Materials : Football (Soccer)

Biomechanical Profile of Danish Elite and Sub-elite Soccer Goalkeepers

Henrik Sørensen*, Martin Thomassen and Morten Zacho*****

*Department of Sport Science, University of Aarhus, Denmark
Dalgas Avenue 4, DK-8000 Århus C, Denmark
hs@idraet.au.dk
**Department of Exercise and Sport Sciences, University of Copenhagen, Denmark
Nørre Allé 51, DK-2200 Copenhagen N, Denmark
***Copenhagen Muscle Research Centre, Rigshospitalet, Denmark
Tagensvej 20, DK-2200 Copenhagen N, Denmark
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The purpose of this study was to define a biomechanical profile of the soccer goalkeeper. We tested whether the skill level of 6 goalkeepers correlated with a number of biomechanical tests. The skill level of each goalkeeper was defined as the league he played in. The biomechanical tests were designed as standardized measurements of typical goalkeeper actions; they comprised various jumps, a short sprint and a leg strength measurement. The results showed no correlation between the goalkeepers' skill level and their score in any of the tests. Thus, with reservation for the limited number of subjects, we conclude that the measured biomechanical parameters are of minor importance for assessment of the goalkeeper's skill level. We suggest that other skills as for example tactical understanding, positioning, perception and anticipation might be more important for the goalkeeper.

Keywords: Soccer, Goalkeeper, Skill level

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1. Introduction

Soccer is a popular and well-known game worldwide with numerous matches of different levels played every day. People are fascinated by the unpredictable game, which, on occasions, can be determined in seconds by extraordinary moves or fatal mistakes. As the last line of defence, the goalkeeper is often directly involved in these decisive moments. Thus, it seems relevant to investigate the goalkeeper's play in greater detail. Although an extensive amount of soccer research has been published, e.g. in conjunction with the scientific congress on the various styles of football held every four years (e.g. Reilly, et al., 2005), the vast majority is of physiological nature, and hence more applicable to the field players. The goalkeeper's actions are typically very short term, explosive type and technically demanding, i.e. more biomechanical in nature (Bangsbo, 1994). However, in their 1998 review, Lees and Nolan (1998) stated that the biomechanics literature only contained one study on goalkeepers (Suzuki, et al., 1988). Five years later, Lees (2003) stated, on biomechanics applied to soccer skills, that "There are various movement skills that the goalkeeper needs to master, but few of them have been subjected to biomechanical analysis", in his chapter of the book "Science and Soccer" edited by Reilly and Williams (2003). This book by Reilly and Williams and an earlier book by Ekblom (1994), as well as a number of original studies, addressed general, biomechanical characteristics of goalkeepers: Goalkeepers and defenders were stronger than midfielders and forwards when measured isokinetically at slow angular velocities (Oberg, et al., 1984; Togari, et al., 1988); goalkeepers, defenders and forwards performed better than midfielders on counter-movement jumps (Di Salvo & Pigozzi, 1998; Wisloff, et al., 1998; Al-Hazzaa, et al., 2001); goalkeepers had shorter whole body choice reaction time than players in other positions (Togari & Takahashi, 1977, cited via Ekblom, 1994). However, all of these studies compared goalkeepers to players in other positions on general performance characteristics; none of the studies dealt with more detailed biomechanical analyses of goalkeeper

Table 1 Subject characteristics.

Subject	AT	BH	DB	MG	KB	MO
Skill level	series 5	series 4	series 3/1	series1/DS	2nd div.	2nd div.
Height (cm)	194	178	181	177	183	188
Weight (kg)	89	73	75	71	84	80
Age (years)	20	32	25	20	26	27

The Danish soccer leagues comprise (from lowest to highest) series 6-1, regional series, qualification series, national series (called Danmarks-Serien (DS)), 2nd division, 1st division, and the Super League. During the season where the tests were conducted subject DB played matches on a series 3 and a series 1 team, and subject MG played matches on a series 1 and a national series (DS) team.

specific movements. Finally, a Pubmed search at the time of submission of the present paper with the term "goalkeeper" revealed a substantial number of mainly case studies on injuries sustained by goalkeepers (Scerri & Ratcliffe, 1994; Resnick, et al., 1996; Narayanan, et al., 2000; Charalambous, et al., 2002; Luthje & Nurmi, 2002; Tomcovcik, et al., 2003; Giannini, et al., 2004; Shyamsundar & Macsween, 2005; Mihalik, et al., 2005).

As for field players, an activity profile obtained via notation analysis (Reilly, 2001; Reilly & Gilbourne, 2003) is necessary for knowing the specific movements goalkeepers perform when they are involved in decisive moments in a game, but although a number of studies using notation analysis have been published (e.g. Hughes, 1988; Olsen & Larsen, 1997; Rahnama, et al., 2002; Andersen, et al., 2003; Di Salvo, et al., 2007) none seem to focus specifically on decisive actions by the goalkeeper. Ekblom (1994) mentioned a number of critical demands on the goalkeeper: "... jumping to catch the ball, and diving to save." (p. 37); "Anaerobic power of football players tends towards the profile of sprinters for the goalkeeper ..." (p. 92); "Goalkeepers are, in general, taller than the average field player" and "The goalkeeper ... must also be quick and have very fast reactions" (p. 198). Based on these statements, and that goalkeepers are stronger than other players, as previously mentioned (Oberg, et al., 1984; Togari, et al., 1988), we hypothesise that vertical and horizontal jumping ability, reaction time and short-sprint time, and leg strength are important performance determining characteristics for the goalkeeper. We further hypothesise that higher ranking goalkeepers, determined by the league they play in, perform better in tests of these particular skills. Thus, the purpose of the present study is to investigate whether the skill level or rank of goalkeepers correlates to their scores in a series of standardised tests of the above mentioned skills. We believe that a correlation between the goalkeepers' skill level and their test scores would indicate that the biomechanical parameters underlying the tests are important factors for a goalkeeper's match performance. Given any such correlations, we would expect that a performance increase in the test scores would lead to a higher skill level as goalkeeper. This could be used directly in the training of goalkeepers. For example, if horizontal jumping ability is strongly correlated with skill level, we would expect that an increase in this ability would lead to better match performance, and hence urge soccer coaches to emphasize training drills for their goalkeepers that will increase horizontal jumping ability.

2. Methods

Six male goalkeepers of varying skill levels, from the Danish series 5 (lowest) to the Danish 2nd division (highest), participated as subjects (**Table 1**). They were tested during the tournament period of the Danish soccer season and hence considered to be in optimum shape. After having had their weight and height measured, the subjects went through a self selected warm up protocol similar to what they would do before a real game. After warming up, the subjects were taken through a test battery comprising assessment of 6 biomechanical parameters considered important for the goalkeeper's match performance: Squat jump, counter movement jump, reaction jumps, maximal horizontal jump, 10 m sprint and concentric squat, performed in the above listed order. Each activity, with the exception of the concentric squat measurement, was captured with a high-speed digital video camera (JVC DV 9800) operating at 120 frames per second. The camera was placed 1.32 m above floor level 9.48 m from where the subject performed the jumps. The rather long distance between the camera and the subjects was chosen to minimise optical distortions. During squat jumps and counter movement jumps the subject wore a reflective marker over the right hip joint. The video captures were transferred to a PC for subsequent analysis with the APAS video analysis system (Ariel Dynamics Inc., San Diego, U.S.A.). Conversion of digitised coordinates to meters was done using a recording of a 1 by 1 meter square calibration frame.

Figure 1 Setup for the reaction jump test. The two lamps, indicating to which side the subject should jump, are visible at the bottom of the picture.

2.1. Reaction jumps

The subject was filmed facing the camera (**Figure 1**). On each side of the subject a soccer ball was suspended 1.5 m above the floor, 2.5 m from the subject's start position, which was indicated by a mark on the floor midway between the suspended balls. The subject was required to stand with the vertical centreline of the body over this mark, but was otherwise free to adopt the start position he preferred. Two small lamps were placed 0.30 m apart between the subject and the camera. Depending on which of these lamps the investigators turned on, the subject would jump and make contact with either the left or the right ball as fast as possible. Cushioning mats were placed on the floor on both side of the subject. The reaction time (test parameter) was determined from the video capture as the elapsed time from when the lamp lid up to when the ball moved. Each subject performed 3 jumps to each side in random order, without being informed about the number of jumps beforehand.

2.2. Maximal horizontal jump

The subject was filmed facing the camera. On the subject's preferred side a soccer ball was suspended 0.30 m above the floor, 3.69 m from the mark indicating the subject's start position. The remaining start position details were similar to those in the reaction jump test. A cushioning mat was placed on the floor on the same side of the subject as the ball. From the start position the subject would jump sideways trying to make contact with the ball. The subject was allowed to take a short side step towards the ball with the foot closest to the ball just prior to the jump. After each successful attempt the ball was moved a fixed distance (0.13 m) further away from the start position until the subject was unable to reach the ball. The maximal horizontal jumping length (test parameter) was determined as the distance from the start position mark to the ball in the last successful attempt.

2.3. Squat jump

The subject was filmed from his right side. The start position for the jump was with the feet placed parallel side by side, the knees flexed to a 90° angle and the hands held on the hips. From this position the subject executed a maximal vertical jump without moving the hands. The jump height (test parameter) was determined from the video capture as the vertical difference between the hip marker's highest position during the jump and its position when the subject stood relaxed with straight legs. Each subject performed 5 jumps.

2.4. Counter movement jump

The subject was filmed from his right side. The start position for the jump was with parallel feet, straight knees and the hands held on the hips. From this position the subject executed a maximal counter movement jump without moving the hands. The subject could freely choose range and velocity of the downward movement as well as pause duration at the crouched position. The jump height (test parameter) was determined by the same method as for the squat jump. Each subject performed 5 jumps.

2.5. 10 m sprint

The subject performed a 10 m sprint run on a wooden floor from a standing start. In the start position the subject stood 10 m to the left of the camera with the feet placed side by side, facing the running direction. The investigators signalled start by turning on a small lamp placed on a post in front of the camera. The running time (test parameter) was determined from the video capture as the elapsed time from when the lamp lid up to when the subject passed an imaginary line between the camera and the lamppost. Each subject performed 3 sprints.

2.6. Concentric squat

As an indicator of leg strength the subject performed a one repetition maximum (1RM) concentric squat lifting a barbell on the shoulders behind the neck. The subject started by assuming a position with the feet placed parallel side by side and the knees flexed to a 90° angle. Prior to this, a set of pins in the squat rack had been adjusted so the barbell could rest in the rack, slightly touching the subject's shoulders. From this position the subject performed a concentric hip and knee extension to standing upright position, where the barbell was put back into another previously adjusted set of pins in the squat rack. Each subject started with 60 kg. After each successful attempt the weight was increased in 20 kg steps up to a total mass of 100 kg, thereafter in 10 kg steps. Concentric squat score was determined as mass lifted (barbell + plates) (test parameter) in the last successful attempt.

2.7. Statistical analysis

Spearman's rank order correlation coefficient was calculated for each test parameter vs. the goalkeepers' rank (the two highest ranking goalkeepers (KB and MO) played in the same league and was thus tied at the highest rank of 1.5). We furthermore calculated Pearson's product moment correlation coefficient between each pairs of test scores. Considering the low number of subjects, we chose a significance level of 10% instead of the more common 5% to avoid type II errors.

3. Results

Figure 2 presents the results from the 6 biomechanical tests and two anthropometrical measurements. On the abscissa, the subjects are ranked according to skill level from lowest to highest (as in **Table 1**). Spearman's rank order correlation coefficient (ρ) is shown for each pair of test score vs. rank (due to the low subject-to-test parameter ratio we abstain from multiple correlation calculations). The correlation coefficients are either negative, i.e. higher ranking subjects have lower test scores, or too low to be statistically significant at 10% level of confidence. The only parameters showing a slight tendency are the maximal horizontal jump and the reaction jumps. It seems that higher skill level is characterized by longer horizontal jumping ability and faster (shorter) reaction time, but the correlations are weak (not significant).

As the skill levels of our subjects could be naturally assigned to a low, a middle and a high ranking group, each comprising two subjects (see **Table 1**), we present the grouped reaction jump results in **Figure 3**. This grouping facilitates comparison to the study on goalkeepers' diving motion by Suzuki, et al., (1988). Presented this way, the tendency that goalkeepers with higher skill level have faster reaction time becomes more obvious.

Several test parameters were mutually, significantly ($P < 0.10$) correlated (values in parentheses are Pearson's correlation coefficient, r): Squat jump vs. counter movement jump (0.866); squat jump vs. reaction jump right (0.806); reaction jump left vs. reaction jump average (0.803); reaction jump right vs. reaction jump average (0.912); concentric squat vs. concentric squat scaled (0.885); height vs. weight (0.898). These correlations are not surprising, since each of the measurements are related to the skill of the individual goalkeeper; however, the correlations have no importance with respect to the purpose of the present study.

4. Discussion

Biomechanical data on soccer goalkeepers are scarce (Lees & Nolan, 1998), so to ease comparison with future studies we have described our test methods in rather elaborate detail. When choosing the tests for our study we considered this comparison issue as well as activity analyses of goalkeepers from the literature. According to the review by Lees and Nolan (1998), only a single published study have dealt specifically with goalkeepers. In this study Suzuki, et al., (1988) compared the diving motion among differently ranked goalkeepers. In addition,

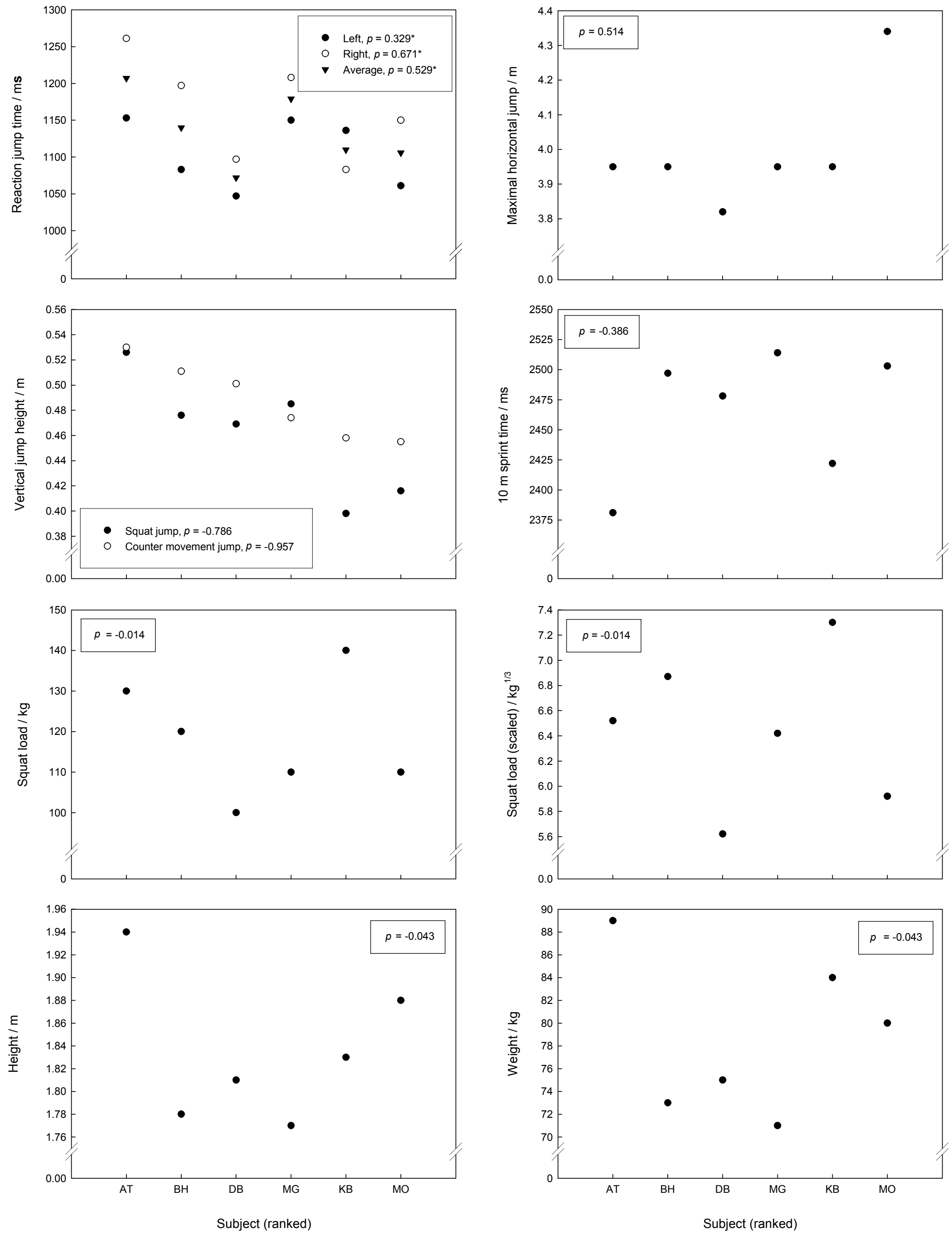

Figure 2 Results from the 6 tests as well as height and weight vs. subject rank. *In the two time measurements (reaction jumps and 10 m sprint) a lower score (i.e. a shorter time) resulted in a higher rank in the rank correlation.

various authors have reported that goalkeepers were stronger than other players (Oberg, et al., 1984; Togari, et al., 1988), performed better than midfielders on counter-movement jumps (Di Salvo & Pigozzi, 1998; Wisloff, et al., 1998; Al-Hazzaa, et al., 2001), and had shorter whole body choice reaction time than players in other positions (Togari & Takahashi, 1977, cited via Ekblom, 1994). In the present study we wanted to employ a broader range of tests, not so much to establish a standardised test battery for goalkeepers, but rather to investigate whether a number of measurable biomechanical parameters are related to the accepted skill level of the goalkeeper. Due to the scarcity of goalkeeper related papers in the literature, our choice of tests was primarily based on the above mentioned studies. However, we tried to design a number of jumps that more closely resemble typical decisive movements by the goalkeeper, while still being easy to standardise. Our choice of these "typical, decisive movements" was in part based on an extensive activity analysis of 21 goalkeepers in 12 matches by one of the authors

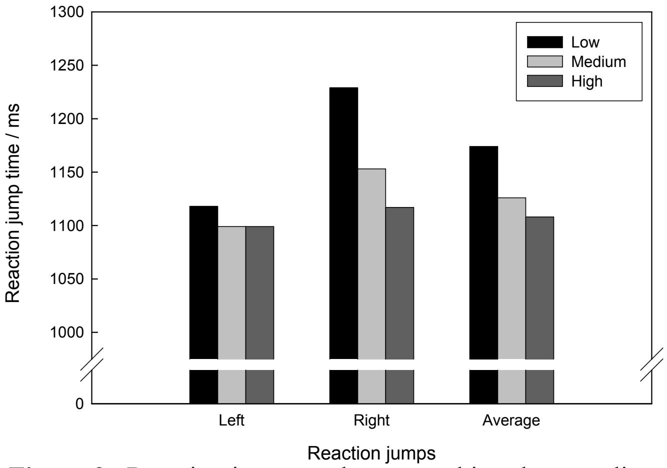

Figure 3 Reaction jump results grouped into low, medium and high skill level.

of the present study (Thomassen, 2000, unpublished thesis). We ended up with 6 tests comprising two horizontal jumps including one similar to the one investigated by Suzuki, et al., (1988), two vertical jumps, a short sprint and a leg strength test.

Suzuki, et al., (1988) stated that the side jump (dive) was the most used technique by the goalkeeper, while Ekblom (1994, p. 37) stated that "diving to save" are among the critical demands on the goalkeeper. In addition, Thomassen (2000) found that the goalkeeper reacted with a side jump in approximately one third of the situations where the ball was played towards him; of these almost 60% were decisive – the opposing team scored. Hence, we included two side jump tests where reaction time and jumping ability were measured. Our reaction jump test was deliberately designed similarly to the one used by Suzuki, et al., (1988), i.e. balls suspended the same distance from the start position, and jump side instruction given by a light signal. Suzuki, et al., (1988) found that two upper class goalkeepers could propel their centre of gravity with greater velocity and in a more direct trajectory towards the ball than two lower class goalkeepers. Assuming that higher velocity jumps give shorter reaction time (from light signal to ball contact) our grouped results (**Figure 3**) corroborate the findings by Suzuki, et al., (1988). Other studies on reaction time are equivocal. Ekblom (1994, pp. 90-91) stated that although reaction time in response to visual stimuli is shorter for athletes than non-athletes, there is no significant difference between goalkeepers and outfield players. The author further speculated that "the apparently rapid responses of goalkeepers in competitive conditions can be attributed to their trained ability to anticipate the attackers' play from antecedent cues". This is in line with Togari and Takahashi (1977, cited via Ekblom (1994, p. 91)), who found no differences in simple whole body reaction time between various playing positions, although goalkeepers were generally faster to react in choice whole body reaction time. These authors also speculated that "this superiority is likely to be largely a product of training specific to that position".

Our maximal horizontal jump test also showed a non-significant tendency towards higher ranking goalkeepers performing better, but the positive correlation was mainly due to a single outlier (subject MO); his better score in this test might be due to his height (he is the second tallest subject), although we did not see a general correlation between height and maximal horizontal jump length. General jumping ability and height have previously been mentioned by Ekblom (1994): "The goalkeeper must be a skilled jumper, as many saves require a maximum jump to reach the ball" (p. 69) and "Goalkeepers should have a certain height to reach the ball, not only because of the size of the goal, but also to be able to dominate the air in the penalty area in, for example, heading situations. Goalkeepers are, in general, taller than the average field player" (p. 198).

Regarding vertical jumping ability, Ekblom discussed the importance and best movement strategy for jumping as high as possible in response to high shots near the cross-bar (Ekblom, 1994, p. 69). In contrast, Thomassen (2000) stated that vertical jumps seldom occur in decisive situations, but he speculated that good vertical jumping ability might allow the goalkeeper to interfere more frequently in the goal field, e.g. in situations where he would otherwise leave high balls to be headed by defending field players. This could indirectly affect his skill level. Hence, we included two vertical jumps among our tests (squat jump and counter movement jump). However, although the subjects expectedly jumped higher with a counter movement (Bobbert, et al., 1996), their vertical jumping ability was not significantly correlated to their skill level.

Reilly and Bangsbo (1998) reported that the goalkeeper on average performs 7 sprints in a match, and Ekblom wrote that goalkeepers anaerobic power are comparable to sprinters (Ekblom, 1994, p. 92). Thomassen (2000) reported an average of 4 sprints per match, of which 41.2% occurred in decisive situations. Thus, we included a 10 m sprint test, but found no significant correlation with skill level. This contrasted Kollath and Quade (1992) who found that professional soccer players sprint faster than amateurs. However, it was unclear whether that study included goalkeepers, and their subjects furthermore started the sprint on their own initiative, which makes comparison to our study difficult, as we used an external start signal, which caused reaction time to be included.

Togari, et al., (1988) found that goalkeepers had significantly higher knee extension torque than other players when tested isokinetically at slow speeds (1.05 rad/s) but not at higher speed (3.14 rad/s). Four years earlier, Oberg, et al., (1984) found the same difference when they measured at 0.52 rad/s; the authors further reported that the difference was caused by differences in body size since correction for body surface area removed the effect of playing position. This was later corroborated by Wisloff, et al., (1998) who found that differences in isokinetic strength between playing positions were removed when data were scaled to weight (W) raised to the power 0.67 ($W^{2/3}$). We included a concentric squat test because we expected leg strength to influence jumping and sprinting performance, and thereby indirectly skill level. The squat movement resembles jumping more closely than isokinetic knee extension, and the two different test modalities have been shown to correlate equally well to vertical jump performance (Augustsson & Thomee, 2000). We used the absolute squat load as well as load scaled to Weight (W) (not shown in **Figure 2**) and the theoretically more correct scaling to $W^{2/3}$ (Jaric, 2003). However, only absolute squat load vs. 10 m sprint time tended to correlate ($r = -0.726$, $P < 0.102$), and we did not find a significant correlation between any of the concentric squat load measures and skill level.

Finally, we recognize that our use of league to rank skill level possibly possesses a validity problem, which is unfortunate, since the entire study is based on this ranking. Until a better ranking method becomes available, future studies should reduce this problem by including more subjects.

5. Conclusions

With the possible exception of the reaction jump test, which showed a slight tendency to correlating with skill level, and thereby to support the findings by Suzuki, et al., (1988), our hypothesis that higher ranking goalkeepers would perform better in the biomechanical tests we employed, has been falsified. Hence, the immediate conclusion is that vertical and horizontal jumping ability, reaction time and short-sprint time are *not* important skills for the goalkeeper. We acknowledge that this conclusion can be incorrect due to a type II error caused by the low number of subjects. On the other hand, if the conclusion is correct, then what is required of the good goalkeeper? One possibility is that skill level is determined by a completely different set of biomechanical parameters, but this does not seem plausible, given the goalkeeper demands and activity analysis by Ekblom (1994) and Thomassen (2000), respectively. Instead, we speculate that a goalkeeper's skill level is determined by more elusive factors such as tactical understanding, positioning, perception and anticipation. This is supported by Ekblom's (1994) notions of goalkeepers' trained ability to anticipate the attackers' play (p. 91) and demand for "a well-developed sense for the play of football" (p. 198) and further by the author's speculations about experience: "… players (may) mature in this position (goalkeeping) with experience in the game" (p. 79). In case of our above conclusion *not* being correct, i.e. vertical and horizontal jumping ability, reaction time and short-sprint time *are* important skills for the goalkeeper, which we simply failed to show because of our limited number of subjects and the ranking validity problem, the more elusive factors might still play an important role alongside the more biomechanical jumping and sprinting skills. If this is the case, goalkeepers should supplement their traditional, biomechanical skills training of specific jumps, etc., with more complex, real play like situations. In popular words: The good goalkeeper never gets himself into a situation where he has to jump!

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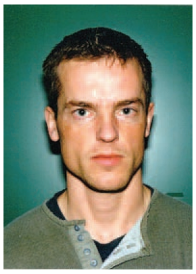

Name:
Henrik Sørensen

Affiliation:
Department of Sport Science, University of Aarhus, Denmark

Address:
Dalgas Avenue 4, DK-8000 Arhus C, Denmark

Brief Biographical History:
2000-2002 Assistant Professo, Department of Sport Science, University of Aarhus, Denmark
2002- Associate Professo, Department of Sport Science, University of Aarhus, Denmark

Main Works:
- Sorensen H, Zacho M, Simonsen EB, Dyhre-Poulsen P, Klausen K (1996). Dynamics of the martial arts high front kick. Journal of Sports Sciences 14(6), 483-495