Effects of fatigue on interlimb communication in soccer players

Frederik Brik, Niklas Bjerrum and Simone May Agger

Department of Health Science and Technology, Aalborg University, Aalborg, Denmark.

Sport science, 7th semester, December 2014

Purpose: The aim of this study was to investigate how the short-latency crossed reflex (SLCR) is affected by fatigue clinically induced by the SAFT 90 protocol in humans during walking. **Methods:** Maximal voluntary contraction (MVC), Twitch Interpolation Technique (TIT) and SLCR responses were measured for 7 healthy, male, amateur soccer players (age 24.72 +/- 2.43, height 181.43 +/- 4.24 cm and weight 75.57 +/- 4.72 kg). Pre and post measurements were collected for a session of control and a session of SAFT90 to induce fatigue. Sessions were separated by one week. **Results:** The SLCR did not change significantly (P>0.05) between the pre and post SAFT condition. MVC force declined significantly (P<0.05) but neither measurements of TIT decreased significantly; voluntary activation (P>0.05) and relaxed post-stimulation max force (P>0.05). **Conclusion:** The SLCR was not affected by fatigue in this study, but further studies are needed to learn more about this area. Fatigue was induced shown by a decrease in MVC, but it could not be shown whether it was central or peripheral fatigue.

INTRODUCTION

Locomotion such as walking and running represents an essential part of human activity, which also constitutes a central part of soccer. For locomotion coordination between the two legs is required. Coordination between the legs is especially important if our balance is challenged by perturbations like any changes in ground surface or by obstacles on our path. Although the structure of the neural networks involved with this coordination are not yet completely known, though studies involving locomotion suggest a coupling of the neuronal circuits controlling each leg (Reisman et al. 2005) and the involvement in this connection of spinocerebellar pathways (Reisman et al. 2007). Direct commissural interneurons connecting the opposing limbs have been found within the spinal cord of animals (Edgleyet al. 2003, Jankowska 2008; Jankowska and Noga 1990). It has been suggested that a similar interneuron exist in healthy humans, which have been suggested by Stubbs and Mrachacz-Kersting (2009), and Stubbs et al. (2011a; 2011b.), which showed a short-latency inhibition of the contralateral soleus muscle (cSOL) after ipsilateral tibial nerve (iTN) stimulation. The onset latencies of the depressed response in the contralateral soleus muscle were measured to be between 37-41 ms, which means that it is too short to be mediated by supra-spinal pathways and therefore must be spinally mediated (Stubbs & Mrachacz-Kersting, 2009). A study by Gervasio et al (2013) showed that this response was accompanied by a response in the synergistic gastrocnemius lateralis muscle and that reversal of the response occurred when an opposite reaction was needed. The short-latency crossed reflex response (SLCR) between the limbs is believed to be important to react promptly if any threat to stability occurs. A study by Gervasio et al (unpublished data) showed the SLCR to produce a displacement of the center of pressure (CoP) location toward the anterior (from 90% to 98% of the ipsilateral gait cycle) and medial direction (from 92% to 100% of the ipsilateral gait cycle). With the ipsilateral leg approaching heel strike when stimulated, it was suggested that the SLCR accelerates the propulsion phase of the contralateral leg to protect the dynamic stability by preparing it to a faster step in case of the ipsilateral leg not being able to sustain the body weight (Gervasio et al, unpublished data). This would be relevant in soccer where the athlete is exposed to perturbations like tackling, challenges for possession of the ball and when playing on a slippery field (Reilly & Williams, 2003).

Not many studies have examined this SLCR and no work has yet been published on how this response would be affected by fatigue. Fatigue is an activity-induced decline in performance seen by a decrease in the contractile function of the skeletal muscle that occurs after prolonged strenuous activity (Westerblad et al, 2010). Especially in a situation like soccer, which requires a prolonged strenuous activity that was proven to induce fatigue by Mohr et al (2007), an impaired interlimb communication due to fatigue may lead to complications for soccer players and increase their predisposition for injuries during the latter stages of the match (Small et al, 2008). Previous studies have shown the Soccer-Specific Aerobic Field Test (SAFT90) protocol to replicate the work performed during a soccer match (Small et al 2008, Small et al, 2009) and thereby the fatigue induced by a soccer match.

Therefore, the current study investigated how the SLCR observed during human walking is affected by fatigue induced by the SAFT90 protocol.

METHODS

Subjects

7 healthy, male, amateur soccer players participated in this study (age 24.72 ± 2.43 years, height 181.43 ±4.24 cm and weight 75.57 ± 4.72 kg). They all practice an average of 6 hours per week.

None of the subjects had neurological, musculoskeletal or mental illnesses.

Each subject was given a written and a detailed verbal explanation of the experiment and signed an informed consent statement.

Design of the study

This was a crossover study, which extended over two days for each subject, with one week apart. Subjects were their own control and underwent one intervention session with a SAFT90 protocol for inducing fatigue and one control session where the subjects were sedentary. The order of this allocation was randomized for each subject.

The control session consisted of a pretest, 2 hours of being sedentary and a posttest.

The intervention session consisted of a pretest, a SAFT90 protocol and a posttest.

Each session lasted 4 hours per subject.

The pre and posttest consisted of measurements of the maximal voluntary contraction (MVC), the twitch interpolation technique (TIT) while seated, and the crossed reflex response during walking at a fixed speed of 4 km/h. The tests were performed in the order as mentioned; MVC, TIT and crossed reflex response.

In this study the non-dominant leg is defined as the ipsilateral leg and the dominant leg is defined as the contralateral leg.

Apparatus and measurements

During MVC and TIT, which were measured while seated, measurements were performed on the contralateral leg using a force platform (AMTI, Watertown, Massachusetts, model no 0R6-7-1000), where the leg was fastened with an adjustable stand, with a 90-degree angle at the knee- and ankle joint. The leg was fastened tightly, preventing the subject from being able to lift the heel from the platform. Tape indicated were to place the heel on the force platform, to secure that the foot was placed at the same point every time.

During TIT, electrical stimulation was applied to the posterior tibial nerve (PTN) of the contralateral leg, were a cathode (PALs platinum round electrode, model no. 879100, 3.2-cm diameter, Axelgaard Man) was located at the popliteal fossa and an anode (PALs platinum rectangular electrode, model no. 895240, 5x9 cm, Axelgaard Man) was placed at the anterior side of the knee, proximal to the patella (approximately 9 cm from the center of the patella to the center of the anode). For each subject the position of the cathode was adjusted until the optimal stimulation site was found, by observing the M-wave from the ipsilateral soleus (iSOL). Electrodes were placed according to Cram et al (1998).

During the crossed reflex measurements, stimulation of the PTN on the ipsilateral leg was applied using the same type of cathode and anode and placed in the same way as during the MVC and TIT. Surface electrodes (Neuroline 720 silver/silver chloride, AMBU) were used to record electromyographic activity (EMG) of the iSOL, the cSOL and the contralateral gastrocnemius lateralis muscle (cGL). The EMG signals were sampled at 2 kHz and acquired using the scientific software Mr. Kick version III (Knud Larsen, Center for sensory-motor interaction, Aalborg University).

A pressure-sensitive trigger was placed on the sole of the shoe at the level of the heel of the ipsilateral leg and used to trigger the electrical stimulation. The subject was stimulated at the iPTN while walking and the response was measured in the iSOL, cSOL and the cGL.

Establishment of fatigue

A SAFT90 protocol was used to establish fatigue similar to fatigue caused by a soccer game. (Lovell et al, 2008). The protocol consisted of standing (0.0 km/h), walking (5.0 km/h), jogging (10.3 km/h), striding (15.0 km/h), sprinting (≥20.4 km/h), and utility movements (side steps and running backwards) (Small et al, 2008). The protocol was executed outdoor, on grass, on a 20-meter course (see figure 1). Tall poles were used so the subject's whole body had to navigate the course.

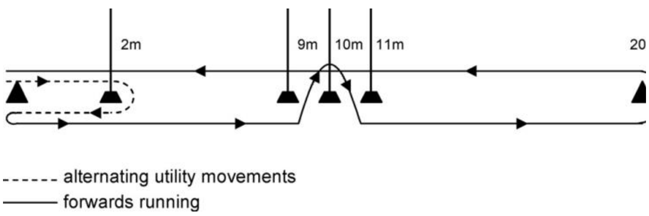

Figure 1. *Schematic representation of the SAFT90 course. The pace and utility movements are directed by verbal signals from and audio CD (Small and Lovell, 2008)*

An audio CD (SAFT90v51) with directions of the pace and movements was played by a transportable speaker. The protocol consisted of two half's, each lasting 45 minutes, separated by a 15-minute passive rest period (half-time).

Prior to the SAFT90 protocol the subject completed a standardized 15-minute warm up (see appendix 1) and a familiarization to the protocol.

The subjects wore their own soccer cleats and clothes during the protocol and electrodes were kept on, protected by football socks. Temperature was measured for each day of the SAFT90 protocol (8.43± 2.2 degrees Celsius).

Procedure

On the first day of the experiment the subject was given detailed verbal information of the experiment and signed an informed consent statement. Height, weight, age and the dominant leg of the subject were determined. The dominant leg was determined by questioning the subjects.

M-max of the cSOL was established while the subject was seated, and 120% of M-max was then used for stimulation during the following TIT. The leg of the subject was then fastened against the force platform. The subject was instructed to sit with a straight back and arms akimbo and to produce a quick and forceful contraction of cSOL and cGL by a plantar flexion of the ankle joint. Before measuring the MVC of the subject a warm up of 2x25%, 2x50% and 2x75% of perceived MVC was conducted. Then four MVC were performed with one 1 minute of rest in between; 2 MVC without stimulation and 2 MVC for the TIT. Stimulation was applied when the subject reached MVC and again when the muscles were relaxed to measure the post-stimulation maximum force, which is used for evaluating whether peripheral fatigue is induced.

A walking profile was obtained by measuring the average gait cycle duration of the subject, by having the subject walking on the treadmill at the predetermined speed for 30 gait cycles. For the stimulation timing, 80% of the gait cycle was used during the crossed reflex response. This stimulation timing has been previous been used to elicit SLCR in the cSOL (Stubbs et al, 2011b). The M-max of iSOL was measured during walking and 85% of M-max was used for stimulation intensity during the crossed reflex measurements. The stimulation intensity has previously been used to elicit SLCR by Stubbs and Mrachacz-Kersting (2009).

Depending on the allocation of the experimental day, the subject underwent either the SAFT90 protocol or 2 hours of being sedentary before the measurements were conducted once again.

Data analysis

Data from the MVC, TIT and crossed reflex response was analyzed using SPSS version 22. A two way repeated measures ANOVA was performed on all the datasets to determine their significance.

To make sure that the calculated 85% of M-max and the measured 85% of the walking M-max for the crossed reflex response was not statistically different, a paired t-test was conducted.

The limit of significance was set at $P<0.05$. Results are expressed as a mean ± standard deviation.

The latencies of the crossed reflex responses had an average onset of 65.17 ± 3.4 ms and had an average duration of 33.82 ±6.4 ms. Therefore, a fixed window of 65-95 ms was used for data analysis of all crossed reflex responses.

RESULTS

All 7 subjects had the right leg as their dominant leg.

MVC

Figure 2 shows the mean MVC recorded from all subjects in the different conditions. Significant difference was found from pre SAFT to post SAFT with a decreased from 1633 ± 151 N to 1263 ± 292 N, ($P < 0.05$). However in the control conditions no significant difference was found with 1354 ± 391 N for the pre control and, 1352 ± 404 N for the post control MVC, ($P > 0.05$).

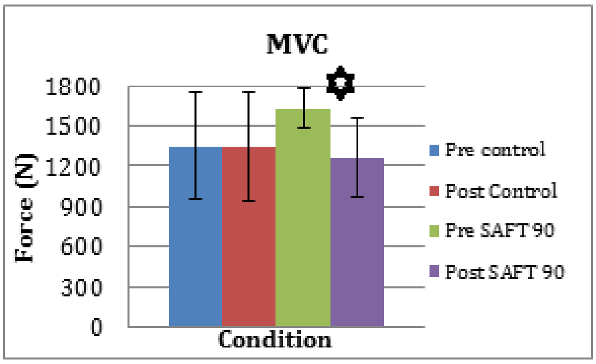

Figure 2. Mean maximal voluntary contraction (measured in Newton) for all 7 subjects during the 4 conditions (pre control, post control, pre SAFT90 and post SAFT90). MVC was measured using a force platform while performing a maximal plantar flexion with the dominant leg.

Crossed reflex response

As seen in figure 3 the mean response was 207 ± 107 % for the pre control condition, 182 ± 85 % for the post control, 171 ± 55 % for the pre SAFT90 and 146 ± 35 % for the post SAFT90.

The data did not show any significant change in response size within the 4 different conditions ($P > 0.05$).

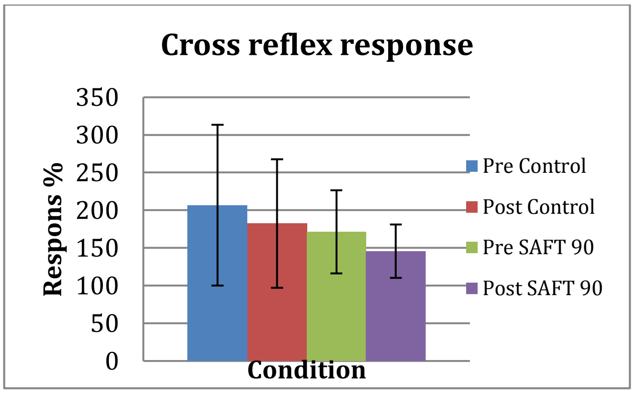

Figure 3. The magnitude of the crossed reflex response as a % of control muscle activity in the cGL for all 7 subjects, for all conditions. The response was evoked by ipsilateral tibial nerve stimulation at 85% of M-max.

Although there are no significant difference between conditions, the mean crossed reflex response decreased with an average of 13 % in the control session and decreased with an average of 18 % in the SAFT session, thus with a larger decrease in the SAFT session.

The magnitude of the M-wave (normalized to the M-max) elicited in iSOL did not show any significant difference within the different conditions ($P > 0.05$).

Figures 4, 5, 6 and 7 show the control muscle activity (uV) and the crossed reflex response (black and red line respectively)

in the time window of 65-95 ms following stimulation onset, during all conditions for a representative subject. As shown in figure 4 the pre control crossed reflex response for the subject had a magnitude of 395 % of control muscle activity.
As shown in figure 5, the post control crossed reflex response for the subject had a magnitude of 350 % of control muscle activity. As shown in figure 6, the pre SAFT crossed reflex response for the subject had a magnitude of 293% of control muscle activity. As shown in figure 7, the post SAFT crossed reflex response for the subject had a magnitude of 116% of control muscle activity

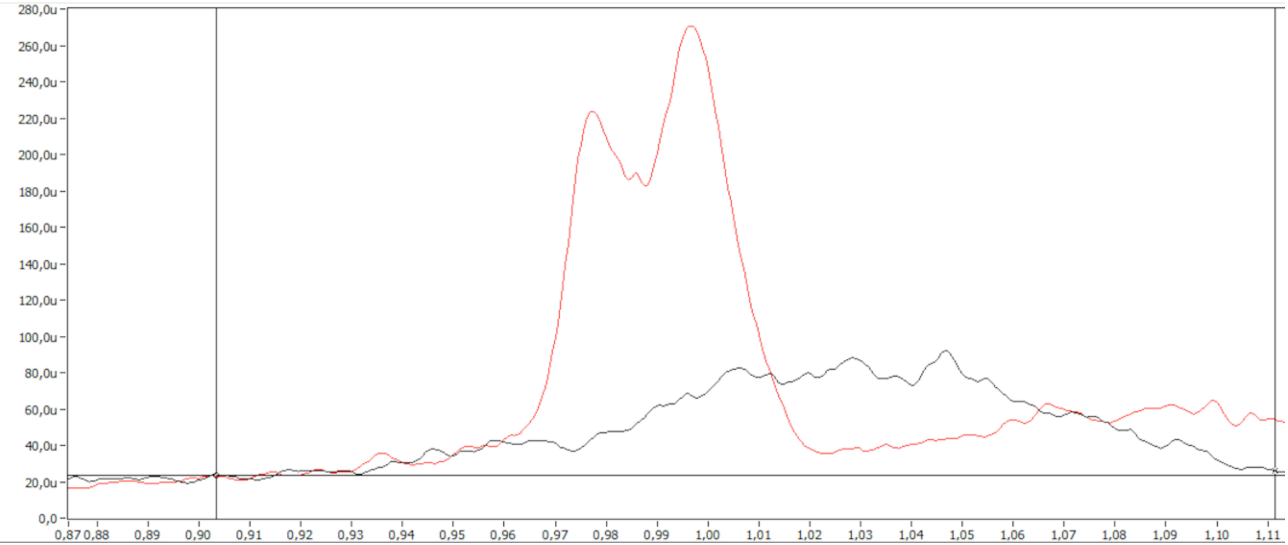

Figure 4. The pre control baseline muscle activity (uV) (black line) and the cross reflex response (red line), elicited by electrical stimulation at 85% of M-max during walking.

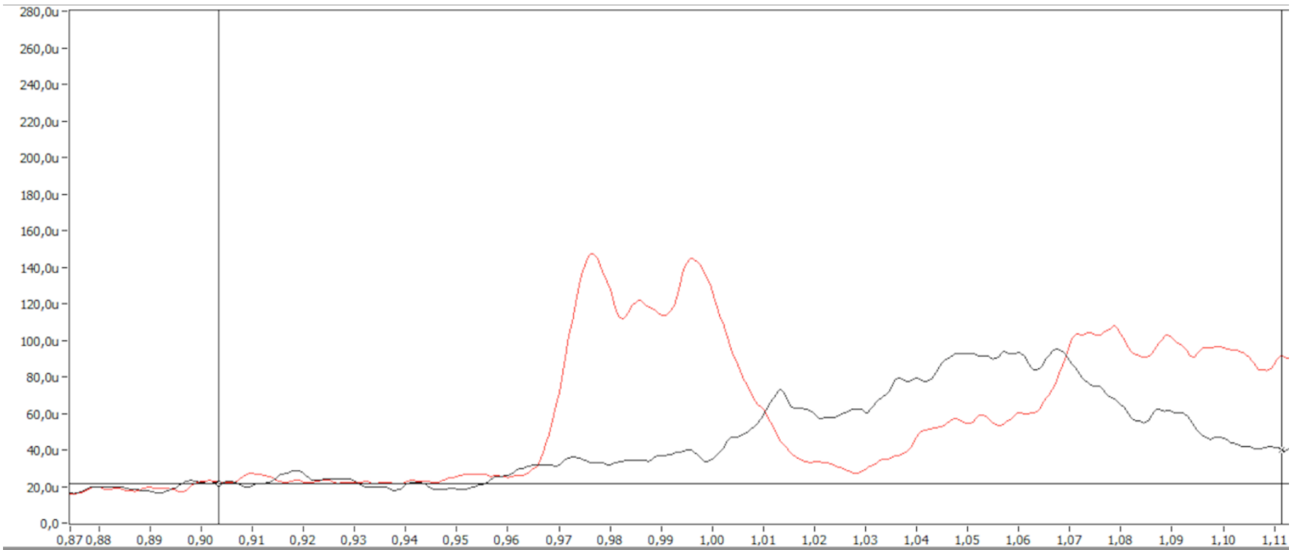

Figure 5. The post control baseline muscle activity (uV) (black line) and the cross reflex response (red line),

elicited by electrical stimulation at 85% of M-max during walking.

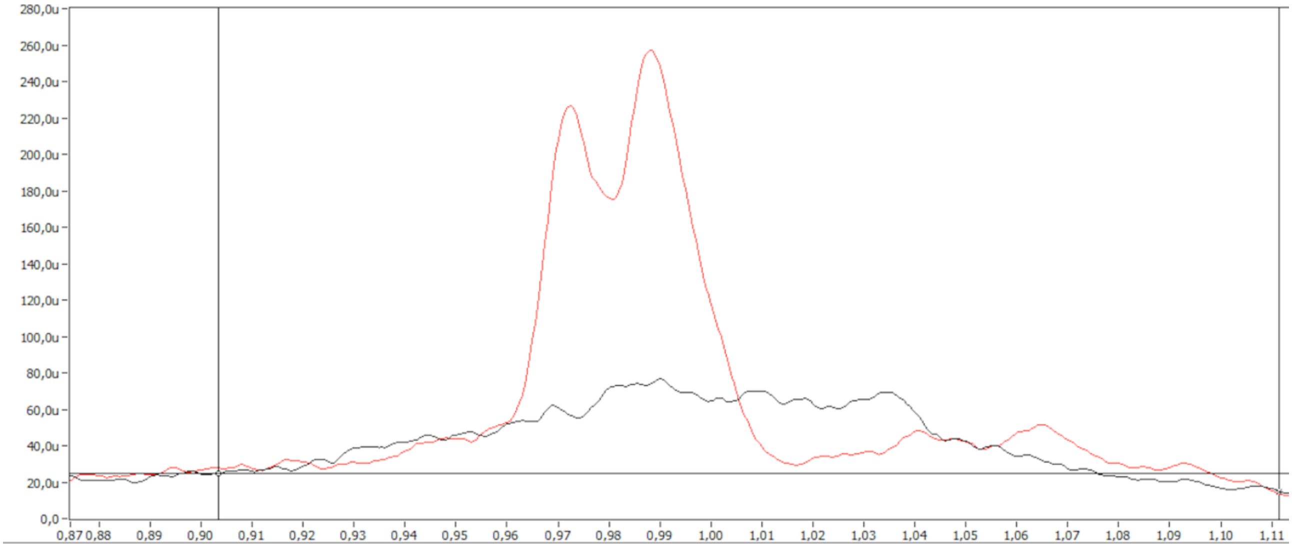

Figure 6. The pre SAFT baseline muscle activity (uV) (black line) and the cross reflex response (red line), elicited by electrical stimulation at 85% of M-max during walking.

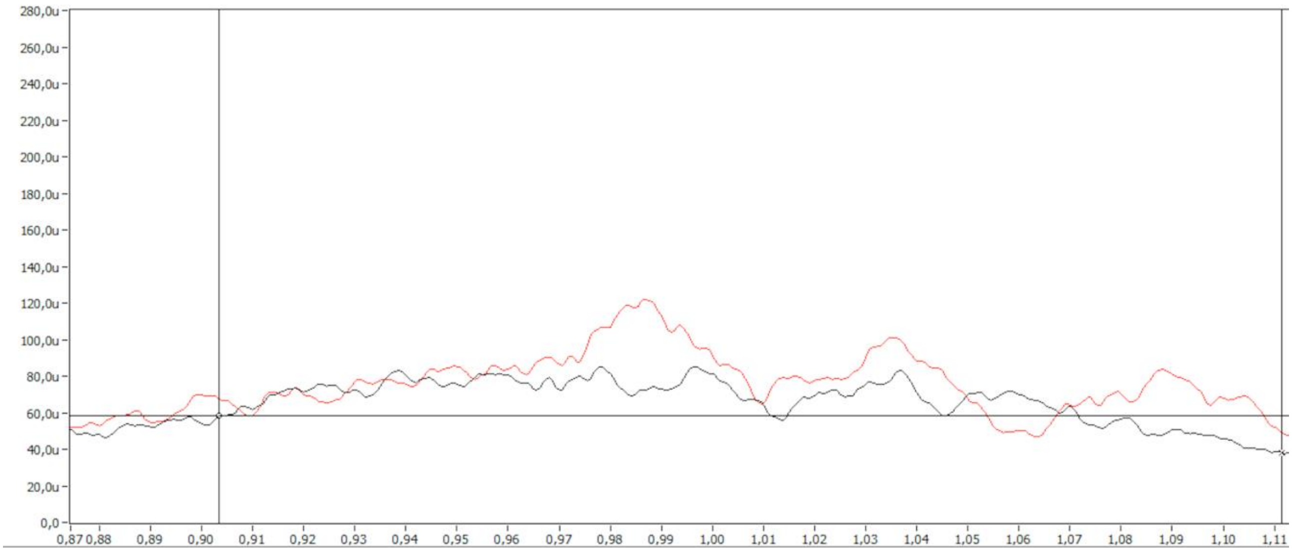

Figure 7. The post SAFT baseline muscle activity (uV) (black line) and the cross reflex response (red line), elicited by electrical stimulation at 85% of M-max during walking.

TIT

The TIT data is divided into two charts; one for the voluntary activation (central fatigue) and one for the relaxed post-stimulation max force (peripheral fatigue). As seen in figure 8, the mean voluntary activation as a percentage of the mean maximal voluntary activation, was 77.1 ± 22.6 % for the pre control, 69.1 ± 31.6 % for the post control 79.6 ± 14.7 % for the pre SAFT90 and 70.3 ± 25.9 % for the post SAFT90.

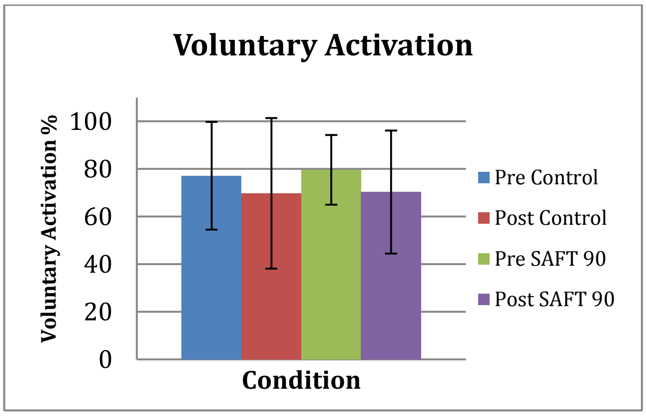

Figure 8. The percentage of the mean maximal voluntary activation of the contralateral leg during the 4 conditions. Measurements are achieved when stimulating the contralateral tibial nerve with 120% of M-max, while subjects performing a maximal plantar flexion with the contralateral leg.

No significant change in voluntary activation was found within the 4 conditions (P >0.05).

As seen in figure 9 the mean maximal force post stimulation at relaxation was measured to be 252 ± 151 N for the pre control, 232 ± 158 N for the post control, 273 ± 171 N for the pre SAFT90 and 248 ±111 N for the post SAFT90.

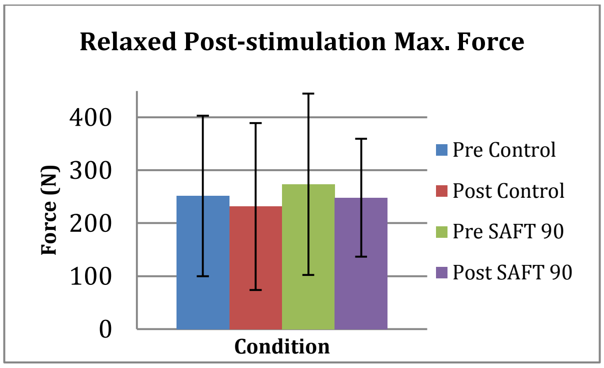

Figure 9. The mean maximal force (N) of the contralateral leg for all 7 subjects, measured when subjects were relaxed, just after subjects had performed a maximal plantar flexion with the contralateral leg. Measurements were achieved when stimulating the contralateral tibial nerve with 120% of M-max.

No significant change in voluntary activation was found within the 4 conditions (P >0.05).

DISCUSSION

The aim of this study was to investigate how the SLCR observed during human walking is affected by fatigue induced by the SAFT 90 protocol.

The present study successfully induced fatigue as shown by the significant

decreased MVC force measured at the post SAFT condition compared to the other conditions. A reduction in MVC from pre to post condition has been validated by literature to be a reliable way of measuring muscle fatigue (Vøllstad, 1997). However, this study did not show any significant change in the SLCR between the pre SAFT and post SAFT condition.
As shown in figure 3 the mean crossed reflex response does not decrease significantly from pre to post measurements in any of the sessions, but a tendency of a decreased response is observed. Even not significant, the largest decrease is observed from pre to post measurements in the SAFT condition. Based on this, it could be argued whether this is due to a lack of statistical power.

Even though the MVC measurements showed fatigue it could not be shown trough the twitch interpolation analysis whether the induced fatigue was central or peripheral, because no significant change could be found in either the relaxed post-stimulation maximum force (indicating peripheral fatigue) or in the voluntary activation (indicating central fatigue). Central fatigue occurs in the central nervous system, where the α-motor neurons, that activate the muscle fibers for contraction, fail to be activated. (Westerblad et al, 2010). Exercise alters the levels of neurotransmitters in the central nervous system, such as dopamine, serotonin and acetylcholine (ACh), which all affects the perceptual state of exercise but also slows the synaptic transmission (McArdle, Katch el al 2010, Bears, Connors et al 2006). Peripheral fatigue occurs at strenuous exercise where metabolic changes affect the steps within the muscle that causes a contraction. (Westerblad et al 2010, McArdle, Katch et al 2010). It is important to distinguish between peripheral and central fatigue because the general picture is that central fatigue is of greater importance during prolonged low-intensity activities, where metabolic changes within muscle cells are likely to be limited, whereas intramuscular factors appear to dominate during activities of higher intensity (Westerblad et al, 2010).

One of the factors that could affect the mediation of the SLCR is different types of afferent fibers in the body. The cutaneous afferents have been ruled as an unlikely course of the reflex mediation (Stubbs & Mrachacz-Kersting, 2009), but the group 1a, 1b an group 2 muscle afferents in the ipsilateral leg have been suggested to mediate parts of the SLCR. (Stubbs & Mrachacz-Kersting, 2009).

As a previous study has shown (Stubbs & Mrachacz-Kersting, 2009), the stimulation intensity has an effect on the size of the SLCR. Therefore a paired t-test was conducted in this study to make sure that the M-wave amplitude, normalized to the M-max for each subject, was not statistically different in any of the conditions. The fact that the calculated M-wave amplitude was not statistically different ($P>0.05$) means that the lack of change in the SLCR between the conditions could not be explained by significantly higher or lower stimulation intensities than at the other conditions.

A significant decrease in the SLCR from the pre SAFT to the post SAFT condition was expected based on several considerations. Previous studies have evidenced a decrease in the H-reflex amplitude during a state of fatigue (Duchateau and Hainaut, 1993). The mechanism responsible for the change in behavior of the H-reflex and long latency response (LLR) has been suggested to be due to changes in peripheral drive. This possibly induces presynaptic inhibition of 1a afferent and/or inhibition of the interneuron in the oligosynaptic pathways but motor neuron activation threshold is not affected. (Duchateau and Hainaut, 1993). They suggest that these inhibitions are caused by metabolical and/or chemical changes in the fatigued muscle (Duchateau and Hainaut, 1993).

A way of considering the SLCR is as being similar to the LLR described by Duchateau and Hainaut (1993) in their paper about short and long latency reflexes in fatigued human muscles. This is based on the fact that the H-reflex is a monosynaptic reflex and the SLCR is a more complex reflex that involves multiple synapses and the fact that the response latency for the LLR was shorter than the SLCR in this study (The LLR had an average of onset latency 50 ms and the SLCR had an average onset latency of around 65 ms) (Duchateau and Hainaut, 1993). The LLR was elicited ipsilaterally in the hand (Duchateau and Hainaut, 1993), which makes the neurological loop much shorter and hereby making a comparison of the onset latencies difficult. In line with reduction seen in the amplitude of the H-reflex, the LLR also showed a reduction in amplitude, but this was not found to be significant (Duchateau and Hainaut 1993).

Another aspect that could affect the measurements of this study is awareness. Early studies by Bathien and Morin (1971) showed that the state of awareness of the subject might be able to alter the amplitude of an H-reflex. They found that a high level of attention on the task would lead to an increase in H-reflex, when the level of attention is high (Bathien & Morin, 1972). This study does not record H-reflexes but it can be argued whether other reflexes like the cross reflex could be affected in the same way. This would make the level of attention of the subjects in this study have an impact on the measurements.

In line with this, it could be relevant for future studies to investigate the effect of the level of attention on the SLCR. It could also be interesting to investigate if the SLCR is present in other physical activities like running or jumping which also constitutes a part of the physical activities in soccer (Stølen et al, 2005). But first of all, future studies should further investigate the effect of fatigue on SLCR with a larger sample size to learn more about this area.

Limitations

The present study contains limitations. The small sample size may reflect a lack of power in the statistical analysis and may therefore be a reason of absence of significant results. A small sample size provides a higher risk of a type 2 error, compared to a larger sample size.

Another limitation could be found in the earlier mentioned fact that the response is not completely known and therefore unknown factors like attention could have modulated the response. The present study did not have any strict rules for controlling the attention of the subject and therefore this could have varied within the measurements.

Conclusion.

In this study fatigue was successfully induced by the SAFT90 protocol shown by a significantly decrease in MVC force at the post SAFT condition compared to the other conditions, but it could not be shown whether it was central or peripheral fatigue. However, the fatigue did not have any effect on the SLCR shown by the lack of significant change in the SLCR between pre SAFT and post SAFT condition. To learn more about this area additional studies with a larger sample size are needed.

Literature:

Bangsbo, J. (1994). *The physiology of soccer – with special reference to intense intermittent exercsise.* Acta Physiologica Scandinavica, 151 (suppl. 619) Vol. 619, 1994, p. 1–155

Bathien, N., and Morin, C. (1972) *Comparing variations of spinal reflexes during intensive and selective attention.* Physiol. Behav. 9, 533–538.Vol. 9, Iss. 4, 1972, p. 533–8

Bear, M. F., Connors, B. W. and Paradiso, M. A. (2006). *'Exploring the brain'.* 3th ed., International ed. Edn, Lippicott Williams & Wilkins, Philadelphia, Pa.

Cram J, Kasman G, Holtz J. *Introduction to Surface Electromyography.*
Gaithersburg: Aspen Publication, 1998.

Duchateau, J. and Hainaut, K. (1993). *Behavior of short and long latency reflexes in fatigued human muscles*. Journal of Physiology. vol. 471, pp. 787-799

Edgley SA, Jankowska E, Krutki P, Hammar I. *Both dorsal horn and lamina VIII interneurones contribute to crossed reflexes from feline group II muscle afferents.* J Physiol 552: 961–974, 2003.

FIFA. (2006). *Big Count: 270 million people active in football*.
http://www.fifa.com/mm/document/fifafacts/bcoffsurv/bigcount.statspackage_7024.pdf. (accessed dec 6, 2014).

Gervasio S., Kersting U., Farina D., Mrachacz-Kersting N. *The effect of crossed responses on dynamic stability.* (Unpublished data)

Jankowska E. *Spinal interneuronal networks in the cat: elementary components.*
Brain Res Rev 57: 46–55, 2008.

Jankowska E, Noga BR. *Contralaterally projecting lamina VIII interneurones* *in middle lumbar segments in the cat.* Brain Res 535: 327–330, 1990.

Lovell, R., Knapper, B. and Small, K. (2008). *Physiological responses to SAFT90: a newsoccer-specific match simulation.* Verona-Ghirada Team Sports Conference Proceedings

McArdle, W. D., Katch, F. I. and Katch, V. L. (2010). *Exercise physiology – Nutrition, energy and human performance.* 7th ed., International ed. Edn, Lippicott Williams & Wilkins, Philadelphia, Pa.

Mohr, M., Krustrup, P. and Bangsbo, J. (2005). *Fatigue in soccer: A brief review- a Institute of Exercise and Sport Sciences.* Journal of Sports Sciences, June 2005; vol. 23(6): 593 – 599

Reisman, D. S., Block H. J. and Bastian A. J. (2005). *Interlimb coordination during locomotion: what can be adapted and stored.* Journal of Neurophysiology Vol. 94 no. 4, 2403-2415

Reisman, D. S., Wityk, R., Silver, K. and Bastian, A. J. (2007). *Locomotor adaptation on a split-belt treadmill can improve walking symmetry post-stroke*. Brain. vol. 130: 1861–1872 Issue 7, 01 July 2007

Small K., McNaughton L., Greig M., and Lovell R. (2008). '*The effects of multidirectional soccer-specific fatigue on markers of hamstring injury risk.*' Journal of science and medicine, vol. 370.

Small K., McNaughton L., Greig M., and Lovell R. (2009). '*Effect of training timing of eccentric hamstring strengthening exercises during soccer training: Implications for muscle fatigability.*' Journal of Strength and Conditioning Research, 0(0)/1–7.

Stubbs, P. W. and Mrachacz-Kersting, N. (2009). *Short-latency crossed inhibitory responses in the human soleus muscle*. Journal of Neurophysiology. vol. 102: 3596–3605

Stubbs, P. W., Nielsen, J. F. and Sinkjær, T. and Mrachacz-Kersting, N. (2011b). *Phase modulation of the short-latency crossed spinal response in the human soleus muscle*. Journal of Neurophysiology. vol. 105: 503–511

Stubbs, P. W., Nielsen, J. F., Sinkjær, T. and Mrachacz-Kersting, N. (2011a). *Crossed spinal soleus muscle communication demonstrated by H-reflex conditioning.* Journal of Neurophysiology. vol. 105: 503–511. Muscle Nerve. vol. 43: 845–850

Stølen, T., Chamari, K., Castagna, C. and Wisløff, U. (2005). *Physiology of soccer – an update*. Sports Med. Vol.35(6), pp.501-36

Vøllstad, N.k. (1997*). Measurement of human muscle fatigue*. Journal of Neuroscience Methods. vol. 74 219–227

Westerblad, H., Bruton, J. D. and Katz, A. (2010) *Skeletal muscle: Energy metabolism, fiber types, fatigue and adaptability.* Department of Physiology and Pharmacology, Karolinska Institutet, 171 77 Stockholm, Sweden.

Demands analysis for soccer

A demand analysis is a tool used for analyzing the demands of the sport that are needed by the athletes to be successful within the sport. Analyzing the demands of the soccer and comparing it to the actual capacity of the athlete can enlighten the limiting issues for performance. (Zacho, 2011). The demand analysis of sport covers physical, psychological, tactical and technical demands (Zacho, 2011) and therefore these topics and the themes within the topics that are evaluated as important for soccer will be analyzed.
This demand analysis focuses on male elite field soccer players but does not focus on a specific role or position. As a conclusion to the analysis the discussed demands of soccer is compared to other sports that is considered as having the highest values within the different demands, to evaluate the importance of the demands.

1.The discipline of soccer:

Soccer is considered the world's most popular sport and is played by men and women at all ages and at all levels of expertise (FIFA, 2012; Stølen et al, 2005; Reilly & Williams, 2003). The soccer match is divided in to half's of 45 minutes each separated by a 15-minute break and is played on a field ranging from 90-120m in length and 45-90m in width (FIFA, 2012).

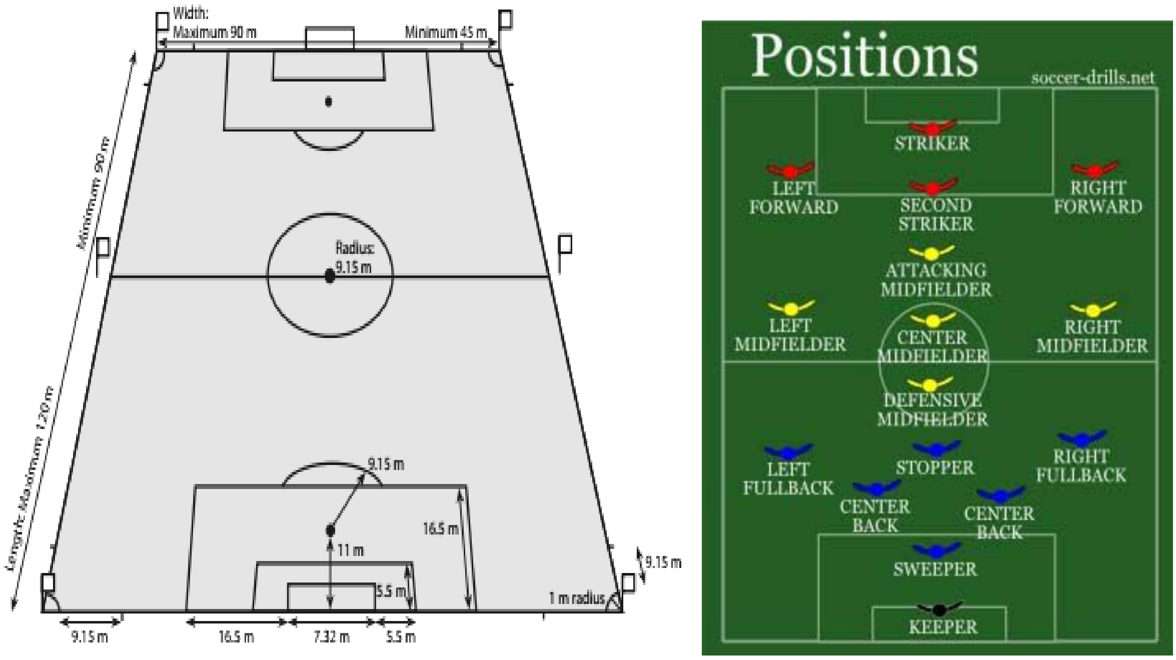

Figure 1. ***Left (1A):*** **Official demands for lengths and dimensions of a soccer field (FIFA, 2012, p. 13).** ***Right (1B):*** **Positions on the field, divided into defend (yellow), midfield (blue) and forwards (red) (Soccer drills, 2014)**

As seen in figure 1B, the players are assigned different positions on the field; goalkeeper, defender, midfielder or forwards, which raises different demands for the players (Mohr et al, 2003). The assignment of positions is based on the player's abilities and anthropometric characteristics (see section 8; 'Anthropometry') due to the different demands of the specific position (Mohr et al, 2003). As mentioned, this analysis will not focus on specific position on the field besides focusing on field players.

During a match a player will encounter changes in pace with walking, jogging, running and sprinting and needing to jump, kick, tackle and changing of directions. A study of Reilly (2003) shows that soccer players perform 1000-1500 changes in pace during a game every 5-6 second. (Reilly & Williams, 2003).

A study by Mohr et al (2003) observed the running intensities of a match and found the value for Danish professional players to be 19,5% standing, walking 41,8%, jogging 16,7%, running 16,8%, sprinting 1,4% and other things 3,7% (see figure 1). (Mohr et al, 2003)

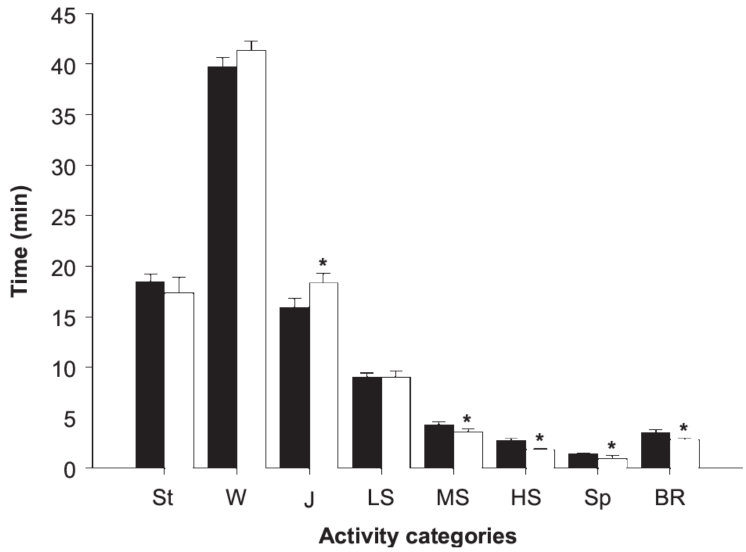

Figure 2. Locomotor categories for top-class players (black) and moderate players (white) during a soccer game expressed as total time (mean+sx_) *Significant difference (P50.05) between groups. St =standing; W=walking; J= jogging; LS, MS and HS= running (Mohr et al, 2003, p. 522)

2. Energy systems

2.1 Aerobic performance

Due to the duration of 90 minutes of a soccer match the soccer player's primary source of energy is coming from the aerobic energy system (Stølen et al, 2005; Reilly et al, 2000). For elite field soccer players a mean running distance of 10-12 km is covered with intensity close to the anaerobic threshold, which is 80-90% of the maximum heart rate. Though, the exercise intensity in the second half is reduced with a 5-10% reduction in the distance covered. (Stølen et al, 2005).

It would be impossible to keep higher mean work intensity at this duration of time because it would result in an accumulation of blood lactate, but at some occurrences during the match the intensity becomes high enough for accumulation to occur. To remove the lactate from the working muscles the players need periods with low intensity (Stølen et al, 2005).

Aerobic energy is achieved by the oxygen break down of proteins, fats and carbohydrate where VO_2max is a measurement that can describe the aerobic fitness of the player (Potteiger, 2011).). VO_2max is generally measured in a lab where the athletes are put on a treadmill or on a cycle ergometer. Soccer players mostly use the treadmill because running is the kind of exercise they perform, to ensure specificity (Stølen et al., 2005). However Hoff et al. (2002) have developed a soccer specific testing method of VO_2max which includes dribbling, jumping, accelerations, decelerations, turning and backward running with the ball through a 30m wide and 55m long track (Hoff et al., 2002). While performing the test a polar sport tester was observing and transmitting the heart rate and a portable metabolic system called 'Metamax II' is placed on the chest to measure volume using a bidirectional digital turbine. A high VO_2max enhance the recovery from the high-intensity intermittent exercise because of the higher aerobic response, improved lactate removal and enhanced phosphocreatine regeneration (Tomlin & Wenger, 2001). The VO_2max for an untrained is about 50 ml/kg/min (Raven et al, 2013). According to a literature review by Stølen et al (2005) the VO_2max varies from 50-75 ml/kg/min for field soccer players which goes in line with a study by Taylor et al (2011) which measured the mean VO_2max for professional male Mexican soccer players to be 54.6 ml/kg/min. An extensive study by Tønnesen et al (2013) who measured VO_2max values on 1545 male soccer players in Norway, found the mean values for national team players to be 67 ml/kg/min and 61 ml/kg/min for soccer players in 3-5 division. (Tønnesen et al, 2013)

It has not been possible so far to establish a precise and valid measurement of VO2 during a soccer match (Stølen et al., 2005), but based on measurements of soccer players' heart rate and body temperature while playing, Bangsbo et al. (2006) evaluates that the average intensity in soccer is near 70% of VO_2max.
When the benefits of a high oxygen uptake is taken into consideration, Stølen et al. (2005) estimates that it would be reasonable to expect a VO_2max around 70 mL · kg-1 · min-1 for professional soccer players of 75 kg.
Soccer is known to be an intermittent sport in the sense where the level of activity and intensity fluctuates during the match, which makes the physiological demands more complex than more continuous sports (Drust et al, 2000).

2.2 Anaerobic performance

Anaerobic performance can be divided into two subcategories; anaerobic power and anaerobic capacity. Anaerobic power is the highest release of anaerobic energy where oxygen to the working muscles is limited and is used at activities that last under 10 seconds, whereas anaerobic capacity is the highest anaerobic energy production a soccer player can obtain when exercising to fatigue, which is the athletes ability to continue using anaerobic energy sources because of a rate limitation in oxygen delivery. Anaerobic capacity is used at high-intensity activities lasting longer than 10 seconds and may last up to 2-3 minutes (Bangsbo,1997; Raven et al 2013).
Although the aerobic energy system is the most active throughout a match anaerobic bouts of exercise are performed. To be able to perform sprints, jumps and tackles the anaerobic energy release is critical for a soccer player and will determine who is the fastest, which in some cases can be essential for the outcome, meaning that it is very important for an elite soccer player to have a high anaerobic threshold. (Stølen et al, 2005, Reilly et al, 2000).
Stølen et al. did a Wingate test on 15 professional soccer players (75,0±8.5 kg) with a peak power output (930W) and found that they in average could produce 638W (Stølen, 2005).

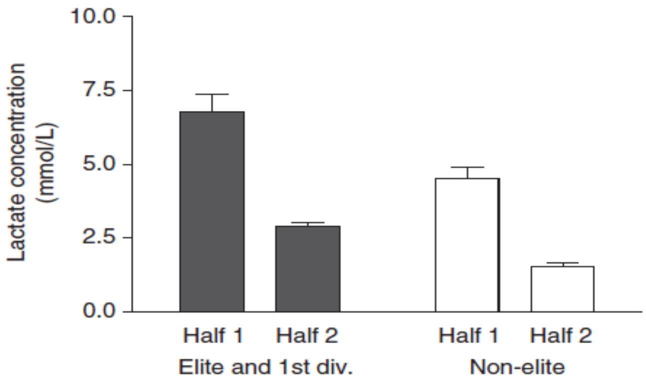

Figure 3. The lactate concentration (mmol/L) for elite and non-elite soccer players in the two half's of a soccer match (Stølen et al, 2005, p. 9)

The energy for the high-intensity intermittent actions in soccer like sprints, jumps and kicks, are delivered by the immediate ATP-CP system (under 10 sec), glycolysis and glycogenolysis (10 sec-3 minutes), in which the two last mentioned produces lactate (Potteiger, 2011).
As seen in figure 2, the lactate concentration is highest in first half of the game and decreases in second half, which correlates well with the studies that shows a reduced distance covered and lower intensity reported in the second half of a soccer match. (Mohr et al, 2003; Bangsbo et al, 1991)

3. Technical ability

According to Ali (2011) technique in soccer can be divided into 1) the player's individual skill with the ball in an action isolated from the game and 2) the player's ability to select and perform the correct technique determined by the situational demands during a match. It is at the same time important for a player to know how and when to use these skills, if not it will be useless in a real match. Ali (2011) has given following definition of the importance of technique in soccer:

"The ability to execute skilled movement patterns efficiently and effectively is the most important aspect of soccer performance, and players must apply cognitive, perceptual and motor skills to rapidly changing situations." (Ali, 2011, p. 170)

Following the quote of Ali (2001), it is worth noting that the efficiency of the movement pattern is a central part of the technical ability. This shows us that movement efficiency is a key part of the technical ability in soccer. Players with improved better running efficiency (around 7%) and higher Vo2 max (around 5ml/kg/min) where shown to have improved technical abilities during match play. (Helgerud et al. 2001). This was evident through a higher rate of possession, maintenance of technical standards even tough more sprints had been performed and a longer distance had been covered. In soccer the technical demands for a player deals with a direct involvement with the ball. It can either be offensive skills like feints, dribbling, juggling, turns, throw-ins, passing, shooting and header or maybe more defensive actions like ball interception, tackling and heading. A good technical player is able to control the ball with all parts of the body and use both leg to pass or shoot. Soccer players must therefore be able to perform sequences of motor skills with or without the ball in different situations in a match. Soccer matches demand a simultaneous requirement of cognitive, perceptual and motor skills in rapidly changing situations. (Ali, 2011). Many different test have been devised to measure these cognitive, perceptual and motor skills, many of them can be found in the article by Ali (2011).

3.1 The analysis of a stationary soccer kick

The kick in soccer is a central skill, and 80% of the goals in the 2006 World Cup were scored by kicking the ball (Acar et al., 2009). There are many techniques in a soccer kick which can be used in different situations. Most literatures have studied the kick where the ball is in a stationary position and found that it depends on various factors (Lees et al., 2010). Quality of the kick depends on the run up, angle, curve and the body stability (Lees et al., 2010). Furthermore, the impact on the ball depends on the force created by the knee extensors, is important to create enough velocity for which the foot in motion correlates with the resulting ball speed. It is important to accelerate the foot until collision with the ball to achieve maximal speed in the kick. (Lees et al., 2010) The player's motor skills are also involved in performing a kick, since it involves a complex series of muscle activities of both agonists and antagonists. (Reilly, Bangsbo & Frank, 2000). During a match the free kick and penalty kick is good opportunities to score and that is why it is important to use the right technique when kicking the ball. Depending on the position different approaches can be taken and the best players have their way of executing a free kick.

4. Tactical ability

A tactical game system consists of a starting formation and guidelines for offensive and defensive play. The formation is an expression of the number of players allocated to a specific position (see figure 1b); how many players are defenders, midfielders and forwards. The goalkeeper is not included in this combination. The number of combinations does not reveal anything about how a team plays but is just an indication of how they organize and it merely shows their base alignment. By knowing where the players are best in the starting formation, coaches use the system to adjust a line-up so the individual players are being used optimally. (Bangsbo, 2007).

Different groups on the team possess various tactical skills which can be divided into tactical combinations of which can be offensive or defensive depending on the schemes. Quick combination plays are examples of offensive tactics, while offensive schemes cover different running patterns. Defensive plays involves disrupting the opponents offensive combinations, while defensive schemes involves whether the team plays zone defense or man vs. man. If a player fulfills his tactical role, it will increase the likelihood of winning the match because of the team's collective play. Players must also be aware of the dynamic and impulsive environment, describing a soccer game, which can make the individual players' tactical role and coordination more complex. (Shestakov et al., 2009). The possession game is an important tactical ability, which is about preserving the ball in own ranks to control the game. The team controls the pace and intensity by moving the ball quickly around the field. This forces the opponent to move away from their ground positions and thereby challenges their organization, which gives opportunities for breakthroughs and shoots at the goal. (Lago & Martin, 2007).

According to Hübscher (2009) 'Game Intelligence' covers the player's ability to do proper evaluations of the game with optimal technical and tactical solutions, both offensively and defensively, meaning being able to 'read and predict the game'. Players must use their individual skills and strengths in a joined team effort. 'Game Intelligence' is about making the decisions when you are in possession of the ball, including choosing the right time to pass or to dribble (Hübscher, 2009). Another form of tactical skill is creativity. Tactical creativity is the ability to perform a surprising action or task to confuse the opponent, which deviates from the "normal" best solution or what is "normally" expected. (Memmert, 2010).

The cognitive and perceptual abilities are also important for the technical skills in soccer

(Williams, 2000). This is due to the fact that the players are confronted with a complex and rapidly changing environment. The player must pick up information from teammates, opponents and the ball before deciding an appropriate reaction. The ability to 'read the game' is thereby a psychological skill that distinguishes the skilled and less skilled players. (Williams, 2000). This can be explained by the more skilled player's ability to recognize and recall patterns of play and having a more effective visual strategy with fewer fixations of longer duration and more focus on the key events and players, making them more successful in making decisions (Vaeyens et al, 2007).

5. Agility, Speed and Acceleration

Soccer players are known to execute several high-speed actions throughout a game, which has an effect on the match performance. High-speed actions cover about 11 % of a total distance covered in a game. Even though high-speed actions only represent 11 % they are in fact a part of the more important moments of the game and might determine if a ball is being won or lost on the field. High-speed actions can be categorized into three different subcategories; acceleration, maximal speed, and agility. Acceleration means rate of chance in velocity, which allows a soccer player to reach his maximum speed in the shortest time possible. Maximal speed is the top velocity of a sprinting soccer player (Little & Williams, 2005). Speed can also be described as the time it takes to run in a linear distance and is a result of the reaction time and the movement velocity. The reaction time equals the time it takes from a stimulus discovers to the first movement is being executed, for elite athletes this is between 130 and 140ms. The movement velocity is generally referred to as the player's ability to move the body with high velocity in small repetitions. The reaction time can be very important if two players have the same acceleration and speed, then the player with the fastest reaction time will get the ball first. (Ackland et al., 2009). It can be difficult to give agility one certain definition, but most refers to it as the ability to start and stop rapidly and to change directions (Little & Williams, 2005). The variety of distances in a game indicates that both acceleration and maximum speed capacities are required. Soccer players often start their sprint while already running and therefore maximal speed will be reached faster than from stationary (Little & Williams, 2005).

Withers et al. (1982) have presented that soccer players make 50 turns per game in average. This means there are many situations in soccer where the demands of rapid chances of direction occur. (Little & Williams, 2005).

6. Coordination and balance

The coordination of muscle activity plays a central role in the success of an athlete's performance (Ackland et al., 2009). The precise coordination of timing and contraction force in skeletal muscles is essential in both balance and agility. Though both are influenced by the physical composition of the player and his technical abilities, they are both dependent on neuromuscular control (Ackland et al., 2009). The ability to maintain balance during movement is important in sports like soccer were players have to adapt quickly to changing conditions, which can be referred to as dynamic balance (Ackland et al., 2009). Dynamic balance is central part of soccer where changing conditions could be when being challenged for possession of the ball or when playing on a slippery field. The body position and posture of soccer players is rapidly adjusted during dynamic movements. These adjustments are needed to maintain dynamic balance, and to be able to perform these adjustments a well-coordinated and well developed skeletal muscle system is required (Ackland et al., 2009).

7. Overall body strength

Muscular strength and power is also an important capacity of the soccer player. Strength in the lower limbs is an important capacity because the quadriceps muscles, hamstrings muscles and triceps surae muscle groups have to generate high forces for kicking, jumping, tackling, turning and changing pace. To maintain control and balance it is also important to be able to sustain forceful contractions. The muscles most often used for field players are the lower part of the trunk, the hip flexors, the plantar flexors and dorsi flexors of the ankle. (Reilly & Williams, 2003). Studies have shown a relationship between leg strength and kick performance (Cabri et al, 1988; Reily & Drust, 1997), which indicate that this is an important capacity of the soccer player (Reilly & Williams, 2003). A study by Zebis et al (2011) measured the maximal voluntary contraction (MVC) to be 1.8 +/- 0.2 $N*m*kg^{-1}$ for the hamstrings and 4.0 +/- 0.5 $N*m*kg^{-1}$ for the quadriceps of male soccer players.
The strength of the upper limbs is also important because it is needed for throw-ins and

heading, but also to avoid being knocked off the ball considering the physical and aggressive nature of the game. Overall muscular strength is also important for the soccer player in reducing the risk of injury. (Reilly & Williams, 2003). A study by Lehnhart et al (1996) show that the number of injuries in soccer can be reduced with up to 50% by performing regular strength training.

Significance in the correlation between the maximal force (1RM), movement velocity and acceleration has been found. By increasing the maximal force in muscle contractions relevant to soccer the acceleration can be increased and thereby improve important skills in soccer like turns, sprints and changes in pace. (Arnason et al, 2004).

It is expected for a professional soccer player who weighs 75 kg to do above 200 kg in half-squat, around 100 kg in bench press and be able to jump 60 cm in vertical height (Stølen, 2005). A high strength level in these parameters will allow a player to execute more powerful jumps, kicks, tackles and sprints (Stølen, 2005).

8. Anthropometry

Anthropometry of the soccer player is an important determinant of success within a playing position in which specific body structures and characteristics can give a functional advantage within the particular playing positions (Hencken et al, 2006). Knowledge of these characteristics can give clues as to the existence of biological prerequisites for playing at the highest standard (Reilly et al, 2000).

Anthropometric predispositions for positional roles within soccer have been reported (Reilly et al, 2000, Hencken et al, 2006). It is seen that goalkeepers and central defenders tend to be heavier and taller, which could give them an advantage in these specific positions because it requires them to be robust and strong in the tackle, while fullbacks, midfield players and forwards have a lighter body mass which could be beneficial to move through space more efficiently, enabling them to cover greater distances (Reilly et al, 2000, Hencken et al, 2006).

Table 1. Stature and body mass comparisons between 24 Premiership soccer players (Hencken et al, 2006), 65 elite Danish soccer players (Bangsbo, 1994, cited in Reilly et al., 2000), and 31 English and Malaysian university soccer players (Reeves et al., 1999). (Adjusted from Hencken et al 2006)

	Goalkeepers	**Defenders**	**Midfielders**	**Strikers**
Bangsbo 1994	N = 5	N =25	N=21	N = 14
Stature (cm)	190 +/- 1	184 +/- 1	177 +/- 6	178 +/- 7
Bodymass (kg)	87.8 +/- 0.0	79.8 +/- 5.3	74.0 +/- 8.0	73.9 +/- 3.1
Hencken et al. 2006	N = 2	N = 7	N=10	N=5
Stature (cm)	185 +/- 12	180 +/-7	178	180 +/-6
Bodymass (kg)	86.3 +/- 12.1	82.5 +/- 6.6	78.3 +/- 6.7	80.9 +/- 9.3
Reeves et al. 1999	N = 2	N=12	N=10	N= 7
Stature (cm)	177 +/- 2	177 +/- 8	173 +/- 6	176 +/- 6
Bodymass (kg)	90.0 +/- 2.0	70.5 +/- 7.3	65.6 +/- 9.5	70.6 +/- 5.1

Rienzi et al (1998) yielded an anthropometric profile of soccer players with mean estimated body fat values at 11% and muscle masses averaging at 62% (Reilly et al, 2000)
Difference in height or other anthropometrics between specific positions on the field may also influence the tactical role of the player. The tall forward player might be used as a target player for high balls, whereas the short forward may prefer to run for balls played deep into the opponents' defense. (Reilly et al, 2000).

It is important to remember that even though a soccer player may have prominent anthropometric characteristics, these will always be influenced and combined with agility, skill and other physiological attributes, and that other factors such as psychological predispositions moreover will influence the performance.

9. Psychological aspects and social demands

Various psychological skills are very important for an elite soccer player to perform successfully, both in matches where stress and anxiety is a factor and when finding motivation for hard and extensive training with numerous hours away from family and friends, but also when having to rehabilitate from an injury mental strength is an important factor. Soccer is a dynamic sport in which players are required to make countless decisions over the course of a match with few, if any, stoppages in play. Timeouts are limited, and halftimes are short which creates a need of the athlete to be capable of making good decisions throughout the course of a game. (Stewart and Meyers, 2004).

The psychological skills are important to cope with the pressure that soccer players experience during matches where decisions are needed to be made at all times. The pressure of soccer players will briefly be described followed by the different psychological skills, which are important for a soccer player to cope with this.

The pressure that a player is experiencing can be divided into arousal, appraisal and stress. (Weinberg and Gould, 2011).

Arousal is the psychological and physiological blend of a person's activity and it refers to the intensity of the motivation in a particular moment, which varies from completely aroused to not aroused at all. Anxiety is associated with arousal of the body, which is a negative emotional state that is characterized by worry, nervousness and apprehension, which can increase arousal. Anxiety is divided into state and trait anxiety, where state anxiety is the changing mood component and trait anxiety is more personal disposition that influences behavior. Stress is a process leading to a change in behavior and occurs when there is an imbalance between physical and psychological demands placed on the player.

Players with a high trait anxiety experience more state anxiety in competition and an increased arousal than players with a lower trait anxiety. This is important for the performance of a player because state anxiety can lead to increased muscle tension, influence the coordination, narrow the attentional field and change the attention to unfortunate cues. (Weinberg & Gould, 2011). The inverted U-hypothesis can describe the relationship between arousal and performance to find the optimal state of arousal during soccer.

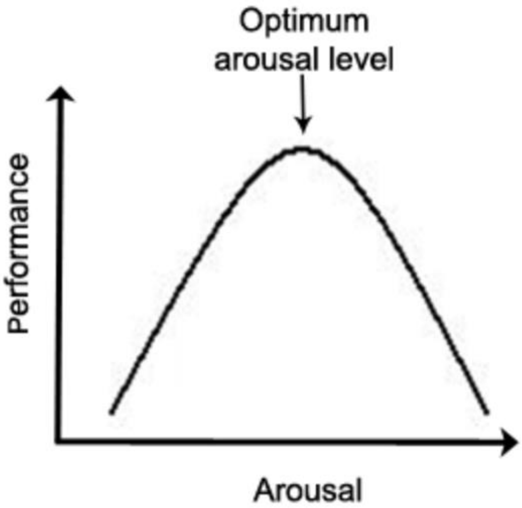

Figure 4. The inverted U: arousal and performance relationship. (Modulated from Weinberg & Gould, 2011, p. 88).

As seen in figure 4, the performance is poor at low arousal levels and at too high levels of arousal, but is optimal at a state in between. The inverted U hypothesis is accepted in general but the optimal state of arousal does not occur in the midpoint of the arousal continuum, which makes it important to find the optimal individual state of arousal for each player, to achieve the best performance. (Weinberg & Gould, 2011).

9.1 Motivation

Motivation can be described as function of how athletes view their ability to control their athletic environment (Stewart and Meyers, 2004). According to the Need Achievement Theory (NAch) by David C. McClelland, individuals have different needs for achieving a specific goal. Overall, the theory distinguishes between two motives of the athlete that represents the motivation; to achieve success or to avoid failure. (Weinberg and Gould, 2011). This has consequences for how the athlete performs in the way that an athlete who plays to avoid failure looses creativity, become reluctant to try a difficult shot or maneuver, exhibit lower effort and only increase effort if the team is successful (Stewart and Meyers, 2004). Stewart and Meyers (2004) showed this using a Sports Attitude Inventory on soccer players to evaluate motivation in competition and a Locus of Control Scale to evaluate the locus of control over one's life. Here it was shown that players with higher motivation to avoid failure were less prone to place locus of control on chance-oriented sources (Stewart & Meyers, 2004). The athlete's appraisal of stress (seeing the task as a challenge or a threat) is thereby represented by the motivation, in which mental toughness plays an important role. Motivation is evaluated as an important part of the psychological skills for soccer due to the fact that the sport is competitive goal-oriented, which is one of the orientations in achievement goal theory (Weinberg & Gould, 2011). This achievement goal is most pronounced in competition where the focus of the team is to win the game, compared to training where it could be argued whether the achievement goal is more oriented towards improving the performance (task goal orientation). Elite players are motivated by winning competitions and showing of their talent (Sanderson, 2003) which may make it more difficult for them to be motivated during training. Therefore the psychological skills must be considered differently depending on whether the situation is competition or training. This demand analysis focuses mainly on psychological skill in competition, but also touches the topic of stressors that the player can experience in training and the personal life.

9.2 Mental toughness

Mental toughness is an important ability of a soccer player for being able to cope and perform well under excessive pressure, both in matches, training and in the personal life. To be mentally tough the player needs skills that enable control, determination, confidence and focus on a consistent basis. (Thellwell and Weston, 2005). Besides being an important resource in confrontations with stress and in times of adversity mental toughness is also important for sustaining effort and standards when things are going well (Cook et al. 2014). Jones et al (2002, p. 209) defined mental toughness as a natural or developed psychological edge that enables the athlete to:

- *Generally cope better than your opponents with the many demands (competition, training, lifestyle) that sport places on the performer.*
- *Specifically, be more consistent and better than your opponents in remaining determined, focused, confident, and in control under pressure.*

A study of soccer penalty shootouts by Jordet (2009) show that players from teams with highest public team status perform worse than players from countries with lower public

status, and suggest that this may be due to the fact that the player is under pressure from the high expectations as a result of being on the certain team (Jordet 2009). This is known as choking under pressure, which gives an example of the importance of mental toughness for soccer players.
The difference in performance between the players in this study is due to their appraisal of stress; seeing the penalty shootout as a threat rather than a challenge and here it is important for the athlete to have a problem-focused coping strategy (Cook et al, 2014).

9.3 Coping

Athletes experience a mixture of stressors that originates from competitive, organizational, environmental and personal sources (Kristiansen et al, 2012). To be successful the athlete must learn to cope with these stressors by strategies and behaviors as response to these stressors. Recent research (Nicholls and Polman, 2007, Weston et al, 2009) suggested problem, emotion, approach, avoidance and social/personal as dimensions of coping strategies but it is important to note that the use of these strategies is dynamic and that there exists a bewildering richness in classification of the coping strategies (Kristiansen et al, 2012). As athletes are exposed to various situations were coping is needed it is therefore important to learn a variety of these coping strategies (Gould and Maynard, 2009) which will enable them to positively adapt to the physical or psychological challenges (Thellwell and Weston, 2005, Wang et al, 2004).

9.4 Group cohesion

An important social factor in interactive sports like soccer is group cohesion. Soccer is a team sport where the performance not only relies upon the abilities of the individual players but also on the cooperation and interactions of the members on the team. (Weinberg & Gould, 2011).

Group cohesion is defined by Festinger, Schacter, and Back (1950) as '*the total field of forces which act on members to remain in the group*' (p. 164) (Weinberg & Gould, 2011) and can be considered as the tendency for a group to stick together and remain united in the pursuit of a common goal (Weinberg & Gould, 2011).

Cohesion may develop through cooperative interactions between team members for attaining a team's goal, where communication and resources are improved and create mechanisms for conferring socially with positive feedback and a warm accepting atmosphere. High cohesion is seen when members develop stronger interpersonal bonds and higher identification with the team goals and values. (Tziner, 2003).

For interactive sports like soccer cohesion increases performance (Weinberg & Gould, 2011) where high cohesion is linked to successful teams (Leo et al, 2013). To be part of a team with high cohesion is associated to positive mood states of the player (Lowter & Lane, 2002) and it could therefore have an effect on the player's performance since the state of mind is evaluated to affect the performance (Harmison, 2006).

9.4.1 Social cohesion and task cohesion

Cohesion can be divided into social cohesion and task cohesion. Social cohesion refers to the degree of members on a team liking each other and enjoying one another's company. Task cohesion reflects the degree on which the members work together to achieve common goals. A common goal could be winning a championship, which partly depends on the teams coordinated effort. The task cohesion is very important for success on the field, where the focus on working towards a common goal can help the team to perform well even though they have a low social cohesion. (Weinberg & Gould, 2011).

9.4.2 Formal and informal roles

On a soccer team there can be formal an informal roles. The leaders of the team like coaches prescribe the formal roles to players, stressing the importance of each player's role to team success. It is important for players to perceive their roles as important for the team (role efficiency) and players that understand what is required of their teammates can begin to develop sympathy and empathy (Weinberg & Gould, 2011; Bray et al, 2004). The formal roles of the team are closely linked to the performance of structured performing groups like a soccer team. Informal roles are developed through interpersonal interactions between players on the team and are more unofficial. Examples of informal roles could be the unofficial leader, the 'team clown' or a social director. (Bray et al, 2004).
The success of the team can be associated with the role efficiency in the way that the players

perceive the roles of the team as important and thereby successfully meets the demands of their individual roles (Bray et al, 2004).

10.Summery

As a conclusion of the demand analysis in soccer, the demands have been summarized in figure 4 which are the important components in soccer. The demands of the components are compared with other sports that are evaluated as the 'golden standard' in the specific demands (as the sport with highest values) (Zacho, 2001).

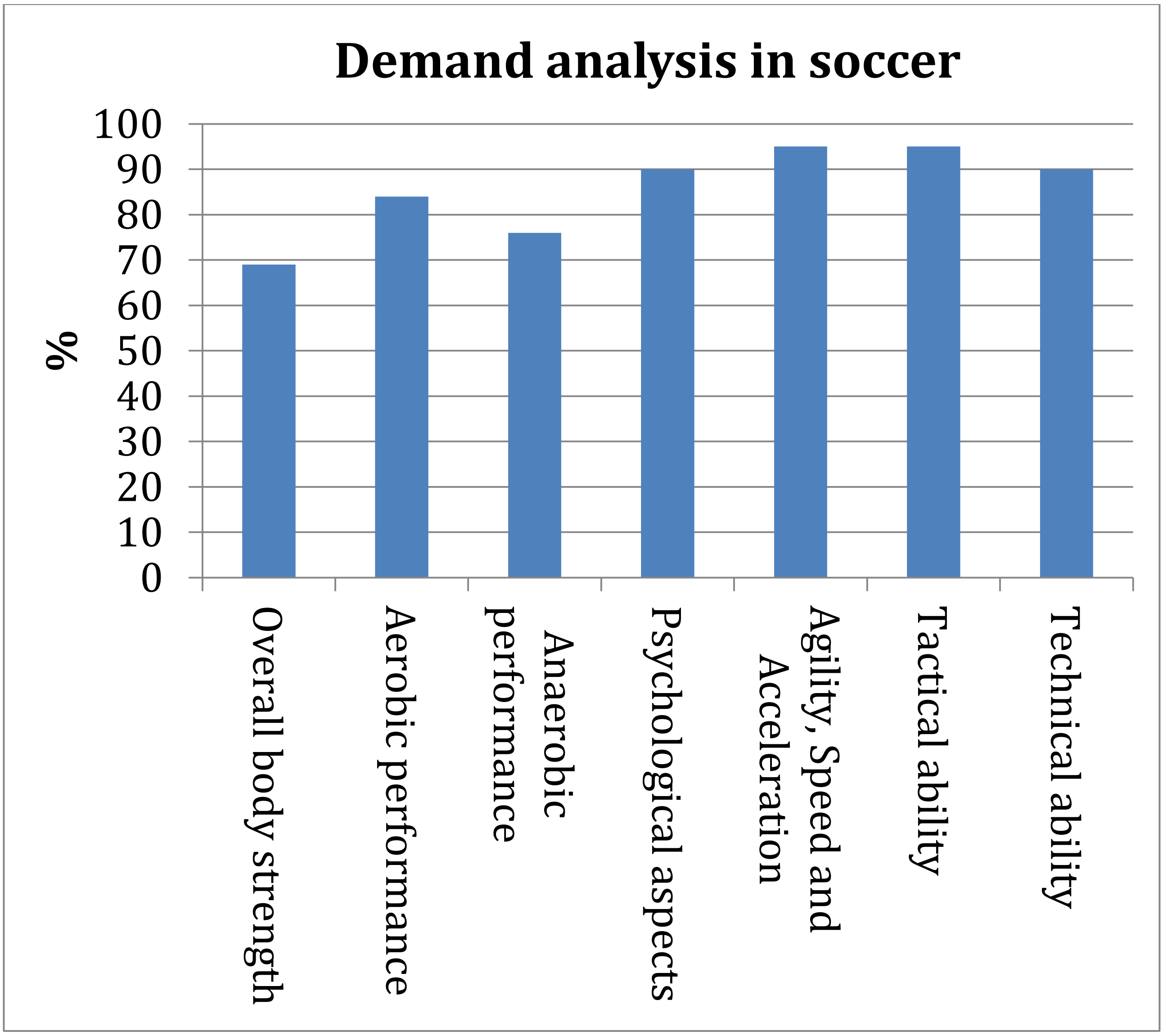

Figure 4. Evaluated demands analysis in soccer. Importance of each ability evaluated in %.

The overall body strength is measured through half-squat and bench press for soccer players and weight lifters. Mean values for squat and bench press were measured to 200kg and 100kg for a professional soccer player. An elite weight lifter has mean values for squat and bench press of 251,8kg and 170kg (USPA, 2013). This leads us to the demands of muscle strength in soccer compared to weight lifters: 200kg/251,8kg*100=79% and 100kg/170kg*100=59%. (79+59)/2=69%.

The aerobic performance is calculated from Stølen et al. (2005) who found that a VO2max estimated to 70 mL·kg-1·min is to be expected from professional soccer players (Stølen, 2005). This value is compared with the highest mean VO2max measured under the Olympics, which were 83 mL·kg-1·min for cross-country skiers (McArdle, 2010). However it has not been possible to measure the precise VO2 values in a soccer match due to the lack of equipment meaning that the expected value might be a little higher (Stølen, 2005).

Anaerobic performance in soccer players is measured performing a Wingate test. Mean values for soccer players was estimated to 638W. To compare this result for soccer players it has been measured for competitive well-trained cyclist to be 841±41W (Jeanniot et al, 2012).

The psychological aspects can vary in many different ways, depending on the situation. This comparison is based upon the fact that soccer penalty shootouts by player players from teams with highest public team status perform worse than players from countries with lower public status. (Jordet (2009) Thereby it is evaluated that elite players are under a lot of pressure and have a higher chance of choking, this puts a lot of strain on the psychological skill, hence the high rating in this analysis.

Agility, speed and acceleration are known to be very important factors in soccer. Mean scores were found for soccer players performing a 30m sprint 4,0 ± 0.2 seconds (Hoff, 2002). These sprint times were compared to the fastest runners in the world who had a mean score of 3,78 seconds for 30m sprint. No valid data were found to compare the top speed or agility for soccer players and elite runners.

The tactical ability in soccer is a subjective demand which is hard to compare with other sports. However we have argued that team sports have a higher tactical demand compared with individual sports due to the many interaction between players and coaches.

The technical ability in soccer can be difficult to compare with other sports. However, the technical ability is evaluated to be high because it demands a simultaneous requirement of cognitive, perceptual and motor skills in rapidly changing situations with the need for making a lot of decisions, and because it requires a certain handling of the ball.

10.1 The present study

The present study investigates how fatigue affects the interlimb communication in soccer. The demands analysis represents the important demands of soccer and how they affect the performance. The demands analysis can be used to evaluate the capacity of a soccer player and what the player should focus upon in the training. As mentioned in the analysis, coordination between the legs is important in soccer to maintain balance, for example when being challenged for possession of the ball or when playing on a slippery field. Therefore it could be interesting to see how fatigue affects coordination; maybe then we could evaluate the possibility of introducing some reflex conditioning training protocols.

Literature

Acar, M. F., Yapicioglu, B., Arikan, N., Yalcin, S., Ates, N. & Ergun, M., (2009). '*Science and Football VI - The Proceedings of the Sixth World Congress on Science and Football.'* [Oxon], Routledge, side 235-242.

Ali, A., (2011). '*Measuring soccer skill performance: a review'.* Scandinavian Journal of Medicine and Science in Sports. Vol. 21, Nr. 2, side 170–183.

Arnason, A., Sigurdsson, S. B., Gudmundsson, A, Holme, I., Engebretsen, L., and Bahr, R. (2004). '*Physical fitness, injuries, and team performance in soccer'.* Med Sci Sports Exerc Feb; 36 (2): 278-85].

Bangsbo, J. (1997). '*Quantification of anaerobic energy production during intense exercise'.* Medicine and Science in Sports and Exercise, 29, 47± 52.

Bangsbo J. (1994). '*The physiology of soccer: with special reference to intense intermittent exercise.' Acta* Physiol Scand; 15 Suppl. 619: 1-156.

Bangsbo J, Norregaard L, Thorsoe F. (1991). 'Activity profile of competition soccer'. Can J Sports Sci Jun; 16 (2): 110-6.

Bray R. S., Balaguer I. and Duda J. L. (2004) '*The relationship of task self-efficacy and role efficacy beliefs to role performance in Spanish youth soccer.'* Journal of Sports Sciences, 22:5, 429-437.

Cabri, J., De Proft, F., Dufour, W. and Clarys, J.P. (1988). 'The relation between muscular strength and kick performance, in Science and Football'. (eds T. Reilly, A. Lees, K. Davids and W.J. Murphy), E & FN Spon, London, pp. 186–93

Cook, C., Crust, L., Littlewood, M., Nesti, M., and Allen-Collinson, J. (2014). '*What it takes': perceptions of mental toughness and its development in an English Premier League Soccer Academy.* Qualitative research in sport, exercise and health, 6:3, 329-347.

Drust B., Reilly T., and Cable N. T. (2010). '*Physiological responses to laboratory-based soccer-specific intermittent and continuous exercise'.* Journal of Sports Sciences, 18:11, 885-892.

Ekblom, B. (1986). '*Applied physiology of soccer.'* Sports Med Jan-Feb; 3 (1): 50-60;

Festinger L., Schacter S., and Back K. (1950). *'Social pressures in informed groups: A study of a housing project.'* New York: Harare.

Gould, Daniel and Maynard, Ian. (2009). '*Psychological preparation for the Olympic Games.'* Journal of Sports Sciences, 27:13, 1393-1408.

Harmison J. R. (2006). '*Peak Performance in Sport: Identifying Ideal Performance States and Developing Athletes'* Psychological Skills.' Professional Psychology: Research and Practice, Vol. 37, No. 3, 233–243

Helgerud, J., Engen, L.C., Wisløff, U. & Hoff, J., (2001). *'Aerobic endurance training improves soccer performance.'* Medicine & Science in Sports & Exercise. Vol. 33, Nr. 11, side 1925–1931.

Hencken, Clare & White, Colin, (2006). '*Anthropometric assessment of Premiership soccer players in relation to playing position.'* European Journal of Sport Science 6:4, 205-211.

Hoff J., Wisløff, U., Engen, L. C., Kemi, O. J., Helgerud, J. (2002). *'Soccer specific aerobic endurance training.*' Br J Sports Med; vol. 36:218–221.

Hübscher, S. (2009). 'B*uild your team's game intelligence.*' Succes in Soccer. Vol. 12, Nr. 4, side 26-31.

Jeanniot, J. and Bertucci, W. (2012). '*Evolution of pedaling biomechanics during a Wingate test for different cyclist types: a preliminary study. Computer Methods in Biomechanics and Biomedical Engineering.'* Vol. 15, No. S1, September, 215–217.

Jones, G., Hanton, S., and Connaughton, D. (2002). *'What is this thing called mental toughness? An investigation of elite sport performers.'* Journal of applied sport psychology, 14, 205-218.

Jordet, G., Hartman, E., and Sigmundstad, E. (2009). *'Temporal links to performing under pressure in international soccer penalty shootouts.'* Psychology of sport and exercise, årg. 10, hft. 6, 11-2009, s. 621–627.

Kristiansen, E., Murphy, D. & Roberts, G. C. (2012). '*Organizational Stress and Coping in U.S.Professional Soccer.'* Journal of applied physiology, 24:2, 207-223.

Lago, C. & Martin, R., (2007). '*Determinants of possession of the ball in soccer.'* Journal of Sports Science. Vol. 25, Nr. 9, side 969-974.

Lees, A., Asai, T., Andersen, T.B., Nonome, H. & Sterzing, T., (2010). '*The biomechanics of kicking in soccer: a review.'* Journal of Sports Science. Vol. 28, Nr. 8, side 805-817.

Lehnhart, R. A., Lehnhart, H. R., Young, R., Butterfield, S. A. (1996*). 'Monitoring injuries matchon a college soccer team: the effect of strength training.'* J Strength Cond Res; 10 (2): 115-9

Little, T. and Williams, A. G. (2005). *'Specificity of acceleration, maximum speed, and agility in professional soccer players.'* J Strength Cond Res Feb; 19 (1): 76-8

Lowter J., Lane A. (2002). *'Relationships Between Mood, Cohesion And Satisfaction With Performance Among Soccer Players.'* PDF. Athletic insight: The online Journal of Sport Psychology. Vol. 4, Issue 3.

Memmert, D., (2010). '*Testing of tactical performance in youth elite soccer.' Journal of Sports Science and Medicine.* Vol. 9, Nr. 2, side 199-205.

Mohr M, Krustrup P, Bangsbo J. (2003). '*Match performance of high standard soccer players with special reference to development of fatigue.'* J Sports Sci Jul; 21 (7): 519-28.

Nicholls, Adam R. & Polman, Remco C. J. (2007). '*Coping in sport: A systematic review.'* Journal of Sports Sciences, 25:1, 11-31.

Reilly, T., Bangsbo, J. and Franks, A. (2000). Anthropometric and physiological predispositions for elite soccer. Journal of Sports Sciences, 18, 669± 683.

Reilly, T. and Drust, B. (1997). '*The isokinetic muscle strength of female soccer players and Coaching*'. Sport Science Journal, 2, 12–17.

Reilly, T. and Williams, A. Mark, (2003). '*Science and soccer – second edition.'* Edited by Thomas Reilly and A Mark Williams. Routlegde.

Rienzi, E., Mazza, J.C., Carter, J.E.L. and Reilly, T. (1998). *'Futbolista Sudamericano de Elite: Morfologia, Analisis del Juego y Performance*.' Rosario: Biosystem Servicio Educativo.

Shestakov, M., Talalaev, A., Kosilova, N., Zasenko, N., Zubkova, A., Leksakov, A., Averkin, A. & Gusev. A., (2009). '*Science and Football VI - The Proceedings of the Sixth World Congress on Science and Football.'* [Oxon], *Routledge*, side 186-190.

Stewart, Craig and Meyers, Michael C. (2004). *'Motivational Traits of Elite Young Soccer Players Physical Educator*'. Early Winter, Vol. 61 Issue 4, p213-218.

Stølen, T., Chamari, K., Castagna, C., Wisløff, U., (2005). '*Physiology of soccer – an update'.* Sports Med.

Taylor, Y. L., Juan R., Esquivel-gonzález, P., Rivera-lima, S., Jimenez-alvarado, J. A., González-gonzález, A., Torres, F. (2011). '*Body composition, playing position and VO2max in a professional Mexican soccer team during preseason.'* Medicine & Science in Sports & Exercise, 2011, Vol.43(Suppl 1), pp.871. [Abstract only]

Thellwell, R., Weston, N., and Greenless, I. (2005). *'Defining and Understanding Mental Toughness within Soccer.'* Journal of applied sport psychology, 17:4, 326-332.

Tomlin, DL., & Wenger, HA. (2002). '*The relationships between aerobic fitness, power maintenance and oxygen consumption during intense intermittent exercise*.' Journal of Science and Medicine in Sport 5 (3): 194-203.

Tziner A., Nicola N., and Rizac A. (2003). *'Relation between social cohesion and team performance in soccer teams'.* Perceptual and Motor Skills, 2003, 96, 145-148.

Tønnessen, E., Hem, E., Leirstein, S., Haugen, T., and Seiler S. (2013).'*Maximal Aerobic Power Characteristics of Male Professional Soccer Players.'* 1989–2012. International Journal of Sports Physiology and Performance, 2013, 8, 323-329

Vaeyens R., Lenoir M., Williams M. A., and & Philippaerts R. M (2007). '*Mechanisms Underpinning Successful Decision Making in Skilled Youth Soccer Players: An Analysis of Visual Search Behaviors.'* Journal of Motor Behavior, 39:5, 395-408.

Wang, J., Marchant, D., and Morris, T. (2004). '*Coping style and susceptibility to choking.'* Journal of Sport Behavior, 21, 1 pg. 75.

Weston, Neil J.V., Thelwell, Richard C., Bond, Simon & Hutchings, Nicholas V. (2009). *'Stress and Coping in Single-Handed Round-the-World Ocean Sailing.'* Journal of Applied Sport Psychology, 21:4, 460-474.

Whitehead, E. N. (1975). *'Conditioning of sports.'* Yorkshire: E P Publishing Co. Ltd,: 40-2;

Williams A. M. (2000). Perceptual skill in soccer: Implications for talent identification and development, Journal of Sports Sciences, 18:9, 737-750.

Withers, R.T., Maricic, Z., Wasilewski, S. and Kelly, L. (1982). '*Match analysis of Australian professional soccer players.' J. Hum. Mov. Stud.* 8:159–176.

Zacho, M (2001). '*Træningsplanlægning'.* Dansk Idræts-Forbund. 2. udgave, 1. oplag

Zebis, Mette K., Andersen, Lars L., Ellingsgaard, Helga, and Aagaard, Per. (2011). *'Rapid hamstrings/quadriceps force capacity in male vs. female elite soccer players.'* Journal of Strength and Conditioning Research, Vol. 25, Iss. 7, p. 1989–93

Books:

Ackland, R. A., Elliot, B.C. & Bloomfield, J., (2009). '*Applied anatomy and biomechanics in sports.'* 2. Edition, [Champaign], *Human Kinetics*.

Bangsbo, J. (1994*). 'Fitness Training in Football - A Scientific Approach'*. Illustreret, August Korgh institute, University of Copehhagen.

Bangsbo, J. (2007). *'Fodbold – træning og undervisning'.* 1. udgave, 1. oplag, bog. Forlag: Frydenlund

Bear, M. F., Connors, B. W. and Paradiso, M. A. (2006). *'Exploring the brain'.* 3th ed., International ed. Edn, Lippicott Williams & Wilkins, Philadelphia, Pa.

McArdle, W. D., Katch, F. I. and Katch, V. L. (2010). *'Exercise physiology – Nutrition, energy and human performance'.* 7th ed., International ed. Edn, Lippicott Williams & Wilkins, Philadelphia, Pa.

Potteiger, Jeffrey A. (2011). '*ACSM's introduction to exercise science.'* Lippicott Williams & Wilkins.

Raven BP., Wasserman HD., Squires GW., Murray D.T (2013). '*Exercise physiology – an integrated approach.'* International edition. Gengage Learning Ink.

Sanderson, F. (2003). '*Science and Soccer.'* 2. Edition, [London], *E & FN Spon*, p. 273-308.

Weinberg, Robert S. and Gould, Daniel. (2011). *'Foundations of Sport and Exercise Psychology.'* 5th edition. Human kinetics.

Ziv, G and Lidor, R (2009). *'Physical attributes, physiological characteristics, on-court performances and nutritional strategies of female and male basketball players.'* Sports medicine, årg. 39, hft. 7, 01-07-2009, s. 547.

Internet:

FIFA. (2012). Laws of the Game 2012/2013. PDF.
http://www.fifa.com/aboutfifa/footballdevelopment/technicalsupport/refereeing/laws-of-the-game/index.html [12.12.14]

USPA. (2013). '*Classification-standards-for-raw-elite-uspa.'*
http://www.lift.net/2013/05/09/classification-standards-for-raw-elite-uspa/
[16.12.14]

Soccer drills (2014). http://www.soccer-drills.net/soccer-positions.aspx (17.12.14)