Paper : Biomechanics

Motion and EMG Analysis of Soccer-ball Heading for the Lateral Direction

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This study investigated head-trunk motion and muscle activity during soccer-ball heading for the frontal and lateral directions. Subjects were six soccer players who each had a soccer playing career of more than 10 years. Kinematic data were collected by three high-speed-video cameras. Head-rotation and trunk-twisting angles in the back-swing, forward-swing and follow-through phases were calculated. The electromyographic (EMG) activities of four muscles (the sternocleidomastoid, trapezius, external oblique abdominal and erector spinae muscle) were recorded bilaterally. The peak-time-lag, the lag between the greatest activation point of the right side and left side muscles, was calculated to evaluate the qualitative features of muscle activation. The volume of variation of head rotation angle in the backswing showed a significant difference between the two conditions (*P*<0.01). In the trapezius and external oblique abdominal muscles, the peak-time lag revealed a significant difference between the two conditions (*P*<0.01). From the results of this study, when skilled players headed the ball for the lateral direction, in the backswing, the head was rotated and the trunk was bent laterally to the opposite direction of the target. In the forward swing, the head was kept in position to see the target and ball in the same field of vision and the trunk was bent laterally toward the direction of target to impact the ball. The muscles surrounding the neck were activated to prepare for ball impact. Finally, in the follow through, back muscles were used to prevent the body from falling forward. We concluded that in the heading motion for the lateral direction, subjects move their trunk laterally while rotating their heads, and that in the heading motion for the frontal direction, subjects move their heads and trunks backward and forward. These results from this study are useful in coaching activities.

Keywords: heading motion, muscle activity, three-dimensional analysis

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1. Introduction

According to an announcement made by the FIFA (Federation International Football Association) in 2001, approximately 240 million people around the world play soccer, indicating that soccer is the most popular sport in the world. Unlike most sports, soccer does not allow its players, with the exception of goalkeepers, to use their hands, which are the most useful parts of the human body.

Heading is an action unique to soccer. In heading, a player intentionally strikes the ball using his head. Considering that this technique involves a significant impact to the head, a delicate part of the body, it is essential to instruct soccer players, particularly beginners, on how to head the ball properly. In terms of heading instruction, the following 3 points have traditionally been emphasized: 1) keeping the players' eyes on the ball; 2) making ball contact with the forehead; and 3) pulling arms back. However, these coaching points are based on experience only. In fact, few soccer instruction methods have been developed as a result of experimental data.

Most of the past research on heading has focused on the risk of head/brain injury (Tysvaer & Storli, 1981; Eaton, 2002; Master, et al., 2001; and Putukian, 2004) or the effect of ball impact on the brain (Schneider & Zernicke, 1988; Babbs, 2001; Kirkendall & Jordan, 2001; and Shewchenko, 2005).

As for studies concerned with motion analysis of heading, it has been reported that the motion of extension and the timing of switches between extension and flexion of the trunk affect ball velocity (Mawdsley, 1978) and that a reduction in velocity of the head immediately before the ball impact can contribute to the stabilization of the head and trunk (Burslem & Lees, 1988). In terms of studies on muscle activities in the motion of heading, it has been reported that sternocleidomastoid muscles contribute to the stabilization of the head and trunk and affect ball velocity (Tysvaer & Storli, 1989; Bauer, 2001) and that trapezius muscles play a role in reducing the velocity of the head after ball impact (Bauer, 2001).

All the previous studies, however, focused on the two-dimensional motion of heading the ball forward. No research has been conducted on characteristics of the three-dimensional motion of heading the ball in a direction which is not forward and on muscle activities during such a motion.

In this study, therefore, three-dimensional motion analysis and electromyographic (EMG) analysis of the motion of heading the ball (a) forward and (b) laterally were conducted. With the purpose of developing coaching methods for heading, this study aimed to clarify characteristics of the motion of heading the ball in a lateral direction and muscle activities during this motion.

2. Methodology

2.1. Subjects

The subjects of this study were 6 regular soccer players (height: 174.0±5.0cm; weight: 64.0±7.0kg; athletic career: 10.0±2.6 years), who belonged to a university soccer club. Written informed consent was obtained from all subjects after a detailed explanation of purpose of this study and of experiment procedures was given.

2.2. Experimental setup

The experimental setup is as shown in **Figure 1**. In this study, the following two heading motions were prescribed as experimental motions: a) the motion of heading the ball forward (frontal-direction condition); and b) the motion of heading the ball laterally (lateral-direction condition). In order to regulate the velocity and angle of the balls delivered to the subjects, a ball-supply device created by investigators

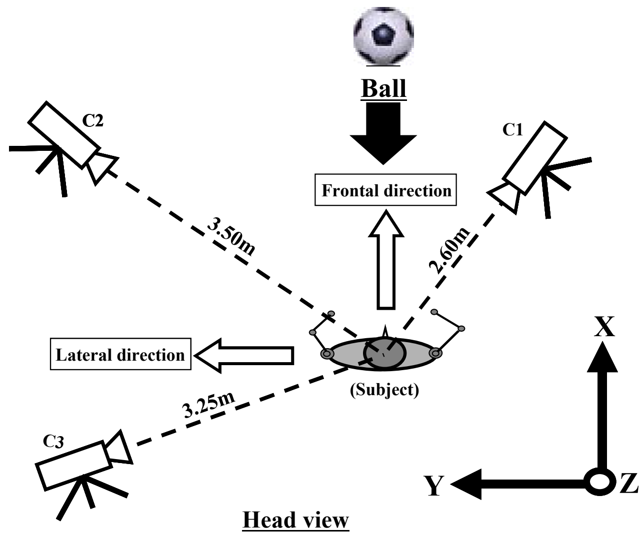

Figure 1 Experimental setup (head view)

for this purpose was used in the experiment. This device comprises 2 sloping rails set 5 meters above the ground. The experimenter places a ball on the rails so that it will fall towards the subject. The ball that was used (Fever nova, #5, Adidas) is officially authorized by the FIFA. During the experiment, the subjects were required to stand with their feet grounded parallel to the sagittal axis and fixed while heading the ball in a manner that would generate high velocity.

2.3. Kinematic data

2.3.1. Data acquisition method

Three high-speed video cameras, HSV-500c3 (NAC Image Technology Inc.), were used for the obtaining of motion data. The sampling frequency was set at 250 Hz. The video cameras were set approximately 1.5 meters above the ground in such a way that their optical axes would not overlap one another (see **Figure 1**). As shown in **Figure 2**, reflective markers were applied to 3 points on the head (vertex, and right and left tragions) and 6 points on the body (right and left acromiales, right and left tenth ribs, and right and left great trochanters) of each subject during the experiment. The movement of these markers was digitized utilizing a Frame-DIAS II (DKH Co. Ltd., Japan) and three-dimensional coordinates were calculated by DLT method. Using a Butterworth digital filter, data smoothing was conducted at a cutoff frequency of 5-15 Hz for the respective measurement points.

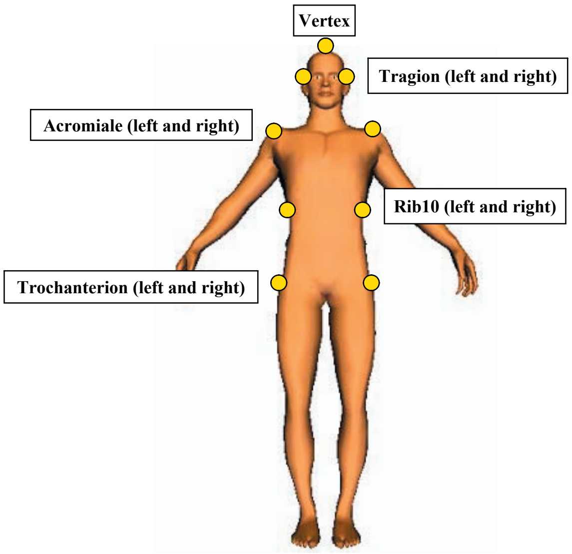

Figure 2 Points of landmarks on the head and body (Vertex, tragion, acromiale, rib10 and trochanterion)

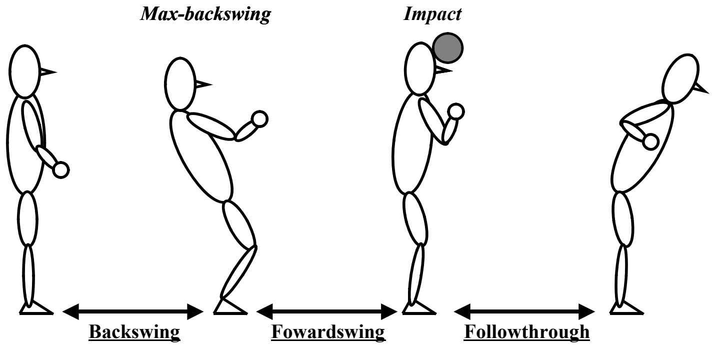

Figure 3 Selected events and phases of heading motion

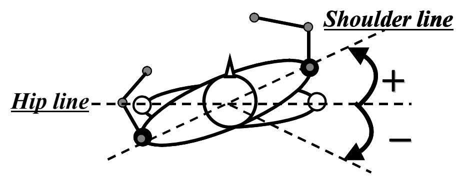

Figure 4 Head-rotation-angle on the horizontal plane

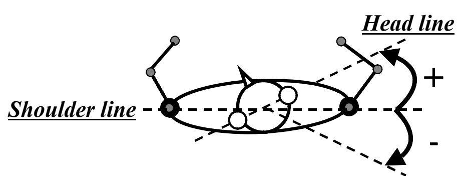

Figure 5 Trunk-twisting-angle on the horizontal plane

2.3.2. Phase division

A series of heading motions was decomposed into 2 events and 3 phases in this study (see **Figure 3**).

Events

- Maximum back-swing (Max-back-swing): A point at which the subject has bent his trunk backward to the maximum degree
- Impact: A point at which the subject makes ball contact with the head

Phases

- Back-swing phase: A phase which covers the period from the onset of the heading motion to the Max-back-swing
- Forward swing phase: A phase which covers the period from Max-back-swing to Impact
- Follow-through phase: A phase which covers the period after Impact

2.3.3. Angle definition

In order to assess the relationship between the head and the trunk, head-rotation angles (**Figure 4**) and trunk-twisting angles (**Figure 5**) were defined on the XY plane. The head-rotation angle was created by a line joining the right and left acromiales and a line joining the right and left tragions on the horizontal plane. Trunk-twisting angle was created by a line joining the right and left trochanters and a line joining the right and left acromiales. For the assessment of anteroposterior and bilateral trunk movements, a forward-bending angle (**Figure 6**) was defined on the XZ plane and side-bending-angle (**Figure 7**) was defined on the YZ plane. The forward-bending angle was made by the Z axis and a line connecting the midpoint of the right and left acromiales and the midpoint of the right and left trochanters on the sagittal plane.

Side-bending-angle was an angle made by the Z axis and a line connecting the midpoint of the right and left acromiales and the midpoint of the right and left trochanters on the frontal plane. In order to assess the movements of the head and the trunk during the heading motion, 2 angle parameters were calculated. As angles at the time of switching phases, head-rotation angle, trunk-twisting angle, forward-bending angle, and side-bending-angle at the Max-back-swing and Impact were calculated. Angle variations were differences between the maximum and the minimum of head-rotation angles, trunk-twisting angles, forward-bending angles, and side-bending-angles at back-swing and forward-swing.

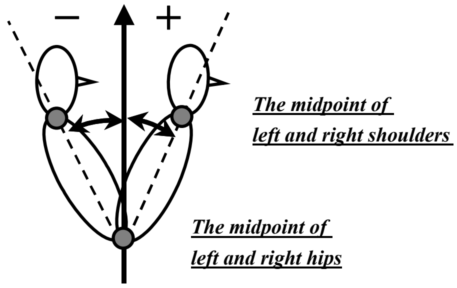

Figure 6 Foward-bending-angle on the sagittal plane

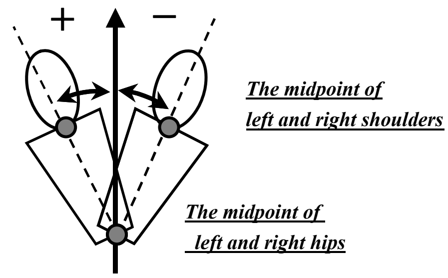

Figure 7 Side-bending-angle on the frontal plane

2.4. Electromyogram (EMG)

Myoelectric potential was obtained by placing Ag-AgCl disposal electrodes (Nihon Kohden Co.) at 2-cm intervals along the long axis of the muscle fiber. All EMG signals were recorded by a portable versatile bio amplifier, Polymate AP1124 (Teac Co. Ltd.), at a sampling frequency of 1 KHz and were loaded onto a personal computer. EMG was synchronized with the high speed video cameras by a trigger device created by investigators for this purpose. The test muscles in this study were the right and left sternocleidomastoid muscles, upper trapezius muscles, external abdominal oblique muscles, and erector spinae muscles (L5 level).

2.5. EMG analysis

After undergoing full-wave rectification, EMG signals were smoothed by second Butterworth low-pass filter at a cutoff frequency of 15-25 Hz (zero phase sift). The peak-times and onset-times of the respective test muscles were calculated for the sake of evaluating qualitative muscle activity. Peak-time indicated the time when each muscle showed the highest myoelectric potential. Onset-time was calculated utilizing the method created by Di Fabio (1987) and Kudoh & Ohtsuki (1998); that is, myoelectric potentials during 200 msec in the resting state were averaged to calculate background activity (BGA). Onset-time was defined as the point at which the myoelectric potential surpassed BGA for a period of 25 msec or longer.

In order to evaluate the effect of quantitative and qualitative muscle activity of the respective test muscles on joint stability, peak-time lags and onset-time lags of the respective muscles were calculated. This indicated time differences of peak-times and onset-times of the right and the left points of each pair of the test muscles.

2.6. Statistical analysis

All obtained figures were shown as average values and standard deviation (SD). A risk rate of less than 5% was taken as significant. Phase switching angles, variations of back-swing angles and forward-swing angles, and peak-time lags and onset-time lags of the respective muscles were statistically processed with the use of paired t-test ($\alpha = 0.05$).

3. Results

3.1. Motion analysis

Table 1 shows averaged values and SDs of head-rotation angles, trunk-twisting angles, forward-bending angles, and side-bending-angles for back-swing and forward-swing. **Table 2** shows the averaged values and SDs of head-rotation angles, trunk-twisting angles, forward-bending angles, and side-bending-angles at the Max-back-swing and Impact. Ball velocities obtained from coordinate data were as follows: Frontal-direction condition, before the Impact: (5.8±0.2m/sec), after the Impact (7.4±1.1m/sec); Lateral direction condition, before Impact: (5.6±1.7m/sec), after Impact (9.7±3.0m/sec). There was no statistically significant difference between the angle conditions in terms of ball velocities before and after Impact.

3.1.1. Head-rotation angle

Figure 8 shows typical changes in head-rotation angle in the frontal-direction condition and the lateral direction condition. In the frontal-direction condition, the head remained in the resting position (2.2±2.2 degrees, -2.2±3.5 degrees) throughout the back-swing and the forward-swing up to the Impact

Table 1 The averaged (S.D.) values of range of motion of head-rotation-angle, trunk-twisting-angle, forward-bending-angle and side-bending-angle and in the Back-swing and Forward-swing

		Frontal direction	Lateral direction
Head-rotation-angle	Backswing	2.16(2.19)	9.05(3.66) **
	Fowardswing	-2.91(3.53)	-1.68(3.63)
Trunk-twisting-angle	Backswing	3.45(2.48)	2.54(1.50)
	Fowardswing	-3.29(2.94)	-4.30(4.33)
Foward-bending-angle	Backswing	-17.03(13.14)	4.31(1.80) **
	Fowardswing	31.65(4.62)	13.57(8.47) **
Side-bending-angle	Backswing	2.54(4.99)	-20.54(9.44) **
	Fowardswing	2.96(5.57)	14.86(18.62)

** shows significant difference (p<0.01)

Table 2 The averaged (S.D.) values of phase-switching-angle of head-rotation-angle, trunk-twisting-angle, forward-bending-angle and side-bending-angle at the Max-backswing and Impact

		Frontal direction	Lateral direction
Head-rotation-angle	Max-backswing	4.26(3.16)	11.38(3.94) *
	Impact	2.87(1.94)	16.79(6.17) **
Trunk-twisting-angle	Max-backswing	4.19(2.96)	4.56(3.38)
	Impact	4.79(3.69)	4.89(3.78)
Foward-bending-angle	Max-backswing	-30.29(12.74)	-8.16(0.91) **
	Impact	8.02(6.24)	10.47(0.91)
Side-bending-angle	Max-backswing	1.94(3.71)	-23.40(8.00) **
	Impact	4.15(4.47)	-2.42(4.49) *

* shows significant difference (p<0.05)
** shows significant difference (p<0.01)

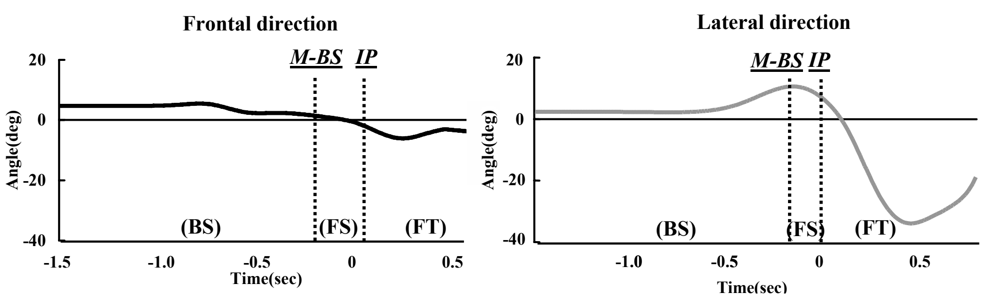

Figure 8 Typical change of Head-rotation-angle on the horizontal plane
BS : Back-swing, FS : Forward-swing, FT : Followthrough, *M-BS* : Max-backswing, *IP* : Impact
Impact was standardized on the time scale.

(2.9±1.9 degrees). In the lateral-direction condition, the head rotated to the left (9.1±3.7 degrees) in the back-swing and maintained this posture (-1.7±3.6 degrees) in the forward-swing up to Impact (16.8±6.2 degrees). As a result of statistical analysis, significant difference was noted between the frontal direction condition and the lateral direction conditions in terms of head-rotation angle variation (p<0.01), head-rotation angle at the Max-back-swing (p<0.05), and head-rotation angle at Impact (p<0.01).

3.1.2. Trunk-twisting angle

Figure 9 shows typical changes in the trunk-twisting angle in the frontal direction condition and in the lateral direction condition. In the frontal direction condition, the trunk remained in the resting position, being at 3.5±2.5 degrees in the back-swing, 4.3±3.2 degrees at the Max-back swing, -3.3±2.9 degrees in the forward-swing, and 4.8±3.7 degrees at the Impact. In the lateral direction condition, the trunk-twisting angles were 2.5±1.5 degrees in the back-swing, 4.6±3.4 degrees at the Max-back-swing,

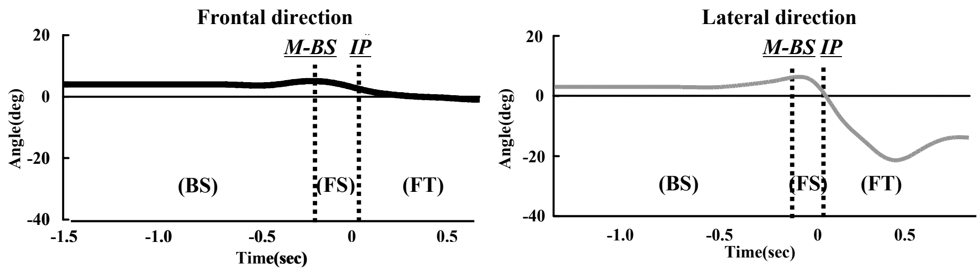

Figure 9 Typical change of Trunk-twisting-angle on the horizontal plane
BS : Back-swing, FS : Forward-swing, FT : Followthrough, *M-BS* : Max-backswing, *IP* : Impact
Impact was standardized on the time scale.

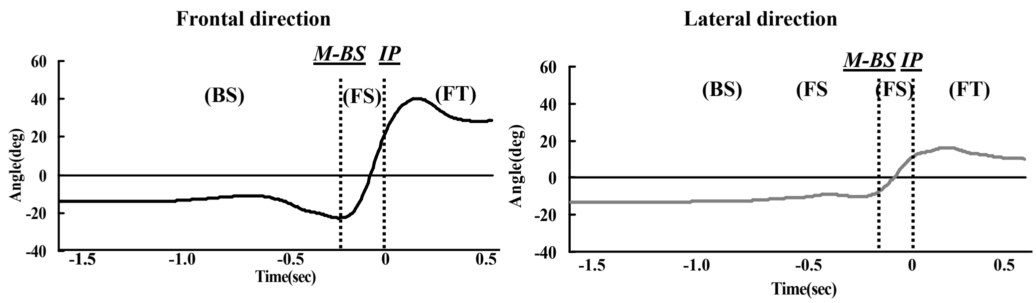

Figure 10 Typical change of Head-rotation-angle on the horizontal plane
BS : Back-swing, FS : Forward-swing, FT : Followthrough, *M-BS* : Max-backswing, *IP* : Impact
Impact was standardized on the time scale.

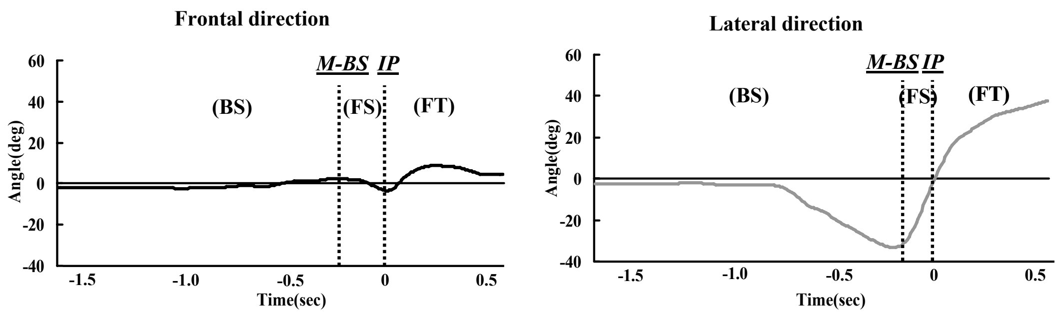

Figure 11 Typical change of Side-bending-angle on the frontal plane
BS : Back-swing, FS : Forward-swing, FT : Followthrough, *M-BS* : Max-backswing, *IP* : Impact
Impact was standardized on the time scale.

-4.3±4.3 degrees in the forward swing, and 4.9±3.8 degrees at Impact, being similar to those in the frontal direction condition. In the phase of follow-through, a distinctive change in trunk-twisting angle was observed in the lateral direction condition (see **Figure 9**).

3.1.3. Forward-bending angle

Figure 10 shows typical changes in the forward-bending angle in the frontal-direction condition and in the lateral direction condition. In the frontal direction condition, the trunk bent backward significantly in the back-swing (-17.0±13.1 degrees) up to the Max-back-swing (-30.3±12.8 degrees), and then rapidly bent forward in the forward-swing (31.7 ±4.6 degrees) up to Impact (8.0±6.2 degrees). In the lateral direction condition, the trunk remained in the resting position in the back-swing (4.3±1.8 degrees), at the Max-back-swing (-8.2±0.9 degrees), and in the forward-swing (8.6±8.5 degrees) up to the Impact (10.5±0.9 degrees). This result indicates that the trunk bent both forward and backward significantly in the frontal direction condition and bent forward slightly in the lateral direction condition during a series of motions.

3.1.4. Side-bending angle

Figure 11 shows typical changes in the side-bending angle of the trunk in the frontal direction condition and in the lateral direction condition. In

Table 3 The averaged (S.D.) values of Onset-time-lag of four muscles

	Frontal direction	Lateral direction
SCM	0.03(0.04)	0.02(0.03)
TR	0.03(0.04)	0.04(0.04)
EO	0.01(0.02)	0.02(0.03)
ESM	0.02(0.03)	0.03(0.04)

SCM : Sternocleidomastoid muscle, TR : Trapezius muscle, EO : External oblique abdominal muscle, ESM : Erector spinae muscle (L5)

Table 4 The averaged (S.D.) values of Peak-time-lag of four muscles

	Frontal direction	Lateral direction
SCM	0.05(0.04)	0.14(0.08) **
TR	0.12(0.20)	0.14(0.15)
EO	0.04(0.03)	0.16(0.09) **
ESM	0.04(0.05)	0.20(0.27)

** shows significant difference (p<0.01)
SCM : Sternocleidomastoid muscle, TR : Trapezius muscle, EO : External oblique abdominal muscle, ESM : Erector spinae muscle (L5)

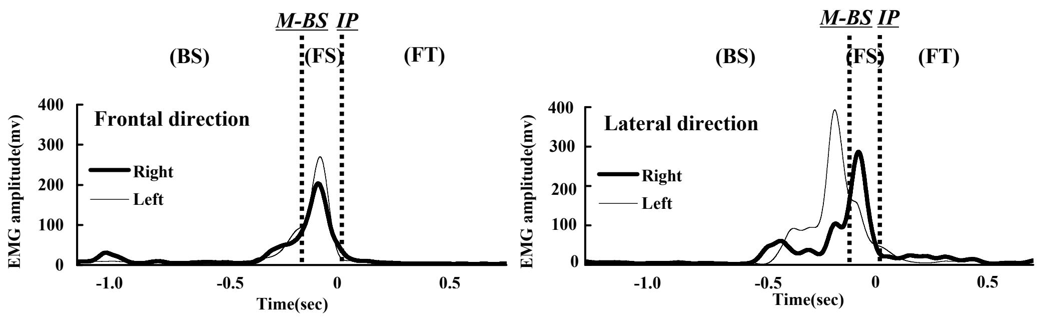

Figure 12 Typical change of rectified and filtered EMG of sternocleidomastoid muscle
BS : Back-swing, FS : Forward-swing, FT : Followthrough, *M-BS* : Max-backswing, *IP* : Impact
Impact was standardized on the time scale.

the frontal direction condition, the trunk did not bend laterally in the back-swing (2.5±5.0 degrees), at the Max-back-swing (1.9±3.7 degrees), or in the forward swing (3.0±5.6 degrees) up to Impact (4.2±4.5 degrees). In the lateral direction condition, the trunk bent to the right (-20.5±9.4 degrees), as viewed from the back, up to the Max-back-swing (-20.4±8.0 degrees) and then bent to the left (14.9±18.6 degrees) in the forward swing up to Impact (-2.5±4.5 degrees). This result indicates that, during a series of motions, the trunk bent slightly laterally in the frontal direction condition and bent significantly to the right and to the left before Impact in the lateral direction condition.

3.2. Muscle activity

Table 3 and **Table 4** show average values and SDs of the onset-time lags and peak-time lags of the sternocleidomastoid muscles, trapezius muscles, external abdominal oblique muscles and erector spinae muscles. Regarding onset-time lags, there was no statistically significant difference between the angle conditions. Regarding peak-time lags, there was a statistically significant difference (p<0.01) between the angle conditions.

3.2.1. Activity of muscles around the neck

Figure 12 shows typical changes in the EMG of sternocleidomastoid muscles, while **Figure 13** shows typical changes in the EMG of trapezius muscles. The sternocleidomastoid muscles of all the subjects reached peak values before Impact in both conditions. Regarding peak-time lags, there was a statistically significant difference (p<0.01) between the experimental conditions. In terms of the trapezius, all the subjects reached peak values before Impact. Regarding both onset-time lag and peak-time lag, there was no significant difference between the angle conditions.

3.2.2. Activity of trunk muscles

Figure 14 shows typical changes in the EMG of the external abdominal oblique muscles. **Figure 15** shows typical changes in the EMG of the erector spinae muscles (L5 level). Peak values of the external abdominal oblique muscles of the majority of subjects appeared before Impact in the frontal direction condition. In the lateral direction condition, the EMG of 5 of the 6 subjects exhibited a bimodal curve, showing marked muscle activity at the Max-back-swing and after Impact (see **Figure 14**).

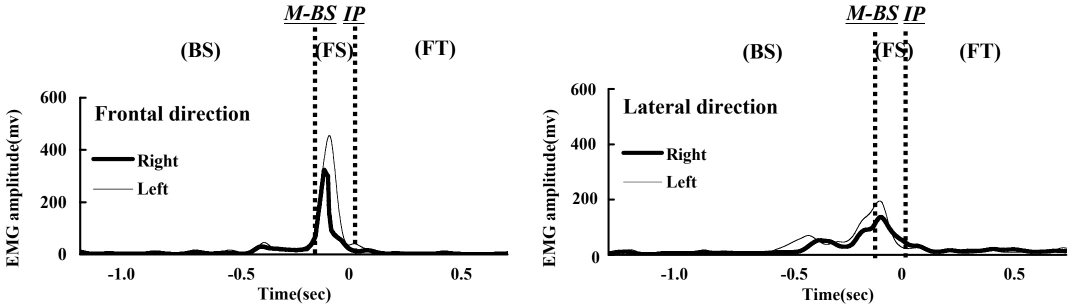

Figure 13 Typical change of rectified and filtered EMG of trapezius muscle
BS : Back-swing, FS : Forward-swing, FT : Followthrough, *M-BS* : Max-backswing, *IP* : Impact
Impact was standardized on the time scale.

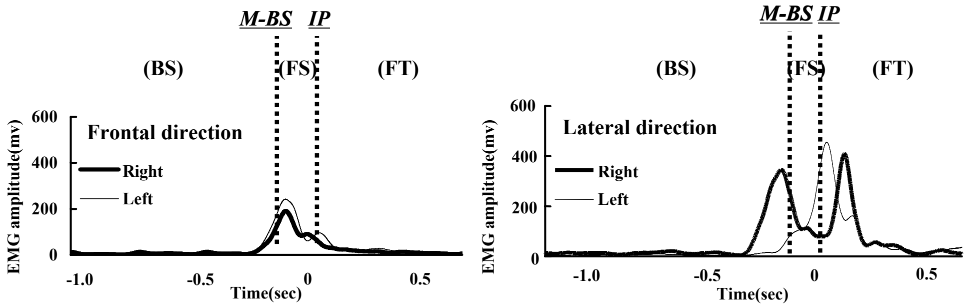

Figure 14 Typical change of rectified and filtered EMG of external oblique abdominal muscle
BS : Back-swing, FS : Forward-swing, FT : Followthrough, *M-BS* : Max-backswing, *IP* : Impact
Impact was standardized on the time scale.

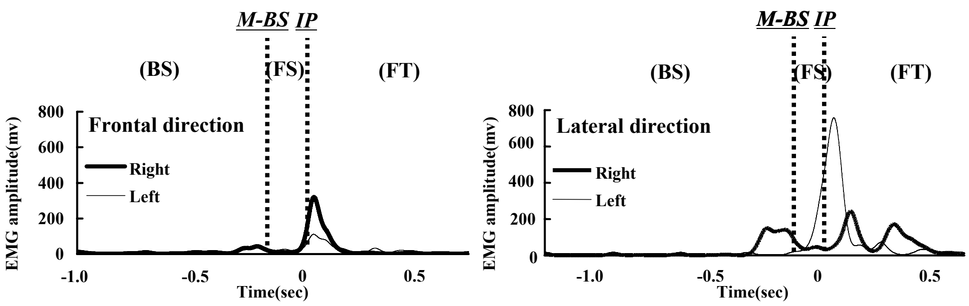

Figure 15 Typical change of rectified and filtered EMG of erector spinae muscle (L5)
BS : Back-swing, FS : Forward-swing, FT : Followthrough, *M-BS* : Max-backswing, *IP* : Impact
Impact was standardized on the time scale.

Regarding peak-time lags of the external abdominal oblique muscles, there was a statistically significant difference ($p<0.01$) between the angle conditions. Peak values of the erector spinae muscles of all subjects were obtained immediately after Impact. There was no statistically significant difference between the angle conditions in terms of peak-time lags and onset-time lags of the erector spinae muscles.

4. Discussion

4.1. Relation between the head and the trunk on the back-swing phase

The back-swing is a phase of motion which is seen in various sports as athletes engage in activities such as pitching and kicking (Elliot, et al., 1988; Burden, et al., 1998). The back-swing motion serves to generate an appreciable amount of time and space for subsequent forward-swing motion, playing the role of preparatory action for the main action. As a result of the analysis of back-swing motion, a statistically significant difference was noted between the 2 angle conditions in terms of variations of head-rotation angles, forward-bending angles, and of side-bending-angles on the back-swing phase and head-rotation angles, forward-bending angles, and side-bending-angles at Max-back-swing (**Table 1** & **2**). This suggests that the head and the trunk significantly bent backward without rotation in the motion of heading the ball forward, and that the head rotated in the direction of the target while the trunk bent significantly in the direction opposite to the target without twisting in the motion of heading the ball laterally. Analysis of EMG of the sternocleidomastoid muscle shows that there was a significant difference between the 2 conditions in terms of peak-time lag (**Table 4**). Regarding EMG waveform in the lateral direction, left peak values of all the subjects were seen during the back-swing motion (see **Figure 12**). In the analysis of the EMG of the external abdominal oblique muscles, there was a significant difference between the 2 conditions in terms of peak-time lag (**Table 4**). In the lateral direction condition, the EMG of 5 of the 6 subjects showed a bimodal waveform (see **Figure 14**). Motion analysis showed a substantial degree of forward-bending motion with little trunk-twisting motion. The right external abdominal oblique muscle has the function of twisting the body to the left and of bending the lumbar spine to the right. Considering this, it was suggested that the trunk bent in a direction opposite to the target without twisting in the back-swing in the motion of heading the ball laterally. These features of the motion of heading the ball laterally are supposed to have been attributable to the following 2 points: 1) In the motion of heading the ball laterally, the player was required to rotate his head in the direction of the target through sternocleidomastoid muscle activity and to watch the oncoming ball and the target simultaneously in order to control ball direction. 2) In order to secure the back-swing motion as a preparatory motion for the main motion, the player significantly bent his trunk in the direction opposite to the target through activity of the external abdominal oblique muscle of the side opposite to the target.

4.2. Motion and muscle activity up to ball impact

In head motion analysis, no statistically significant difference was revealed in variations of head-rotation angles (**Table 1**), while there was significant difference in head-rotation angles (**Table 2**). These results suggest that in the motion of heading the ball laterally, the player significantly rotated his head in the direction of the target in the back-swing and impacted the ball while keeping his head in the same position in order to watch the target during the forward-swing. In trunk motion analysis, there was a statistically significant difference between the 2 conditions in terms of forward-bending angle variations in the forward swing and side-bending angles at Impact, but not in terms of trunk-twisting angle variations nor trunk-twisting angles at Impact (**Table 1** & **2**). This result indicates that the trunk did not twist in the motion of heading the ball laterally just as in the motion of heading the ball forward. Based on the results of two-dimensional motion analyses in a previous study, which have shown that the motions of the head and the trunk contribute to the acceleration of ball velocity (Bauer, et al., 2001), we initially thought that moving the head in conjunction with the trunk in the same direction would contribute to increasing reduced body mass and producing larger exercise volume in the motion of heading the ball laterally as well. Though this hypothesis has been disproved, the analysis results of this study clearly offer new insight into the study of the head and the trunk through three-dimensional analyses.

In EMG analysis, the sternocleidomastoid muscle showed a statistically significant difference in terms of peak-time lag, while the trapezius muscle did not (**Table 4**). The appearance of these features of activity in the muscles around the neck can be explained as follows: In the motion of heading the ball laterally, the motion of a sternocleidomastoid muscle on the side that was opposite to the target was thought to contribute to maintenance of the position of the head which had rotated in the direction of the target during the back-swing. Also, synchronized motion of the right and left trapezius muscles were thought to contribute to the stabilization of the head and trunk in preparation for ball impact. The role of the sternocleidomastoid and trapezius muscles in the preparation for ball impact has been demonstrated in previous studies (Burslem & Lees, 1988; Bauer, et al., 2001; Schwchenko, et al., 2005). In terms of trapezius muscle activity for heading the ball laterally, while the analysis results in this study conform to those in previous studies, the specific activity of the sternocleidomastoid muscles was observed in this study and is here offered as new insight.

4.3. Characterstics after ball impact

From the average change of body trunk angular velocity (frontal-direction condition: -38.2± 9.6m/sec^2; lateral-direction condition: -19.6± 12.4m/sec^2) during the 0.5msec after Impact, it was affirmed that the motion of heading the ball forward or laterally was characterized by a rapid reduction in velocity of the head and the trunk after ball impact. On the phase of follow-through, trunk muscle groups such as the external abdominal oblique muscles and erector spinae muscles showed characteristic muscle activity. The EMG waveform of the right external abdominal oblique muscles in the lateral-direction condition showed bimodal activity (see **Figure 14**). The first wave crest line is thought to have contributed to back-swing motion, while the second crest line is thought, from comparison, to change in angular velocity of the upper body to have contributed to a reduction in velocity of the trunk. The erector spinae muscle activity of all subjects showed peak value on the follow-through phase in both angle conditions (see **Figure 15**). There was no statistically significant difference between the angle conditions in terms of peak-time lag (**Table 4**). These results may be explained as follows: In the motion of heading the ball laterally, the spine extends through the activity of the external abdominal oblique muscle of the side that is opposite to the direction to the target and the synchronized activity of the erector spinae muscles which functionally contribute to the extension and side flexion of the spine, and consequently the upper body moves naturally after ball impact. Considering that these activities of the dorsal muscle group of the body trunk at the end of motion can be observed in other sports (Watkins, et al., 1996; Hirashima, et al., 2002) and are supposed to play a role in the completion of the motion (Pink, et al., 1993), it is speculated that these muscles play a similar role in the motion of heading.

5. Conclusion

In this study, phase-based characteristics of three-dimensional dynamic states of the head and the trunk and of activities of muscles of the trunk and around the neck in the motion of heading the ball laterally were clarified as follows:

● **Back-swing**

Because of a need to watch the oncoming ball and the target to which the ball should be impact, the head rotated in the direction of the target through unsynchronized activities of right and left sides of the sternocleidomastoid muscles. Meanwhile, in order to generate larger back-swing motion without twisting or bending forward, the trunk bent in the direction opposite to the target through activity of the external abdominal oblique muscle of the side opposite to the direction of the target.

● **Forward swing**

The head maintained its posture after rotating in the direction of the target through the activity of the sternocleidomastoid muscle on the same side as the target, while synchronized activity of trapezius muscles served to stabilize the head and the trunk in preparation for ball impact. Without twisting or bending forward, the trunk bent in the same direction as the target through activity of the external abdominal oblique muscle on the same side as the target.

● **Follow-through**

Through the synchronized activity of the external abdominal oblique muscle on the side opposite to the target and the erector spinae muscles, the trunk reduced velocity rapidly after ball impact in order to prevent the upper body from falling and to complete the action.

The characteristics of the motion of heading a ball laterally and the muscle activity accompanying the motion have been clarified in this study, and it is expected that this will contribute to the creation of new coaching methods in the future.

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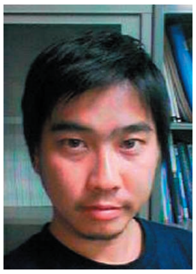

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