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Original Article

Characteristics of Sway in the Center of Gravity of Badminton Players

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Abstract. [Purpose] To clarify the characteristics of fluctuations in the center of gravity (CoG) of badminton players by comparing them between those with high and low performance levels. [Subjects] Eight male badminton players belonging to teams ranked among the top 3 at the All Japan Badminton Championships (high-level group) and 8 playing badminton for recreation in university clubs (low-level group) were studied. [Methods] CoG sway during two- and one (dominant and non-dominant)-leg standing with the eyes open and closed were recorded for 30 seconds, using a stabilometer. [Results] With their eyes open, the CoG was maintained near the center by the high-level group, while it was displaced in the direction of the dominant leg by the low-level group, with a significant difference between the two groups. In contrast, with the eyes closed, the trace length, sway area, and X- and Y-axis sway amplitudes were greater in the low- than in high-level group, with significant differences between the two groups. [Conclusion] These results support the usefulness of standing on the non-dominant leg with the eyes closed for the evaluation of badminton players' balance ability.
Key words: Badminton player, Center of gravity, Balance ability

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INTRODUCTION

To win a badminton game, players need to effectively deliver shots to disrupt opponent's readiness and dominate rallies. Previous studies of badminton games have reported the development of skills to deliver effective service and overhead strokes[1, 2)] performing smashes and the characteristics of upper-limb muscle activity in high-level badminton players[3)]. To disrupt an opponent's readiness by effectively delivering a shot, players need to instantaneously predict the spot where the shuttlecock will fall. In addition, increased leg strength for rapid movement to the spot where the shuttlecock falls[4)], and endurance to continue to move without decreasing the speed of movement[5, 6)] are important factors. It is also necessary for badminton players to move with a stable stance, while maintaining their own readiness. In this respect, balance ability is likely to markedly influence badminton player's performance levels.

Balance ability is associated with multiple factors, including visual information; for example, greater fluctuations in the center of gravity (CoG) are observed when standing with the eyes closed than with them open[7)]. There has also been a report suggesting that the CoG fluctuates less with increased lower-limb muscle strength[8)]. For postural stability, the appropriate contraction of lower-limb muscles based on sensory information obtained through the plantar surface is necessary[7)]. In short, balance ability is influenced by various factors, and balance improvement is crucial for skill advancement[9)]. With poor balance ability, postural stability decreases, consequently increasing the load on the lower limbs. In badminton, the physical burden has been reported to be marked[6)], and the rate of injury to be high[10–12)]. Therefore, it is important to reduce the risk of injury and increase the performance level by enhancing balance ability[13)]. In addition, to return a shuttlecock falling near the net, players lunge forward mainly by moving their dominant legs. This pattern of movement places a great burden on the muscles of the dominant leg, and is frequently executed in badminton games. It is likely to be a characteristic of badminton, as it is not observed in other sports. On the other hand, when the shuttlecock falls in the back section of the court, players jump off the dominant or non-dominant leg to return it on some occasions. In short, badminton is characterized by the execution of combined jumping and stepping movements, and, in this respect, badminton players' balance ability is likely to be under the influence of these combined movement patterns. However, badminton players' balance ability has not yet been fully examined.

Considering the importance of addressing this issue in terms of injury prevention and performance improvement, this study aimed to clarify the characteristics of CoG sway in badminton players by comparing them between players with high and low performance levels.

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SUBJECTS AND METHODS

Eight male badminton players (high-level group) belonging to teams ranked among the top 3 at the All Japan Badminton Championships and 8 playing badminton for recreation in university clubs (low-level group) were studied (Table 1). The leg on the side on which they gripped the racket was considered the dominant limb. All subjects were provided with explanations regarding the study's objectives and safety before obtaining their consent to voluntarily participate in the measurements. This study was conducted with the approval of the Research Ethics Committee of the Health Science University (approval number: 15).

CoG sway during two- and one (dominant and non-dominant)-leg standing with subject's eyes open and closed were recorded using a stabilometer (WBS-1NK, UNIMEX Inc.). To maintain the posture during measurement, the subjects were positioned in a space surrounded by white walls, and were instructed to fix their eyes on a target placed 2 m ahead at their eye level. In the comparison of the high- and low-level groups, the possible influence of the body height on CoG sway was considered insignificant, as there were no marked differences between the groups in height.

CoG sway in each stance was recorded at a sampling frequency of 100 Hz for 30 seconds. The obtained data were analyzed using sway analysis software (COG-samp Version 2.00) to calculate the following 5 items: (1) the total CoG sway path length, (2) CoG sway path length per unit area, (3) CoG sway area, (4) X- and Y-axis CoG sway amplitudes, and (5) mean X- and Y-axis center displacements. Item (1) is the total length of the CoG sway path during the 30 seconds of measurement, and (2) was obtained by dividing 1) by 3), (3) being the area surrounded by the circumference of the CoG sway path. (4) are the amplitudes of CoG sway in the horizontal and anteroposterior directions, and (5) indicates the mean center displacements in these directions, respectively. Furthermore, the positive and negative directions along the X-axis represent CoG displacements in the directions of the dominant and non-dominant legs, respectively, and those of the Y-axis represent the ventral and dorsal directions, respectively.

Student's t-test was used to examine the significance of differences between the high- and low-level groups. Significance was accepted for values of $p<0.05$.

Table 1. Mean age, years of playing badminton, and physical of the groups

Group	n	Age (years)	Years of playing badminton (years)	Height (cm)	Weight (kg)
High-level	8	19.3±0.7	11.8±1.4	173.0±5.7	65.0±5.2
Low-level	8	20.3±0.7	5.3±1.3	172.4±4.4	63.6±10.4

RESULTS

Table 2 shows the CoG sway when the badminton players stood on two legs with their eyes open and closed. With their eyes open, the CoG was maintained near the center by the high-level group, while it was displaced in the direction of the dominant leg by the low-level group, with a significant difference between the two groups ($p<0.05$). In contrast, with the eyes closed, significant differences were not observed for any item.

Table 3 shows the CoG sway of standing on the dominant leg with the eyes open and closed. With their eyes open, the CoG was maintained near the center by the high-level group, while it was displaced by 2 cm on average in the dorsal direction by the low-level group, with a significant difference between the two groups ($p<0.05$). In contrast, with the eyes closed, significant differences were not observed for any item.

Table 4 shows the CoG sway of standing on the non-dominant leg with the eyes open and closed. With their eyes open, significant differences between the 2 groups were not observed for any item. In contrast, with the eyes closed, the trace length, CoG sway area, and X- and Y-axis sway amplitudes were greater in the low- than in high-level group, with significant differences between the two groups ($p<0.05$).

DISCUSSION

This study compared CoG sway between badminton players with high and low performance levels, Our results show that when the badminton players stood on two or the dominant leg with their eyes open, the CoG was maintained

Table 2. CoG sway when players stood on two legs with their eyes open and closed

Standing on two legs	With eyes open			With eyes closed		
	High-level group	Low-level group	Significant difference	High-level group	Low-level group	Significant difference
Total CoG sway path (cm)	28.9±6.8	27.3±6.9		39.3±8.4	33.6±6.3	
Sway area (cm^2)	26.7±9.4	24.1±12.2		44.2±27.0	41.0±16.4	
Trace length per unit area (cm/cm^2)	1.2±0.3	1.3±0.3		1.1±0.4	0.9±0.3	
X-axis sway amplitude (cm)	15.3±3.5	14.4±3.9		22.6±6.6	17.9±4.4	
Y-axis sway amplitude (cm)	21.0±5.6	19.7±5.4		26.9±6.5	24.3±5.8	
Mean X-axis center displacement (cm)	−0.2±0.4	0.7±0.7	*	−0.1±0.5	0.6±0.9	
Mean Y-axis center displacement (cm)	−2.0±1.5	−3.5±1.6		−2.1±1.6	−3.2±2.3	

*: $p<0.05$

near the center by the high-level group, while it was displaced toward the dominant leg or in the dorsal direction by the low-level group and when standing on the non-dominant leg with the eyes closed, the total CoG trace length markedly increased in the low-level group.

It has been reported that postural maintenance when standing depends on muscle strength, sensory functions, such as the somatic and visual senses, and complex interactions of the spinal reflex and vestibular system[14]. For example, the otolith and semicircular canals in the inner ear (the vestibular system), sensory organs perceiving the positions of the head and body, are involved in postural maintenance[15]. Furthermore, as CoG sway are generally greater when standing with the eyes closed than open, the availability of visual information also markedly influences balance ability[16]. Rooks et al.[17] reported that the elderly's balance ability was improved by resistance training to enhance their muscle strength, suggesting that muscle strength is an important factor for postural maintenance. In agreement with this, the variations in CoG sway and displacements observed in the present study are likely to have reflected differences in the functions associated with the balance ability of the subjects; however, as none of the previous studies of badminton players compared the vision and sensory organs of subjects with different performance levels, it is difficult to discuss whether such functional differences led to the variations in CoG sway found between the high- and low-level groups in the present study. Also, considering that badminton players with high performance levels have been reported to have greater lower-limb muscle strength[4], it is possible that differences in the muscle strength influenced the variations in CoG sway between them. However, as Wolfson et al.[18] reported that improvement was not observed, even with increased muscle strength, the degree of such influences may not be marked. In short, variations in CoG sway due to differences in performance level are likely to be associated with differences in the central nervous activities, responsible for integrating sensory information and generating motor commands, although measurements of such performance-dependent differences in central nervous activity were not made in the present study. In some previous studies, experience-related functional changes were observed even in the spinal neurons with poor plasticity. The H-reflex is frequently used to evaluate stretch as a spinal reflex, and has been reported to show sport-specific changes. For example, the soleus H-reflex is greater in swimmers than in non-swimmers[19], while the H-reflex level is lower in professional ballet dancers than in general athletes[20]. The fact that long-term physical training leads to specific and plastic changes in the central nervous system is widely recognized, and, in this respect, we speculate that the variations in CoG sway observed in the present study may have been associated with experience-related differences in central nervous activity, even though measurements in relation

Table 3. CoG sway when players stood on the dominant leg with their eyes open and closed

Standing on the dominant leg	With eyes open			With eyes closed		
	High-level group	Low-level group	Significant difference	High-level group	Low-level group	Significant difference
Total CoG sway path (cm)	111.1±14.5	118.4±25.8		227.4±48.7	278.6±65.5	
Sway area (cm^2)	114.5±37.3	124.2±30.1		404.7±190.4	823.6±551.8	
Trace length per unit area (cm/cm^2)	1.0±0.3	1.0±0.1		0.6±0.1	0.5±0.2	
X-axis sway amplitude (cm)	74.5±7.3	78.2±13.6		145.4±26.3	163.8±17.2	
Y-axis sway amplitude (cm)	67.2±13.1	73.1±22.4		143.0±37.9	189.1±67.1	
Mean X-axis center displacement (cm)	0.6±0.6	0.6±0.5		0.8±0.9	1.2±0.8	
Mean Y-axis center displacement (cm)	−0.3±1.1	−2.3±1.7	*	−0.5±1.4	−1.6±1.8	

*: $p<0.05$

Table 4. CoG sway when players stood on the non-dominant leg with their eyes open and closed

Standing on the non-dominant leg	With eyes open			With eyes closed		
	High-level group	Low-level group	Significant difference	High-level group	Low-level group	Significant difference
Total CoG sway path (cm)	106.3±17.4	112.9±22.0		216.5±39.9	306.9±87.7	*
Sway area (cm^2)	111.8±32.1	119.9±47.7		355.1±133.2	683.8±347.3	*
Trace length per unit area (cm/cm^2)	1.0±0.3	1.1±0.4		0.7±0.2	0.5±0.2	
X-axis sway amplitude (cm)	70.9±14.9	75.8±13.5		140.8±28.3	178.8±35.7	*
Y-axis sway amplitude (cm)	64.9±12.2	69.4±16.5		134.2±31.7	208.3±79.6	*
Mean X-axis center displacement (cm)	−0.5±0.8	−0.9±0.5		−0.5±0.5	−0.5±0.9	
Mean Y-axis center displacement (cm)	−1.0±1.2	−1.7±1.7		−1.0±1.1	−1.7±0.8	

*: $p<0.05$

to this were not made.

In the present study, when badminton players stood on two or the dominant leg with their eyes open, the CoG was maintained near the center by the high-level group, while it was displaced toward the dominant leg or in the dorsal direction by the low-level group. In badminton, to return a shuttlecock falling near the net, players need to adopt a lunge position with the dominant leg forward. This pattern of movement places a greater burden on the dominant than on the non-dominant leg, and is a characteristic of badminton, which presumably results in CoG displacement toward the dominant leg. On the other hand, players need to maintain their CoG near the center of the body to be ready to move in any direction after returning the shuttlecock despite the lateral difference, and this may explain the result that the CoG was maintained near the center by the high-level group. In addition, the marked increase in the total CoG trace length by the low-level group when standing on the non-dominant leg with their eyes closed (without visual information) may also be regarded as an experience-related tendency. In general, afferent information plays an important role in the motor learning process, but its contribution significantly decreases after learning[21]. Therefore, assuming that there were marked differences in the experience of standing on the non-dominant leg between the high- and low-level groups, the lack of visual information may not have affected the former with such experience. This tendency may also be associated with an ability to appropriately return a shuttlecock falling near the non-dominant leg.

In badminton players instantaneously react to the shuttlecock and rapidly move to it throughout the game. The player's physical burden is marked[6], and the rate of injury is high[12]. In order to prevent injury, it is important to improve badminton players' balance ability, and therefore, establish methods to objectively evaluate it. Although the results of this study may be insufficient in some respects, they support the appropriateness of evaluating balance based on the characteristics of CoG sway.

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