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Original Article

Characteristics of lower limb muscle activity during upper limb elevation in badminton players

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Abstract. [Purpose] To clarify the characteristics of postural control in badminton players by examining their lower-limb muscle activity during upper-limb elevation. [Subjects and Methods] Fourteen badminton players and 14 non-players were studied. The subjects were instructed to perform an upper-limb elevation task in order to measure the activities of the biceps femoris and biceps brachii. [Results] When elevating the dominant hand, the mean biceps femoris integrated electromyogram showed markedly higher values in the player group, for the contralateral compared with the ipsilateral leg. Similarly, when elevating the dominant hand, the difference in the maximum integrated electromyogram response time between the ipsilateral and contralateral legs was significantly smaller in the players compared with non-players. [Conclusion] It may be possible to reduce the time needed to elevate the dominant hand by shifting lower-limb activity from the ipsilateral to the contralateral leg more quickly, while increasing the rate of rise in contralateral leg muscle activity.
Key words: Badminton, Muscle activity, Biceps femoris

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INTRODUCTION

Previous studies on badminton, focused on the development of skills to deliver effective service and overhead strokes[1, 2)], which are characteristic upper limb muscle activities in skilled badminton players when hitting a smash[3)], as well as other stroke-related issues. In badminton rallies, quick steps are essential for returning shuttlecocks at various speeds in all directions. To win a rally, increased leg strength is essential to rapidly move to the spot where the shuttlecock falls[4)], and for endurance to continue to move without decreasing the speed of movement[5)] are crucial. In addition, in order to effectively return a shuttlecock (to disrupt the opponent's readiness), it is necessary to deliver a stroke with a stable stance. In such a situation, players must instantaneously predict the spot where the shuttlecock will fall, and immediately begin to move toward it. In a study examining mechanisms by which badminton players instantaneously react and move toward the shuttlecock[6)], the excitability of spinal motor neurons was reduced by continuous play, suggesting that instantaneous leg movements to return a shuttlecock are based on brain signals.Therefore, individuals who continuously play badminton are likely to develop the ability to instantaneously move their legs because of balance improvement and reduced spinal motor neuron activity. In these previous studies, even the spinal cord, which is regarded as having poor plasticity, exhibited functional changes related to sports experience. Furthermore, according to a report on badminton players' predictive ability[7)], beginners are also able to appropriately observe the opponent (racket and forearm movement), but it is difficult for them to accurately predict the spots where the shuttlecock will fall due to insufficient experience-based perceptive abilities. Based on these findings, reducing the excitability of spinal motor neurons to promote the readiness of muscles and predict the trajectory of a returned shuttlecock

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Table 1. Subjects' age, badminton experience, and physical characteristics

Group	n	Age (years)	Badminton experience (years)	Height (cm)	Weight (kg)
Experienced	14	19.5 ± 1.3	10.5 ± 2.5	172.9 ± 5.5	64.4 ± 4.7
Inexperienced	14	21.1 ± 0.8	-	168.5 ± 6.3	60.2 ± 8.3

Mean ± standard deviation

based on the opponent's position may contribute to badminton players' ability to perform instantaneous movements. However, these reports only discussed these characteristics in early phases, and the phases during which movements are actually initiated have not yet been examined. Furthermore, the functions of individuals with disabilities requiring rehabilitation and of athletes who need to maintain an upright position have frequently been measured using stabilometers[8)]. However, while the sensory-dependence of static postural maintenance is analyzable, it is still difficult to examine the dynamic mechanisms of postural reflexes. The evaluation of dynamic postural control is likely to be useful to clarify the balance ability of not only athletes, but also individuals undergoing rehabilitation in more detail.

Therefore, to clarify the characteristics of postural control in badminton players, the present study examined lower limb muscle activity during upper limb elevation.

SUBJECTS AND METHODS

Fourteen male badminton players belonging to a team ranked number 1 at the All Japan Badminton Championships (experienced group) and 14 non-players (inexperienced group) were studied (Table 1). All subjects were provided with explanations of the objective and safety of this study and consented to voluntarily participate. This study was conducted with the approval of the Health Science University Research Ethics Committee (approval number: 13).

During task implementation, the subjects were instructed to initially adopt a relaxed standing position with both arms straight at the sides of the trunk, and subsequently elevate one arm overhead as soon as a light was turned on (Fig. 1). To measure muscle activity during upper limb elevation, AgCI electrodes were attached to the biceps femoris and biceps brachii on both sides. The electromyogram (EMG) signals were amplified (Myo System 1200; Noraxon, USA), and input into a computer using an A/D converter (Power Lab; ADInstruments Incorporated) at a sampling frequency of 4 kHz. On EMG measurement, web cameras (Buffalo Incorporated) at a photographing speed of 30 Hz were synchronized with the computer to confirm movements. Furthermore, the subjects were instructed to ensure that their elevated hands passed through a frame at the level of their shoulders. The frame was equipped with a photosensitive sensor at its end to synchronously input signals into Power Lab via a BNC cable at the moment when the subjects' hands passed through the frame. The upper limb elevation task was performed 3 times on both (dominant and non-dominant) sides.

The EMG data were integrated by a decay time constant of 0.02 (integrated EMG: IEMG) to identify the point of biceps brachii muscle activity initiation (Fig. 2). For this identification, the mean biceps brachii IEMG (for 0.1 seconds) in a relaxed standing position was calculated, and the moment when the value exceeded the mean + 2 standard deviations was regarded as the point of initiation. The period between this and the moment when the hand passed through the photosensitive sensor at the level of the shoulder (point of termination) was defined as the elevation phase for analysis. Subsequently, the times when the mean and maximum (IEMGmax) biceps femoris IEMG values appeared during the elevation phase were calculated. The rate of rise in the absolute biceps femoris EMG amplitude (RRE) was also calculated by smoothing IEMG values using a Gaussian filter at a segmental frequency of 4 Hz. After time-differentiating the smoothed signals, the initial peak amplitude was adopted as an RRE.

In this study, the hand holding the racket and the leg on that side were defined as the dominant limbs, and the hand not holding the racket and the leg on that side were defined as the non-dominant limbs.

The upper limb elevation task was performed 3 times on both the dominant and non-dominant sides, and means were adopted. The mean biceps femoris IEMG during the elevation phase was calculated as the rate of rise when the mean IEMG 0.1 seconds before the point of initiation was regarded as 100%. Furthermore, to normalize temporal axes, 0 and 100% were allocated to the points of initiation and termination, respectively. For data analysis, LabChart (ADInstruments Incorporated) and KyPlot 5.0 (KyensLab Incorporated) were used. All measurement values are shown as the mean ± standard deviation.

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

RESULTS

Table 2 shows the rate of rise in the mean biceps femoris IEMG and the IEMGmax appearance time. When experienced players elevated the dominant hand, the contralateral leg showed markedly higher values compared with the ipsilateral leg

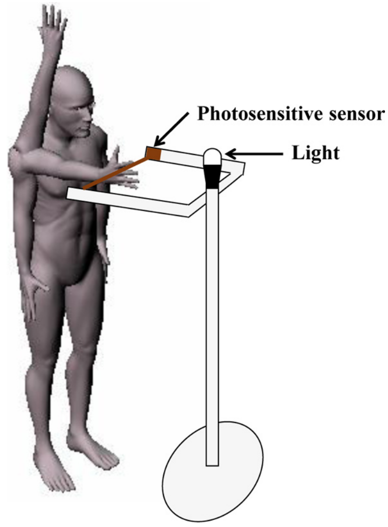

Fig. 1. Upper-limb elevation measurement scheme

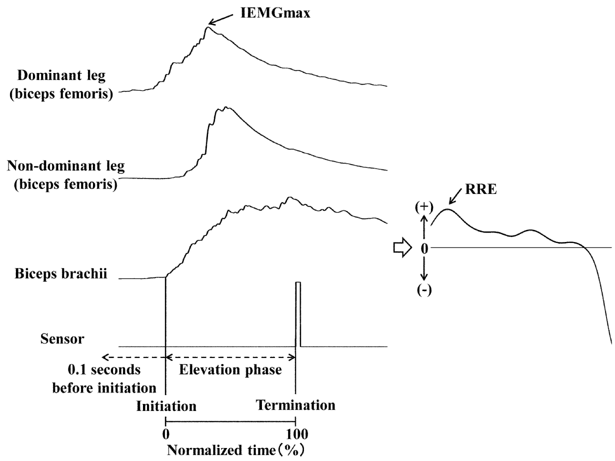

Fig. 2. Outline of analytical phases
Initiation: the mean biceps brachii IEMG (for 0.1 seconds) in a relaxed standing position was calculated, and the moment when the value exceeded the mean + 2 standard deviations was regarded as the point of initiation. Termination: the moment when the hand passed through the photosensitive sensor at the level of the shoulder was regarded as the point of termination. RRE: The rate of rise in the absolute biceps femoris EMG amplitude

Table 2. Rate of rise in the mean biceps femoris IEMG and the IEMGmax appearance time

Item	Group	When elevating the dominant hand			When elevating the non-dominant hand		
		Dominant leg	Non-dominant leg	Significant difference	Dominant leg	Non-dominant leg	Significant difference
Rate of rise (%)	Experienced	422.4 ± 308.2	835.3 ± 647.2	*	633.1 ± 753.8	616.3 ± 807.2	
	Inexperienced	365.8 ± 281.1	431.1 ± 265.6		384.6 ± 237.0	330.4 ± 187.5	
IEMGmax appearance time (%)	Experienced	36.0 ± 12.9	61.8 ± 23.1	*	64.4 ± 16.7	44.4 ± 20.4	*
	Inexperienced	25.2 ± 12.5	71.9 ± 14.8	*	66.9 ± 14.7	33.1 ± 6.6	*

*p<0.05

(p<0.05), while significant differences between the ipsilateral and contralateral legs were not observed in the non-players. When the non-dominant hand was elevated, there were no significant differences between the ipsilateral and contralateral legs in the experienced and inexperienced groups. A significant correlation was observed in both groups for the IEMGmax appearance time, as ipsilateral leg activity was followed by that of the contralateral leg when the dominant hand was elevated, and ipsilateral leg activity was also followed by that of the contralateral leg when the non-dominant hand was elevated (p<0.05).

Table 3 shows lateral differences in the biceps femoris IEMGmax appearance time, biceps brachii RRE, and duration of the elevation phase. Lateral differences in the biceps femoris IEMGmax appearance time when the dominant hand was elevated were markedly smaller in the experienced compared with the inexperienced group (p<0.05). In contrast, when the non-dominant hand was elevated, there were no significant differences between the groups. Similarly, when the dominant or non-dominant hand was elevated, there were no marked differences between the groups in the biceps brachii RRE. However, the duration of the elevation phase when the dominant or non-dominant hand was elevated was significantly shorter in the experienced compared with the inexperienced group (p<0.05).

DISCUSSION

Center of gravity sway is under the influence of various factors, and executing stable movements while maintaining an appropriate posture contributes to effective performance in various sports. Furthermore, reducing such sway and enhancing balance ability are essential for injury prevention[9]. For example, with poor balance ability, postural stability decreases, consequently increasing the level of loading on the lower limbs. Therefore, it is important for athletes to reduce the risk of

Table 3. Lateral differences in the biceps femoris IEMGmax appearance time, biceps brachii RRE, and duration of the elevation phase

Muscle	Item	When elevating the dominant hand			When elevating the non-dominant hand		
		Experienced	Inexperienced	Significant difference	Experienced	Inexperienced	Significant difference
Biceps femoris	Lateral differences in the biceps femoris IEMGmax appearance time (%)	26.3 ± 20.2	46.7 ± 15.0	*	28.7 ± 16.6	33.7 ± 11.1	
Biceps brachii	RRE (V.s/s)	0.51 ± 0.23	0.44 ± 0.19		0.50 ± 0.18	0.4 ± 0.17	
	Duration of the elevation phase (s)	0.22 ± 0.03	0.27 ± 0.06	*	0.22 ± 0.03	0.27 ± 0.05	*

*p<0.05.
RRE: The rate of rise in the absolute biceps femoris EMG amplitude

injury and increase the performance level by enhancing balance ability. The present study examined the characteristics of postural control by lower-limb muscles during upper limb elevation in badminton players.

When the dominant hand was elevated, the rate of rise in the mean biceps femoris IEMG in the contralateral leg showed markedly higher values in the experienced group compared with the ipsilateral leg. In contrast, there were no significant differences between the legs in the inexperienced group. When the non-dominant hand was elevated, differences were not observed in the experienced or inexperienced groups. When delivering strokes in badminton, the ipsilateral leg steps with the contralateral leg as an axis to simultaneously swing the racket. Therefore, during such badminton-specific movements in the experienced group, the contralateral leg may have been activated and stabilized as an axis to facilitate the dominant leg's movements when the dominant hand was elevated.

In the present study, a significant correlation was observed for the biceps femoris IEMGmax appearance time in both the experienced and inexperienced groups, as ipsilateral leg activity was followed by contralateral leg activity when the dominant hand was elevated, and ipsilateral leg activity was followed by contralateral leg activity when the non-dominant hand was elevated. This indicates the following pattern of muscle activity: when one hand is elevated, lower limb muscles on the same side are initially activated, followed by those on the other side. Furthermore, the difference in the IEMGmax appearance time between the ipsilateral and contralateral legs was more marked in the inexperienced compared with experienced groups when the dominant hand was elevated. In the latter, postural stability necessary for instantaneous movements may have been ensured by shifting lower limb activity from the ipsilateral to contralateral leg more quickly when the dominant hand was elevated. Similarly, while the RRE representing upper-limb muscle activity did not markedly vary, there were significant differences in the duration of the elevation phase between the 2 groups, confirming that the experienced group needed less time for upper limb elevation. Based on these results, it may be possible to reduce the time needed to elevate the dominant hand by shifting lower limb activity from the ipsilateral to the contralateral leg more quickly, while increasing the rate of rise in contralateral leg muscle activity.

The present study examined the dynamics of lower limb muscles during upper limb elevation, and demonstrated that experienced badminton players need less time to shift lower limb muscle activity from the ipsilateral to the contralateral leg when the dominant hand is elevated, with instantaneous increases in the rate of rise in contralateral leg muscle activity. It was suggested that these characteristics contribute to the ability of players to elevate their arms within a shorter period of time. In a previous study, continuous badminton training was shown to reduce the excitability of spinal motor neurons when returning shuttlecocks, suggesting the possibility of instantaneous leg movements based on brain signals to return a shuttlecock being promoted by reducing such excitability[6]. Thus, in the present study, badminton players may have been able to elevate their upper limbs more rapidly due to the influences of cerebral, rather than spinal, reflexes-The method used in the present study may also be useful to evaluate the dynamic postural control that plays an important role in badminton. For example, it is possible to evaluate the level of recovery of dynamic postural control from injury after a rest period using this method. Thus, more performance-focused evaluation may become feasible with dynamic postural control, as examined in the present study, added to conventional evaluation items, such as muscle strength and physical functions. As a future challenge, it may be necessary to further examine the usefulness of the system used in the present study to measure dynamic postural control as a method for evaluating the balance ability of athletes and individuals undergoing rehabilitation in clinical settings.

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