INVESTIGATION OF SEGMENTAL CHARACTERISTICS IN POWERFUL SOCCER HEADING

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The aim of this study was to investigate segmental characteristics of the jumping header in soccer, with prime focus on the arms, legs and the head. To accomplish this a standardization of the skill was also created. Five skilled subjects impacted soccer balls delivered at 13.1 [±0.22] m/s from a ball canon. The body and ball movement were video filmed at 120/240 Hz. It was concluded that the head accelerates forward, relative to the torso, throughout the impact phase and that the mass impacting the ball (13.8 % of the whole body mass) was a significant larger mass than the head's mass alone. Furthermore, the segmental angular momentum of the legs indicated that these segments were used mechanically well in the execution of the skill, while this was not the case with the arms. From the development of the segmental velocity and angular momentum throughout the heading phase, it could also be concluded, that the over all timing of the skill was not optimum.

KEY WORDS: soccer, heading, angular momentum.

INTRODUCTION: As more and more attention is drawn to soccer, there is also additional focus on the many skills in the game. One of these is the jumping header, which, due to its complexity and growing importance in soccer, is very interesting but also very difficult to investigate from a biomechanic point of view. Some have investigated the standing header (i.e., Burslem & Lees, 1998), but it is not obvious that parallels can be drawn from this to the jumping header. The two skills appear very different, especially due to the involvement of the ground-reaction force throughout the whole execution of standing header. Combining this with the focus and results of prior studies gives motivation and objectives for further investigation of the jumping header. First of all, prior studies have found the head to deaccelerate before impact both in the standing (Burslem & Lees, 1998) and the jumping header (Mawdsley, 1978). In both studies this was seen as an indication of a more rigid contact mass at impact with the head and torso working as one mass to avoid large head accelerations. These findings and conclusions could be questioned, since soccer games today reveal a great deal of forward head movement at impact. Secondly, it is also not clear how arm and leg movements influence on the execution of the skill. Mawdsley (1978) pointed out that the leg and torso movements *are* important in the skill, but no quantified investigation of the movement and their importance in the jumping header have been found in the literature. These observations have provided impetus for the current study. The purpose of this study was to 1) create a valid practical standardization of the jumping header on which further investigation could be based, 2) investigate the head's velocity relatively to the torso around the time of impact and 3) evaluate the head, arm and leg movements and their influence on heading in general.

METHODS: Five skilled soccer players served as subjects. All of them had more than 15 years of experience with soccer at a high level. They all performed more than 10 jumping headers on balls delivered at an average velocity of 13.1 [±0.22] m/s from a soccer ball canon (Jugs Pitching Machine, MVP Sports, NY, USA). The trials were videotaped at both 120 and 240 Hz. with a high speed camera (JVC DV 9700, JVC, USA). The subjects all had joint markers on special pre-selected joints (see Figure 1a) and performed headers that caused a larger resultant velocity of the ball after impact than before ("powerful heading"). The four technically best trials for each subject were chosen for the further analysis. With the use of the APAS System (APAS Inc, USA) position data for all the jointmarkers at any time t_i were retrieved from the video data. *Standardization of the trials:* Due to individual characteristics and uncontrolled factors in the jumping header, such as jumping height, ball velocity after impact, and twisting of body part, it is a very difficult skill to standardize and thereby investigate across subjects. One of the purposes of this study was to create a normalization of the skill so such an investigation could be made. The following was chosen as a valid standardization: 1) All subjects performed headers with ball and body movement only in the sagittal plane (only arm movement out of this plane were acceptable). 2) The ball was to pass between two markers located in front of the subject after impact. 3) The subject was to take off from a specific initial point. 4) The ball's velocity before *and* after impact was to be statistical alike for all subjects and trials. 5) The performances were to meet subjectively defined minimal technical demands based on body movement prior to impact. Setting the ball canon so the balls were delivered approximately 0.3 m. above the standing subject controlled the jumping height. A lateral view of the set-up can be seen in Figure 1c. *Models:* To analysis the skill, this study modelled the body in two ways: 1) as a thirteen-segment body consisting of the following segments: 2 lower and upper legs, pelvis, abdomen, torso, neck, head, 2 lower and upper arms (see Figure 1a for joint markers) and 2) as one rigid body consisting of one segment, denoted the "impact mass". Both models were 2D models. The kinetics were based on the theoretical fact, that both the angular and the horizontal linear momentum of the body and ball are conserved in the sagittal plane in the aerial part of the heading, if one neglects the air resistance (no other horizontal extern forces are applied after take-off). By using the introduced models one can look at the *total* or *segmental angular momentum* of the body and evaluate these at any given time. Furthermore, the conservation of *horizontal linear momentum* of the ball *and* body gives a possibility of investigating the impact mass (i.e. a quantification of the total mass affecting the ball at impact) without involving the coefficient of restitution. *Translatory model:* If it's assumed that the total mass impacting the ball is unchanged throughout impact it's value can be deduced as follows:

$$M_{\text{impact mass}} = m_{ball} \cdot (v(x)_{\text{ball, after impact}} - v(x)_{\text{ball, before impact}}) \,/\, (v(x)_{\text{impact mass, before impact}} - v(x)_{\text{impact mass, after impact}})$$

The velocities consist only of the horizontal part. The head's movement served as data for the impact mass velocities and it was assumed that it had minimal vertical movement around impact. This assumption was verified by data after the trials.

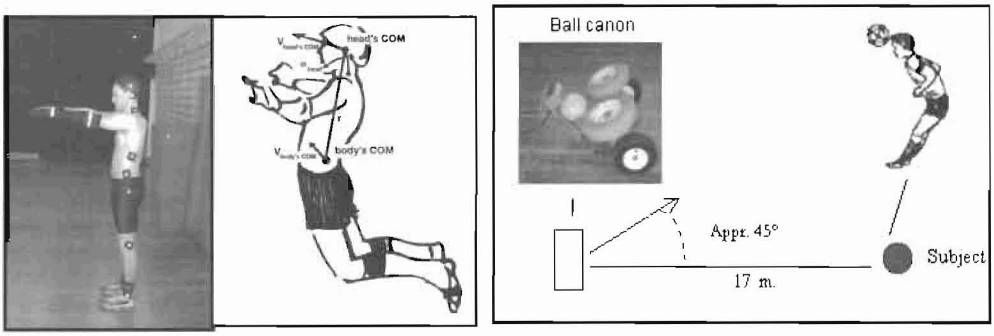

Figure 1 . (a) Placement of joint markers. (b) Illustration of angular model. (c) Setup.

Angular model: When viewing the whole body with initial point at the body's centre of mass (COM) the gravity force can be neglected and no external forces acts on the system/body. After take-off the position data on the thirteen-segment model can by used to calculate the total body momentum as the sum of the segmental angular momentum in the sagittal plane (e.g., see Figure 1b).

$$H_{segment} = (I_{segment} \cdot \varpi_{segment} + \bar{r}_{segment/COM} \times (m_{segment} \cdot \bar{v}_{segment/COM})),$$

$$H_{\text{whole body}} = \sum_i H_{segment,\,i}$$

where $I_{segment}$ is the moment of inertia, $\varpi_{Segment}$ is angular velocity, $m_{segment}$ is the segment mass, $\bar{r}_{Segment/COM}$ is the vector from the segment's COM to the whole body's COM, $\bar{v}_{segment/COM}$ is the relatively velocity between the segment COM and the whole body's COM.

The segments' masses and moment of inertia were calculated using the anthropometrical data from Winter (1990).

RESULTS AND DISCUSSION: To facilitate the evaluating of the segments' movement in heading four events were identified (see Figure 2).

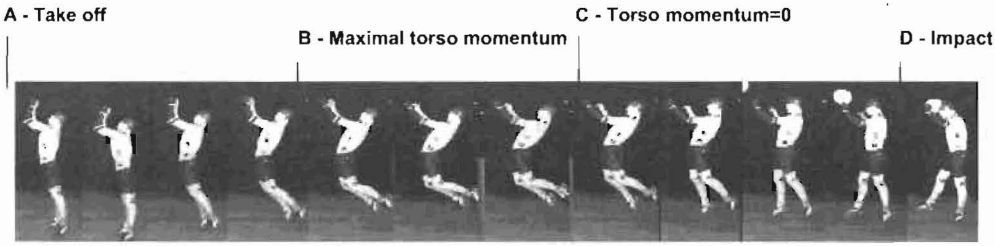

Figure 2. The events of the heading.

Table 1. Impact Masses, the Heads Translatory Velocity Relative to the Torso and Leg Length at Impact.

	Impact mass		The head's transl. velocity relatively to the torso (m/s)				Segt. length at impact
Sub.	Impact mass [kg]	% of body mass	-3/240 sec	-2/240 sec	-1/240 sec	Impact	Leg [% of full] (R/L)
1	10.80 [±0.89]	12.9 [± 1.12]	0.95 [±0.38]	1.02 [±0.30]	1.10 [±0.19]	1.17 [±0.11]	0.94 [±0.06] / 0.96 [±0.02]
2	10.40 [±0.81]	12.6 [± 0.74]	0.79 [±0.24]	0.85 [±0.17]	0.96 [±0.13]	1.00 [±0.06]	0.96 [±0.02] / 0.96 [±0.03]
3	12.31 [±0.80]	15.8 [± 2.16]	1.79 [±0.31]	2.01 [±0.27]	2.21 [±0.24]	2.35 [±0.23]	0.97 [±0.02] / 0.98 [±0.02]
4	11.62 [±0.84]	13.5 [± 0.83]	0.90 [±0.23]	1.04 [±0.27]	1.17 [±0.32]	1.26 [±0.33]	0.95 [±0.05] / 0.97 [±0.02]
5	11.78 [±0.65]	14.0 [± 2.09]	1.69 [±0.15]	1.89 [±0.08]	2.09 [±0.50]	2.28 [±0.15]	0.91 [±0.04] / 0.97 [±0.03]

Across the subjects the impact mass was estimated to be 13.8 % of the body's mass with no statistical differences between the subjects (ε=0.18). The impact masses are no different from those found by Kristensen and Terp (2001) in standing heading. The results also showed that the head accelerated forward relative to the torso throughout the impact phase. This is opposite to the findings by Burslem and Lees (1998) and Mawdsley (1978). Thus the head accelerates throughout the impact phase even though the ball is hit with a larger impact mass than the head's mass. This can only occur if the neck muscles are used actively in bringing the head forward at impact. This indicates that an optimal header very much involves the head as a segment in the movement, though not completely as a normal segment in a "standard" open kinetic link model.

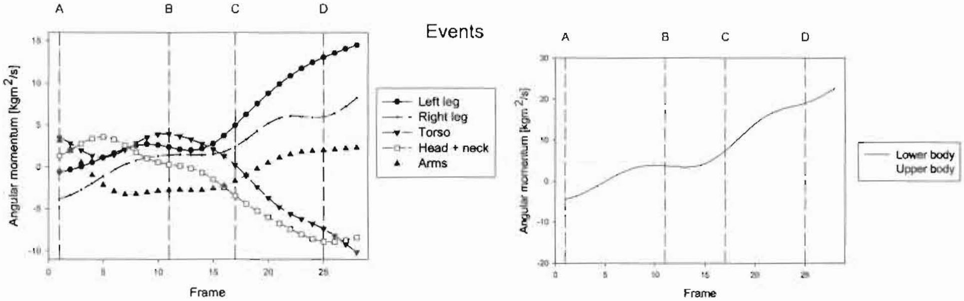

Figure 3. Examples of angular momentum. (a) Different segments. (b) Lower body/upper body. Note the orientation of the angular momentum and the events (see Figure 2).

Figure 3a shows an example of the segmental momentum in the aerial phase. The segmental angular momentum was not quantitatively comparable across the subjects (see Table 2 for leg and arm momentum), but the development was alike. Also, the legs were close to completely extended at impact (Table 1). First of all, this shows that few of the segments reached their peak angular momentum at impact, which is also illustrated through the end-segments (ankles and head) velocities in Table 2. This means that impacting the ball later in the segmental link movement properly would cause a better performance (a higher ball velocity after impact) though this is a theoretical prediction. Secondly, due to the orientation of this study, a large *negative* upper body angular momentum is wanted at impact. Hereby the head can affect the ball with the greatest momentum and the ball can reach a larger velocity after impact. While the angular momentum is conserved in the aerial phase, this can only happen if other segments (i.e. arms and legs possess a positive angular momentum directed in the opposite direction of the upper body at impact).

Table 2. Segmental Linear Velocities at Impact/Maximum and Segment Angular Momentum at impact.

	End segment velocity [m/s]			**Angular momentum at impact**	
Sub.	**v_{ankle} (left) Impact / max.**	**V_{ankle} (right) Impact / max**	**v_{head} Impact / max**	**Legs [mkg^2/s]**	**Arms [mkg^2/s]**
1	6.25 [±0 98] / 6.52[±1.09]	6.08[±1.01] / 7 25[±0 30]	2 31[±0.50] / 2 53[±0.40]	15.51 [±1.91]	0.85 [±3 95]
2	1 49 [±0.51] / 1 98 [±0.36]	4.40[±0 18] / 4 68[±0.32]	3 01[±0.43] / 3 16 [±0.55]	14.39 [±2.97]	-4.28 [±1.01]
3	3.42 [±0.66] / 3.48 [±0 74]	2 67[±0.59] / 3.36[±0.33]	3 12[±0 38] / 3.43 [±0.27]	13.89 [±2 30]	-2.75[±1.51]
4	3.64 [±0 83] / 4.55[±0.92]	2.52[±0.66] / 2 82[±0.66]	3.01[±0.32] / 3.17[±0.49]	16 66 [±2.11]	-0.72[±1.90]
5	3.15 [±0 91] / 3 18 [±0 86]	4.71[±0.35] / 5 12[±0.21]	3.59[±0.47] / 3.76 [±0 52]	21 05 [±0.32]	-4.68 [±3.02]

This is generally not the case for the arms (Table 2). It is assumed that the arms have other primary uses, such as altering the location of the COM, balancing the body and protecting the subject against the opponent. For the legs the situation is different. Comparing the upper body and the leg's angular momentum (see Figure 3b) reveals a picture of an almost perfect "jack-knife" movement, where the body "folds" around the pelvis. While the legs are also almost fully extended, the subjects uses the legs mechanically well in execution of the skill, though the timing, as mentioned, is not perfect. This is properly due to the fact that several parameters are attempted optimised at the same time in the skill.

CONCLUSIONS: This study found that the jumping header is a difficult skill to standardize due to large individual variations from subject to subject. With the limitations and assumptions made in this study, it was found that the body mass impacting the ball is significantly larger than the head's mass alone. Furthermore, it was also shown that the head accelerated relative to the torso throughout the impact phase. This indicates that a skilled subject uses the head as a free segment in the jumping header. It is also concluded that the arms do not contribute significantly in production of angular momentum at impact; they are not used optimally in creating a high ball velocity after impact. The arm movements are assumed to have other effects. The leg's angular momentum, on the other hand, was found to be large at impact, so these segments are used in a biomechanical optimal way in the skill. Finally, throughout the aerial phase the development of the segmental momentum showed that the jumping header is not optimised from a theoretical point of view because most of the segments reached their peak angular momentum after impact. This means that the skill could be timed better, though this study did not evaluate if this can actually be done in practice. The results emphasizes that the jumping header is a very complex full-body movement.

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