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Optimizing Segmental Movement in the Jumping Header in Soccer

L. B. KRISTENSEN, T. BULL ANDERSEN and H. SØRENSEN

ABSTRACT

This study looks at segmental movements in the jumping header from an optimization viewpoint. Investigations on the header so far have focused on head restriction in the movement but have not clarified how and to what extent body segments influence the performance of the skill. In the present study a biomechanical model was used to analyze the jumping header in simulated competition to give a clear picture of an optimized header. Skilled soccer players headed balls at speeds of 13 m.s.⁻¹ the results indicated that the head moves as a free non-restricted segment in the jumping header and should be allowed to do so, even though much soccer literature says otherwise to prevent injuries. The arm movement showed individual characteristics and gave no general advantages in optimizing ball speed after impact in the header. The movement of the legs was, on the other hand, the single most important factor in the skill.

Therefore, coaches and players should focus on developing muscle strength in the stomach, back and pelvis and should put no restrictions on head and arm movement to optimize the jumping header.

Keywords: heading, optimization, segmental movement, soccer.

INTRODUCTION

The main focus of this study was the jumping header in soccer. This investigation elaborates on the study by Kristensen (2002) from a practical viewpoint and will show possible applications for players and coaches.

Interest in the jumping header is growing, but for several years the skill has suffered from a lack of scientific interest, probably because of one of the following postulates: heading is mostly based on physics and courage, or heading is not an important skill in the game.

The first postulate may have some truth to it. But as pointed out by Mawdsley (1978) and Luhtanen (2004) – and as this study will show – the skill also consists of some very difficult technical aspects.

The second postulate is far from being true today. Match analysis done

across different soccer leagues indicate that players on average encounter over six headers per game (Smolaka, 1984; Asken and Schwartz, 1998). Furthermore, in the last FIFA World Cup in Japan and Korea over 20% of the goals were scored by headers, an increase of 5% from the World Cup in 1998 (FIFA, 2004).

Before we consider the jumping header we will have a short general look at sport, soccer and research. Like other sports soccer has undergone different forms of development over time. One of these is technical development in skill performance. This improvement – and here we call it an improvement, as we assume that the player now performs with greater success – can mean quantum leaps in results like the Fosbury flop in high jump – or small steps – such as a new dribble in soccer. The development in technical ability is often a cumbersome process to go through for the primary system (Hölmich and Kierulf, 1989) consisting of the performer and people around the performer, such as the coach or trainer. In short, this primary system locates a technical aspect – a skill or part of a skill, which the player wants to optimize to perform better. This leaves them with an optimization problem that they solve in a suitable way by practice, evaluation and correction. Over time they improve the performance of the skill – or develop a different skill that meets the demands better – and the performers hereby perform better: they have solved the technical movement–optimization problem.

Though some of this technical development in skills might be very individual and non-transferable across persons, examples of general solutions to optimization problems in sports are often seen, as in the Fosbury flop in high jump (passing a higher bar) and the somersault turn in crawl (saving time in turning). In soccer the improvements are mostly seen in kicking techniques. A current example is a further development of the in-step kick into an ‘in-step free-kick’. The latter has been perfected today by players such as Roberto Carlos and David Beckham. This example is very important while, in contrast to the large amount of biomechanical research into some of the skills in soccer, researchers and trainers seem to forget that the common performance of a skill may not be the optimal solution for the soccer game of today. As pointed out earlier, the primary system must sometimes evolve the skill and come up with new ideas. In the free-kick example David Beckham and Roberto Carlos have used the basic ingredients of the in-step and come up with a better solution to their free-kick problem: to score goals at free-kicks!

With these thoughts in mind we turn to the main focus of this study: the jumping header in soccer. The statistics mentioned indicate that the jumping header is a skill, which soccer players have to master, and master well. They have to optimize the problem of hitting the ball in the ‘best way’ and this is done by using the primary system in the process. The ‘best way’ has to be defined, but if we firstly acknowledge that there are person-transferable ingredients in jumping header, the primary system can use coaching literature in this process. But what if the skill (as in the Beckham and Carlos kicking techniques) has evolved over time, leaving coaching literature and other publications with descriptions of a jumping header that is outdated? A few examples of these descriptions from coaching and academic literature are shown in the following. Figure 1 shows a classical heading movement.

Figure 1 The jumping header illustrated. Reproduced from Peitersen (1993) by kind permission of the author.

‘Keep your eyes focused on the ball, with your chin in, neck muscles locked, arms out and back arched . . . Thrust your upper body forward, and contact the middle of the ball with the front of your head. Follow through’ (Soccerjr, 2001).

‘To absorb the force of impact with the ball, and to prevent jarring at the neck, there must be a transfer of momentum; and to achieve this, the head must be rigid at impact. The forward velocity of the head, relative to the trunk, must be reduced to almost zero to produce this rigidity but deceleration must not come so soon as to lose the forward velocity of the head altogether’ (Mawdsley, 1978).

When recalling modern soccer scenarios these descriptions can be questioned. First of all the prevention of jarring of the neck is of course important from an injury minimization viewpoint – but if a player wants to score a goal, such precautions are often not taken. On the other hand the achievement of transferring momentum to the ball involves some biomechanical aspects that are important – especially when the player heads the ball for distance or speed rather than to reduce the risk of injury. Both citations focus on rigidity between

head and trunk at impact with the ball. Mawdsley (1978) elaborated more technically on this aspect, to which we will return, as being important in 'achieving well' in heading. Some studies have actually quantified this rigidly and found the head to decelerate before impact both in the standing (Burslem and Lees, 1988) 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 and avoiding injuries. It should be noted that several studies have found that soccer heading is not dangerous for adult soccer players (Schnieder and Zernicke, 1988; Townend, 1988; Liberi and Richards, 1994). Even though heading has been indicated to affect short term memory (Sortland and Tysvare, 1989) the professional soccer player performs jumping headers with no risks.

The problem is, again, that this rigidity is not often seen in professional soccer. Observations on modern soccer clearly indicate – and thereby question the above – that soccer players move the head forward relative to the trunk while impacting the ball, even at high ball speeds.

Apart from the above, the literature can also highlight other parts of the skill, on which we should focus. The actions of the trunk and hip flexors are important factors as well as leg movement:

'The action of the body in heading has been compared to that of a catapult, in which both the upper and lower halves of the body are extended backwards after leaving the ground. Trunk extension may be an important factor in achieving greater trunk velocity in the standing jump technique, and works like a bow. The further back the trunk extends, the greater the maximum forward velocity of the upper trunk and head. Force is produced by strong contraction of the trunk flexors, hip flexors, and knee extensors prior to impact. The role of the trunk flexors in this skill is very important, and need to be strengthened in this skill. The force of the header can be increased by using more body parts through a greater range of motion during airborne phase of the jump, and during takeoff. A longer run-up prior the takeoff will generate more momentum at takeoff' (Luhtanen, 2004).

Here Luhtanen (2004) pointed out – on classic biomechanical grounds – that the leg, arm and torso movements are important in the skill. Trunk flexion can be spotted as the single most important factor in the skill, but it is an open question to what extent arm and leg movements influence the execution of the skill. Luhtanen (2004) underlined that moving more body segments over a greater range of motion will generate a more powerful header. Though the knee and hip flexors are mentioned as playing important roles here, it is not clear to what extent a player should focus on leg or arm movement when optimizing the skill.

In summary, the jumping header might not be clearly investigated in a fully satisfactory way from a modern optimizing viewpoint. The coaching literature and biomechanical observations might not be as precise and up to date as hoped for in given guidelines for trainers and players.

From the foregoing, we formulated the main aim of the present study: to determine the essential body movements in the jumping header to maximise ball speed and accuracy. The purpose was thereby to quantify the important parts of the movement, giving the players and the people around the player (the primary system) guiding principles to optimize the skill.

METHODS

The optimization parameters for the header in this study are ball speed after impact combined with an accuracy demand. This seems appropriate since the jumping header is used in many different circumstances in the game – from attacking to defending. The common factor in the application of the skill is getting the ball to another part of the soccer field – quickly or over a large distance – or hitting a chosen target, such as a team mate, the goal or just away from the defence zone. So we will demand high ball speeds and accuracy from the skill before we accept the indications of the results as essential parts of an optimized jumping header.

Initially we also have to trace which body parts move and how they move to locate essential parts of the skill, using the tools provided by the mechanical laws – biomechanics.

To analyse the jumping header, this study looks at the body as a thirteen-segment model consisting of the following segments: two lower and upper leg parts, pelvis, abdomen, torso, neck, head and two lower and upper arm parts. In this study the joints separating the segments are indicated with markers (joint markers) as seen in Figure 2.

From the location of the marker's position at any given time one can retrieve segment velocities around ball impact (the kinematics). These results can show how fast segments move and in what direction they move. But to give a better picture, the introduced model can be used to calculate the angular momentum of each segment. The angular momentum describes each segment's contribution in the jumping header much more precisely since this quantity is the product of segment velocity and segment mass. In the aerial phase of heading, the total angular momentum is constant. That is, if the hip flexor contracts, the angular momentum of the legs will increase in one direction and that of the upper body in the other direction. The sum is still the same. An external force – in heading the reaction force from the ground before take off – creates this total angular momentum. If a body has a large angular momentum in a given direction it can transfer a great force to an object – as in heading a ball – or it will continue rotation until it meets resistance – as in a gymnastic somersault before hitting the floor (Barthels and Kriegbaum, 1996). A rotating segment or body always has angular momentum. By considering the body as consisting of many segments, each with angular momentum, we can better evaluate the jumping header.

The theoretical aspects of the deeper analysis (the kinetics) in the study are based on the assumption of conservation of angular momentum in heading. When no objects other than the ball and performer are involved in heading, the angular momentum is conserved in the aerial phase of heading. There are also

Figure 2 Placement of joint markers.

some assumptions about body movement out of the sagittal plan and head movement in the vertical direction around impact that must be considered. Likewise air resistance is neglected. After take-off the position data on all the joint markers in the thirteen-segment model can now be used to calculate the segmental angular momentum – and the total body momentum as the sum of these – at any given time (see Appendix 1 for model). This gives a basis for analysing the jumping header through how the body uses the segments in the skill, while the total angular momentum of all the segments is constant.

The study used five skilled soccer players, whose anthropometrical data are shown in Table 1. All of the players had more than 15 years of experience of soccer at a high standard and were chosen because of their excellent heading

skills. All performed more than 10 jumping headers on balls delivered at a speed greater than 13.1 m.s^{-1} from a soccer ball machine (Jugs Pitching Machine, MVP Sports, NY, USA). From the 15 jumping headers, at least five were picked for analysis.

Table 1 The performers' anthropometrical data.

<i>Performer</i>	<i>Body mass (kg)</i>	<i>Height (m)</i>	<i>Age (years)</i>
1	83.5	1.83	27
2	82.5	1.85	29
3	78.0	1.82	28
4	83.0	1.79	29
5	87.0	1.87	27

The trials were videotaped perpendicular to the player's sagittal plane with a high speed camera (JVC DV 9700, JVC, USA) recording at 120 Hz. With the use of a computer program (the APAS System, APAS Inc, USA) position data for all the joint markers and the ball were retrieved from the video recordings. From this position data and the model in Appendix 1, the momentum and velocity of all segments were calculated with the use of Microsoft Excel (Microsoft, USA). This data was used for further analysis.

The heading was performed in a very controlled environment – but with great freedom in the skill itself. There are several good reasons for this. First of all the controlled environment makes it possible to look for significant body movement in the skill across players and, secondly, such a set-up provides accurate and valid data from which conclusions can be drawn. Keeping the considerations mentioned in the introduction in mind, we must allow great freedom in the movement, so that the player performing should give us indications of 'the optimized modern jumping header' – but also standardize the skill to obtain valid results. Setting the ball machine so that the balls were delivered approximately 0.3 m above the standing performer controlled the jump height – one of the individual aspects that have to be standardized. The precision of the header was controlled by ensuring that the ball did not deviate more than 14° from the sagittal plane. Accordingly, the maximal error of the calculated ball speed was below 3%. Furthermore, the performers were instructed to keep the ball trajectory below its vertical position at impact.

The intended speed was met by using ball speeds greater than 13 m.s^{-1} and not allowing ball speed after impact to be less than ball speed before impact (a powerful header). Apart from making the players jump from a defined initial point and moving purely vertically, there were no other technical demands on the skill.

The authors found that these limitations on the skill did not have a restrictive effect on the player's performance – they could still perform an optimized header. On the other hand the restrictions allow a good scientific evaluation of the skill.

RESULTS

The results of the study are presented in the following tables and figures. The tabulated results are shown as mean $\pm$ standard deviation, illustrating differences between the trials of each player. A two-way analysis of variance (ANOVA) was used to ensure that there were mathematical grounds for viewing the different performers as one group.

Figure 3 shows the events into which the jumping header can be divided. Point B indicates the time at which the torso is moving with the greatest momentum (see the Methods section), whereas C reveals the time the torso is positioned the furthest back in the aerial phase of heading (angular momentum = 0). At D the ball is impacted. The events of heading can also be seen in Figure 4, where the angular momentum of the largest body segments are presented from take-off to impact. This figure gives a visual representation of the complex timing of the skill. The development of the torso and leg momentum after impact should be noted.

Figure 3 The events of the jumping header.

Figure 4 Angular momentum of body segments throughout the jumping header.

Figure 5 shows the scissor movement and the action-reaction element. Here it is shown that the upper body (trunk, arms and head) moves opposite to the lower body (legs and hip) in the aerial phase of the heading, where the angular momentum are in different directions. Note that the absolute magnitude of angular momentum for the two parts is very similar.

Figure 5 Angular momentum of upper and lower body throughout the jumping header.

We stress that the segmental angular momentum was not quantitatively comparable across the players, but its development was similar. That means that Figures 4 and 5 can be used to illustrate the tendencies for all players but not as a general quantity indicator.

The speed of the head relative to the torso is shown in Table 2. The measurements were made using the high speed data and illustrate the development of the head movement before impact. The table shows that the head accelerated forwards relative to the torso throughout the impact phase, while the speed increased up to impact.

Table 3 shows some of the segments' speed at impact compared to the maximum speed of these segments around impact. It indicates that all of the body's end segments do not reach highest speed at impact.

Table 4 illustrates the angular momentum for selected segments at the time of impact with the ball. Note the changing orientation (sign) of the arm's angular momentum across the performers and the large positive angular momentum created by the legs for all performers. This gives a picture of which segments are important in the skill.

Table 2 The speed of the head relative to the torso (in m.s⁻¹) up to impact (mean $\pm$ SD).

<i>Performer</i>	<i>-3/240 s</i>	<i>-2/240 s</i>	<i>-1/240 s</i>	<i>Impact</i>
1	0.95 $\pm$ 0.38	1.02 $\pm$ 0.30	1.10 $\pm$ 0.19	1.17 $\pm$ 0.11
2	0.79 $\pm$ 0.24	0.85 $\pm$ 0.17	0.96 $\pm$ 0.13	1.00 $\pm$ 0.06
3	1.79 $\pm$ 0.31	2.01 $\pm$ 0.27	2.21 $\pm$ 0.24	2.35 $\pm$ 0.23
4	0.90 $\pm$ 0.23	1.04 $\pm$ 0.27	1.17 $\pm$ 0.32	1.26 $\pm$ 0.33
5	1.69 $\pm$ 0.15	1.89 $\pm$ 0.08	2.09 $\pm$ 0.50	2.28 $\pm$ 0.15

Table 3 Segmental linear speeds (in m.s⁻¹) at impact/maximum (mean $\pm$ SD).

<i>Performer</i>	<i>V_{wankle} (left)</i> <i>Impact / max.</i>	<i>V_{wankle} (right)</i> <i>Impact / max.</i>	<i>V_{head}</i> <i>Impact / max.</i>
1	6.25 $\pm$ 0.98/ 6.52 $\pm$ 1.09	6.08 $\pm$ 1.01/ 7.25 $\pm$ 0.30	2.31 $\pm$ 0.50/ 2.53 $\pm$ 0.40
2	1.49 $\pm$ 0.51/ 1.98 $\pm$ 0.36	4.40 $\pm$ 0.18/ 4.68 $\pm$ 0.32	3.01 $\pm$ 0.43/ 3.16 $\pm$ 0.55
3	3.42 $\pm$ 0.66/ 3.48 $\pm$ 0.70	2.67 $\pm$ 0.59/ 3.36 $\pm$ 0.33	3.12 $\pm$ 0.38/ 3.43 $\pm$ 0.27
4	3.64 $\pm$ 0.83/ 4.55 $\pm$ 0.92	2.52 $\pm$ 0.66/ 2.82 $\pm$ 0.66	3.01 $\pm$ 0.32/ 3.17 $\pm$ 0.49
5	3.15 $\pm$ 0.91/ 3.18 $\pm$ 0.86	4.71 $\pm$ 0.35/ 5.12 $\pm$ 0.21	3.59 $\pm$ 0.47/ 3.76 $\pm$ 0.52

Table 4 Segmental angular momentum (in kg.m².s⁻¹) at impact for selected segments (mean $\pm$ SD).

<i>Performer</i>	<i>Torso</i>	<i>Head</i>	<i>Legs</i>	<i>Arms</i>
1	-8.33 $\pm$ 2.65	-6.70 $\pm$ 1.06	15.5 $\pm$ 1.9	0.85 $\pm$ 3.95
2	-3.55 $\pm$ 1.02	-4.71 $\pm$ 0.98	14.4 $\pm$ 3.0	-4.28 $\pm$ 1.01
3	-9.33 $\pm$ 1.58	-9.80 $\pm$ 1.33	13.9 $\pm$ 2.3	-2.75 $\pm$ 1.51
4	-6.09 $\pm$ 2.64	-6.44 $\pm$ 2.53	16.7 $\pm$ 2.1	-0.72 $\pm$ 1.90
5	-12.4 $\pm$ 2.1	-12.68 $\pm$ 1.91	21.1 $\pm$ 0.3	-4.68 $\pm$ 3.02

DISCUSSION AND IMPLICATIONS

In this section we discuss the main implications of the presented results and give some guidelines for focus points in the jumping header.

The results illustrated in Figures 4 and 5 show that few of the body segments reached their peak angular momentum at impact, which is also illustrated through the body's end-segment (ankles and head) speeds in Table 3. In none of the trials did the players hit the ball when the ankles, head or arms had the largest speed of the aerial phase of the header. This is a notable result as a theoretical optimization – timing – of the header would focus on hitting the ball when most momentum can be transferred to the ball. If we keep in mind that, owing to the set-up in this study, we assume that we are already looking at an optimized performance, we can conclude that the best execution of the header does not demand a maximization of the angular momentum at impact, but involves a broader concept of timing. One explanation could be that the aim of heading is to hit the ball horizontally – not towards the ground. Hitting the ball later in the aerial phase could perhaps give larger ball speeds but would not produce a better result for the player. Another aspect of the timing can involve the arms, which could be expected to be used to create an action, forcing the upper body forward with larger angular momentum as a reaction. Typically this would mean that the arms would move in the opposite direction to the torso, though this is a vague definition in this case, as illustrated in Figure 3. The set-up of this study results in a large negative upper body angular momentum being created at impact if the players hit the ball with great force. Thereby, the head impacts the ball with the greatest momentum and the ball can reach a greater speed after impact. While the angular momentum is conserved in the aerial phase, this large negative momentum can only be created if other segments (i.e. arms and legs) create a positive angular momentum directed in the opposite direction to the upper body at impact: an action creates a reaction. The arms being located at the upper body, coaches often focus on moving the arms backwards to help make this possible. Analyses of the arm movement, not shown here, suggest that, from a biomechanical viewpoint, this is not correct. The arms should be moved downwards and backwards to give advantages in angular momentum. And in Figure 4 and Table 4, we found that the angular momentum of the arms and the torso for four out of five performers had the same direction (sign), thereby causing no biomechanical advantages in the performance. Combining this with the visual findings in Figure 3, we can conclude that the timing of the arm movement in the header is controlled by other factors, perhaps balancing the body and protecting the player from opponents. There is no optimization caused by pulling back with the arms in the jumping header. A coach should consequently focus on arm movement as a very individual part of the skill and not expect any trade-offs in creating greater ball speeds in association with arm movements.

The picture is very different for the legs. Comparing the upper body and lower body's angular momentum (see Figure 5) reveals a picture of an almost perfect jack-knife movement, where the body folds around the pelvis. The legs move forwards around impact, after they have been moving backwards in the

pre-tension phase of the header (Figure 3). Though the angular momentum of the legs is not peaking at impact, the legs are also almost fully extended so the performers use the legs mechanically well in execution of the skill. It creates a large action, which can be seen in Table 4. The lower body moves forwards relative to the pelvis, which causes a reaction and the upper body moves forwards relative to the pelvis. Again recalling the action–reaction principle it is, as pointed out by Luhtanen (2004), very important that the legs and the upper body move backwards in the preparation phase of the aerial part of the header to make this forwards movement possible.

This study, therefore, underlines the fact that not only the abdominal muscles and the hip flexors are very important for the success of the jumping header, but also the back muscles. The legs alone have to contribute angular momentum that corresponds to that of the upper body at impact, and a player must, therefore, train these muscle groups to perform well in heading.

The fact that the head accelerates relative to the torso throughout impact is seen in Table 2. This is contrary to the findings by Burslem and Lees (1998) and Mawdsley (1978) and is very interesting from a practical point of view. This shows that the head and torso are not rigid at impact and the players and coach shall not focus on this in the training of the skill. Instead, it is important to let the player know that the head should move freely around impact if he wants to perform an optimized header. This is not how the header is described in soccer literature today and should very much be taken into consideration. Table 4 underlines the above finding in showing that the head has almost as much angular momentum as the torso in all performers. In one case, it even contributes more than the much heavier trunk.

CONCLUSIONS

This study found that the jumping header involves individual variations from player to player in the performance of the skill. This is important when training soccer players in the skill. These variations are primarily seen in arm movements and in the segment's angular momentums in the aerial phase of the skill.

Furthermore, this investigation found that the head accelerated relative to the torso throughout the impact phase. This indicates that a skilled player uses the head as a free non-restricted segment in the jumping header and should be allowed to do so, even if the soccer literature says otherwise. And although the performance of the arm movement in the header differs from player to player, we can also conclude that the arms do not contribute significantly to the generation of angular momentum at impact. This means that the arms have little role in creating high ball speed after impact. It should, therefore, be accepted that the arms have other applications in the header, such as keeping the opponents away, and that the player moves them as he or she finds appropriate. The movement of the legs, on the other hand, was found to be very significant at impact – the results showed that the movement of the legs can be seen as a limiting factor in the header. The correct movement of these segments does, therefore, merit attention from players and coaches. The legs should be pulled backwards, as flexed as possible in the first part of the aerial phase of

heading. Close to impact, the legs should move forwards fully extended before heading the ball. It is, therefore, important that the abdominal muscles and hip flexors are strong and well coordinated.

APPENDIX I: THE ANGULAR MODEL

Each segment's angular momentum was calculated using the following formula

$$\mathbf{H}_{\text{segment}} = (I_{\text{segment}} \cdot \omega_{\text{segment}} + \mathbf{r}_{\text{segment/COM}} \times (m_{\text{segment}} \cdot \mathbf{v}_{\text{segment/COM}})),$$

From these the total angular momentum could be found using

$$\mathbf{H}_{\text{whole body}} = \sum_i \mathbf{H}_{\text{segment}, i}$$

where I_{segment} is the moment of inertia, ω_{segment} is angular velocity, m_{segment} is the segment mass, $\mathbf{r}_{\text{segment/COM}}$ is the vector from the segment's centre of mass (COM) to the whole body's centre of mass, $\mathbf{v}_{\text{segment/COM}}$ is the relative velocity between the segment centre of mass and the whole body's centre of mass. The calculation and the segments are illustrated in Figure 6.

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

Figure 6 Illustration of the model used.

REFERENCES

- Asken, J. M., and Schwartz, R. C. (1998). Heading the ball in soccer: What's the risk of brain injury? *The Physician and Sportsmedicine*, **26**, 37–44.
- Barthels, K. M., and Kriegbaum, E. (1996). *Biomechanics – A Qualitative Approach for Studying Human Movement*. Boston: Allyn and Bacon.
- Burslem I., and Lees, A. (1988). Quantifications of impact accelerations of the head during the heading of a football. In T. Reilly (ed.) *Science and Football* (pp. 243–248). London: E. & F. N. Spon.
- FIFA (2004). <http://www.fifa.com/en/display/article,43628.html>. Downloaded 14-01-2004.
- Hölmich, P., and Kierulf, S. (1989). Teamwork for eliteudøvere, notes from TEAM Danmark seminar 1989 (pp. 1–4). Copenhagen: TEAM Denmark.
- Kristensen, L. B. (2002). Investigation of segmental characteristics in powerful soccer heading. In K. E. Gianikellis (ed.) *Scientific Proceedings of the XXth International Symposium on Biomechanics in Sports* (pp. 409–412). Caceres: Universidad de Extremadura, Servicio de Publicaciones.
- Liberi, V., and Richards, J. G. (1994). Determining linear head accelerations and risk and injury in soccer heading. In *Abstracts of the U.S. Soccer Symposium on the Sports Medicine of soccer*. Orlando: United States Soccer Federation.
- Luhtanen, P. (2004). <http://www.coachesinfo.com/article/107/>. Downloaded 02-02-2004.
- Mawdsley, H. P. (1978). A biomechanical analysis of heading, *Momentum*, **3**, 30–40.
- Peitersen, B. (1993). *Fodboldteknik, ungdomstræningens ABC*. Herning, Denmark: Systime/DHL.
- Schneider, K., and Zernicke, R. F. (1988). Computer simulation of head impact: Estimation of head-injury risk during soccer heading. *International Journal of Sport Biomechanics*, **4**, 358–371.
- Smodlaka, V. N. (1984). Medical aspects of heading the ball in soccer. *The Physician and Sportsmedicine*, **12**, 127–131.
- Soccerjr (2001). <http://www.soccerjr.com>, Triplepoint, Inc. Downloaded 01-02-2001.
- Sortland, O., and Tysvaer, A. T. (1989). Brain damage in former Association Football players, *Neuroradiology*, **31**, 44–48.
- Townend, M. S. (1988). Is heading the ball a dangerous activity?; In T. Reilly (ed.) *Science and Football* (pp. 237–242). London: E. & F. N. Spon.
- Winter, D. A. (1990). *Biomechanics and Motor Control of Human Movement (2nd ed.)*. New York: Wiley-Interscience.