, which may lead to more advanced postural control during one-leg standing. Therefore, it is suggested that stable one-legged standing corresponds to an adequate ventilatory response by increasing RR rather than increasing TV to perform stable one-legged standing. The results of this study suggest that when advanced postural control is required, the ventilatory response is commensurate with the exercise intensity by controlling RR.

In addition, as a new finding of this study, the TV change rate positively correlated with the total trajectory length during one-leg standing. Furthermore, the rate of change in RR during one-leg standing was negatively correlated with the total trajectory length. The TV and RR change rates in this study show the rate of change in respiratory motion in the closed-leg and one-leg standing positions, respectively. If the rate of change was greater than 100%, the respiratory data increased during one-leg compared with closed-leg standing. The total trajectory length is the total distance traveled by the COP during the measurement period. A longer total trajectory length indicated a larger COP swing. The results of this study indicate that an adequate ventilatory response in the one-legged standing posture requires an increase in RR. However, the rate of change in RR between closed-leg and one-leg standing was smaller in those who had a greater COP sway during one-leg standing. In other words, the participants had difficulty performing the dual tasks of maintaining balance in the one-leg standing position and increasing RR per exercise intensity. In contrast, the rate of change in TV between closed-leg and one-leg standing was greater for those with greater COP sway during one-leg standing. The rate of change in TV differed from the original ventilatory response in participants with a large COP swing during one-leg standing. In the one-leg standing posture, the greater the COP sway, the greater is the activity of the external oblique muscles[6]. Therefore, one possible factor is that those with greater COP sway always work on their abdominal muscles, thereby limiting thoracic dilation during respiratory motion. This results in unstable respiratory motion, which prevents a smooth increase in the respiratory rate, suggesting an anomalous ventilatory response that increases the per minute ventilation volume. Further studies are required to elucidate these underlying mechanisms. In contrast, participants with less COP sway and better balance ability performed ventilatory responses more smoothly with exercise intensity.

However, several issues remain to be addressed. First, sex, age, and the number of participants need to be considered, as 15 healthy adult males were included in the sample. We believe that the characteristics of respiratory motion in closed-leg and one-leg standing positions can be further elucidated by clarifying the possible baseline postures for the measurement procedure. To apply the system clinically, we validated it for respiratory diseases. Furthermore, because we could not measure thoracic movements, respiratory muscle activities, or dyspnea, additional data analysis is required to elucidate the mechanisms of postural control and respiratory movements.

This study investigated changes in the characteristics of respiratory motion in closed-leg and one-leg standing positions in healthy men. Furthermore, the relationship between postural control and respiratory movement in the one-leg standing posture was demonstrated. The total trajectory length, RR, MV, and METs were higher in the one-leg standing posture than in the closed-leg standing posture. It was also found that the greater the rate of change in the total trajectory length during one-leg standing, the greater the rate of change in TV and the smaller the rate of change in RR. Despite some limitations, we believe that the results of this study can serve as primary data for clarifying the relationship between postural control and respiratory motion.

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Conflicts of interestc

The authors declare that there is no conflict of interest regarding the publication of this article.

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