DETERMINATION OF THE IMPACT MASS IN SOCCER HEADING

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This study's aim was to determine the body's impact mass in soccer heading and the impact mass's variations when altering the head's mass. It was expected that initial impact mass would be larger than the head's mass, due to muscle activity in the torso/neck. This enables the torso's mass to contribute in impact. It was also expected that altering the head's mass would have little effect on the impact mass. The hypotheses were tested in standing heading trials, where a skilled subject impacted soccer balls at low velocities. The study concluded that the above hypotheses could be supported. The impact mass was found to 9,94 kg (± 1,5 kg), which is clearly larger than the heads initial mass (6,4 kg). No significant distinct correlation between the impact mass and the extra head mass was found, though the impact mass was altered by the extra mass.

**KEY WORDS:** soccer, heading, impact mass, head acceleration, linear momentum

INTRODUCTION: Heading is an essential skill in soccer that is used in all phases of the game, and should therefore be optimised by the performer. This optimisation can be done primarily in two forms, namely with focus on performance maximisation or on injury minimization, but involves an initial location and investigation of the important elements of the skill in both cases. Prior biomechanical investigations of soccer heading have primarily focused on the minimization of the level of injury as an optimisation parameter. In these investigations the crucial aspects on which the conclusions were based, were the linear acceleration experienced by the head (Townend, 1988; Liberi & Richards, 1994; Schnieder & Zernicke, 1988) and angular acceleration (Schnieder & Zernicke, 1988; Burslem & Lee, 1988). In trying to avoid the large accelerations and thereby injuries, the focus is often on the mass-ratio (head mass/ball mass) as the interested variable. This ratio can alter the danger-factor in heading, by causing a smaller or larger impulse on the impacting human body (Schnieder & Zernicke, 1988). In youth soccer the use of lighter balls often raises this mass-ratio, but due to the game's traditions, this is not possible in adult soccer. Therefore, adult soccer players must find other ways to lower the possible risk. A solution to this problem could be found in connection with the impact mass, while, according to Newton's 2nd Law, the masses have a central role in impact situations. If the mass is large the experienced acceleration will be low. Therefore it is interesting to evaluate the mass-properties of soccer heading.

It is generally accepted that the head is not the only mass contributor in heading (Schnieder & Zernicke, 1988; Townend, 1998). Nevertheless, it is not completely clear to what extent the upper body's mass and muscles supplement the head in heading, thus creating a larger impact mass. The expression "impact mass" is adopted from classic mechanics, and should not be viewed as a classic mass, because this "extra mass" is only mobilised due to existence of muscle activity in the neck and torso area. When heading at low ball velocities, the quantity of the impact mass is specially interesting. Here exist a long reaction time, and the subject can prepare the body for impact in the best way. If it can be supported that the impact mass is large at these ball velocities, the acceleration is low, and one should try to transfer the subjects technical performance of this skill to more realistic situations with higher ball velocities, and thereby reduce the possibility for injury.

This study was set up to evaluate the impact mass's quantity in heading at low ball velocities and investigate the impacts mass's variations at different head masses. Thereby it should be possible to discuss heading from a classic mechanics' point of view.

METHODS: One skilled soccer player served as a subject. The subject was standing, and the soccer ball was impacted by the head at velocities between 3,6 and 4,1 m/s (see TABLE 1), which is considered to be low velocities in soccer. The ball was a so-called heading ball (size 5), and was therefore string connected (string length = 2,5 m.) to a bar, in a pendular arrangement,

above the subject, and then released from level to a free swing towards the subject. Hence the ball followed a circular arc before impact with the head, at the bottom of the circle arc, where the ball followed a close to linear path in the x-direction (see FIGURE 1 for picture and drawing of trial set-up). The ball mass was 0,430 kg. The subject was instructed to direct the ball forward in a controlled manner, something that the low ball velocity allowed. All movement in the x-y plane was allowed, though the subject was instructed to keep his feet at the same spot, and his hands at the back, to simplify analysis. Also, he wore a bathing cap, in which rice were placed to raise the heads mass in part of the trials. Thereby the impact mass's dependence on the heads weight could be investigated. The rice mass was 0,1; 0,2; 0,3 and 0,4 kg, and was placed in level around the heads centre of gravity. For use in a detailed movement analysis of heading, not presented here, reflective markers were put on various joint on the subject's left side. The joints were thought to be central in spotting the relevant movement of heading. An example of the body segment's movement while heading is presented and commented in FIGURE 2. In the mechanical analysis presented in this article, only the heads reflection marker, combined with data on the ball movement, was used. Three accepted captures of heading without extra mass were evaluated, and one from each of the trials with extra mass. A capture was accepted when the ball moved away in a circular pattern after impact, and the subject hit the ball according to the directions given.
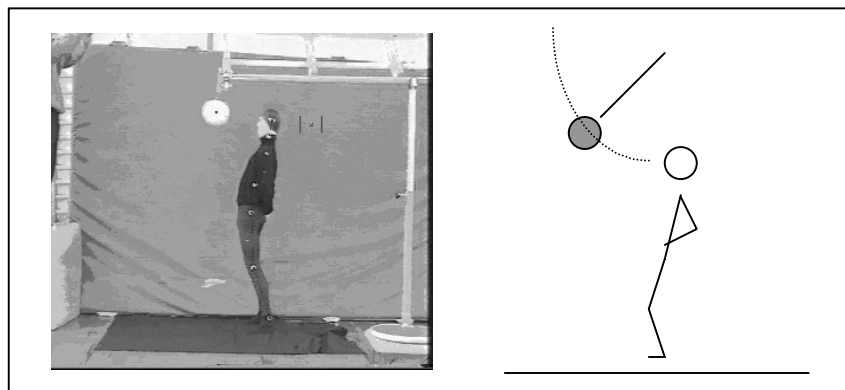
Figure 1 - Picture and drawing of trial setup.

The movement of the body and the impacting ball was recorded by a high-speed camera (JVC GR-DVL 9500 Digital Video Camera) at 120 Hz**.** The ball & heads impact characteristics were simulated with the use of a force platform (AMTI model OR6-5, Biomechanics Platform), where the ball was thrown to at similar resultant impact velocities, as in the actual heading trials (see TABLE 1). Hereby the balls' coefficient of restitution could be found, if it is assumed that the forceplatform has the same material characteristics as the head/skull.

The videoclips and forceplatform data were analysed with the software package Arial Performance Analysis System (APAS), Ariel Dynamics INC. The raw data from the film was filtered with a digital 6-Hz filter. Thereby velocities of the head and ball were retrieved. The subject head's mass was calculated to 6,4 kg by the use of anthropometric tables (Barthels & Kriegbaum, 1996).

If it is assumed, as by Townend (1988), that the ball and the impacting body (the head) follows a linear horizontal pattern at impact, and the sum of external momentum acting on the system is zero, the hypothesis of preservation of linear momentum (equation II) can be applied. From this we are able, theoretically, to determinate the impact mass. But prior investigations on this area have found that the impact mass's velocity immediately after impact is difficult to determine, while an active de-acceleration is taking place (Burslem & Lee, 1988). Therefore, to avoid this practical problem, equation II is combined which a measurement of the coefficient of restitution from the forceplatform trials. If this is used through equation I, we can reach and evaluate equation III without knowledge about the impact mass's velocity immediately after impact. Furthermore, if one wants an unequivocal quantity of the impact mass, it is essential, that the

impact is strictly in the x-direction. While the ball describes a linear pattern around impact, and the head is assumed to contact the ball with pure movement in the x-direction, one can assume that the impact mass can be quantified by examining the movement in this direction only.

Coefficient of restitution:

$$e = v_{system,\,after} \,/\, v_{system,\,before} = (v_{ball,\,after} - v_{impact\,mass,\,after}) \,/\, (v_{ball,\,before} - v_{impact\,mass,\,before}) \qquad \textbf{(I)}$$

Linear momentum before impact = linear momentum after impact:

$$m_{impact\,mass}\, v_{impact\,mass,\,before} + m_{ball}\, v_{ball,\,before} = m_{impact\,mass}\, v_{impact\,mass,\,after} + m_{ball}\, v_{ball,\,after} \qquad \textbf{(II)}$$

$\Rightarrow$ (through equation (I))

$$m_{impact\,mass} = (m_{ball} \cdot (v_{ball,\,after} - v_{ball,\,before}))/(e \cdot v_{ball,\,before} - v_{ball,\,after} + (1+e) \cdot v_{impactmass,\,before}) \qquad \textbf{(III)}$$

Newton's 2. Law:

$$F_{forceplatform} = m_{ball} \cdot a(t)_{ball} \qquad \textbf{(VI)}$$

, where v are velocities, m masses, e the coefficient of restitution, a(t) an acceleration function, and the impact mass's velocity is estimated as the head's velocity.

RESULTS AND DISCUSSION: The assumption that the forceplatform behaves as the skull/head in an elastic impact situation, enable us to use the force-curves from the forceplatform trials. Through a-t curves (equation VI), and numerical integration, these trials revealed ball velocities before and after impact. Using this data equation I showed a coefficient of restitution, 0,7 (± 0,11), statistical similar to other studies (Townend, 1988: 0,8; Schneider & Zernicke, 1988: 0,8). In the further calculations the value 0,7 was used, while this illustrate the characteristics of the actual ball used. Because the coefficient is kept constant this does influence the later statistical test. The collected and estimated data from the heading trials and equation III are shown in TABLE 1.

TABLE 1 Results from Trials and Calculations

Extra head mass [kg]	$v_{ball,\,before}$ [m/s]	$v_{ball,\,after}$ [m/s]	$v_{impact\,mass,\,before}$ [m/s]	Estimated impact mass [kg]
0	3,803(± 0,05)	6,417(± 0,32)	2,227(± 0,16)	9,94 (± 1,5)
0,1	3,972	6,166	2,052	9,18
0,2	3,778	5,682	1,825	12,58
0,3	3,706	5,056	1,465	20,23
0,4	3,713	5,997	2,027	14,32

The results from the computer analysis showed that the absolute ball velocities after impact were higher than the absolute ball velocity before impact, illustrating the assumption that the subject is controlling the heading. The impact mass in the heading trials without extra mass averaged at 9,94 kg (± 1,5 kg), clearly larger than the heads' mass (6,4 kg). Furthermore, a statistical t-test could not reject the hypothesis of identical means across the extra mass on significance level 5 %. Therefore, we can conclude, first of all, that the impact mass is invariant under headmass alterings. This means that the impact mass is a stabile property, which is not dictated by the head's mass. Second, while we have an initial experienced impact mass larger than the heads mass, it is a clear sign of consistence of some form of torso/neck contribution which is accessible only because of muscle activity in the same area. As mentioned earlier, this means that the experienced linear head acceleration probably is low, though this study gives no exact evaluation of this hypothesis. There are some perspectives of this study. If it is assumed that the result can be transferred and used in high ball velocity soccer situations, this investigation showed that the impact mass can be large, when the heading is performed controlled by the subject. This means that the performer is able to lower the head's acceleration

and the injury level in other ways than by using lighter balls. The mobilisation of a larger impact mass can be gained by correct training of the right techniques and muscles used in heading. It is the author's opinion that this transformation to higher velocities can be done, though it remains to be proved. The results also indicate that heading in soccer should be further investigated in general. First of all, the impact mass should be located more distinct, while it is a diffused property. A more detailed model, accepting free movement, could do this. Secondly, the assumption of pure linear movement in the heading is not completely correct, which is clearly illustrated in FIGURE 2. This figure shows stick figures of two heading trials without extra weight on the head.
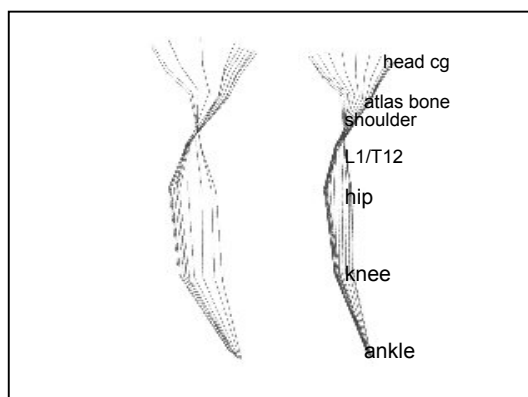
FIGURE 2 - Stick figures of the body movement in soccer heading.

Here is seen some form of angular movement of the marked joints, and this should be taken into consideration in further investigations of the impact. This is possible by including an analysis of the angular momentum, which gives a more realistic picture of which parts of the body contribute to accelerate the ball. After a such analysis one will be able to name the interesting training points of heading, from an injury-minimisation point of view. To make a connection to performance optimisation, one should also include trials, where the subject is to slow down the ball or direct it towards a target at higher ball velocities, and see what influence this has on the impact mass.

CONCLUSION: The conclusion of this study was that the body's impact mass in heading at low ball velocities is invariant under alterations of the head's mass. Furthermore, the investigation showed that, at low ball velocities, the impact mass in heading is larger than the heads mass (6,4 kg), here total 9,94 kg (± 1,5 kg), which underline the fact that the head is not the only mass contributor in this skill. The results thereby also indicate that the experienced linear accelerations are not large, and some form of performance transfer to more realistic soccer situations should be tried. This study did not locate what was the exact cause of the extra impact mass, though it is clear that it is due to muscle activity in the torso/neck area.

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