

**QUADRICEPS AND HAMSTRING MUSCLE EMG ACTIVITY
DURING A FOOTBALL MATCH**

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ABSTRACT

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Fatigue represents a reduction in the ability of muscle to generate force and in the context of football, it has been often related with injury. Surface electromyography is a valuable technique for evaluating muscle activation and fatigue but it has never been applied during a football match. The development of washable textile electrodes has opened up possibilities to investigate muscular activity in non-laboratory settings, without skin preparation and wires hanging around the body. It has also been shown to be a valid and feasible method for assessing the average rectified value of electromyography (EMG).

The aim of this study was to investigate the effect of football specific fatigue on EMG activity of right and left hamstring (RH, LH) and quadriceps (RQ, LQ) during an entire football match, using bursts analysis method. Muscle activity and inactivity were compared between the first 15 minutes of the 1st half (PRE) and last 15 minutes of the 2nd half (POST). Seven professional players (age 23.1 ± 3.13 years; height 181 ± 5.24 cm and mass 78.4 ± 10.5 kg) wore shorts with EMG electrodes during a match. EMG was normalized to maximal voluntary contraction (EMG_{MVC}) and inactivity threshold was defined as an EMG level below 2% of EMG_{MVC} . A low, moderate and vigorous activity threshold was determined during a 3 stages (1 minute) treadmill test. Low, moderate and vigorous threshold were defined as EMG value corresponding to the 3 running speeds (6 km/h, 12 km/h and 16 km/h). Percentage of average normalized EMG ($aEMG_{MVC}$) decreased for RQ (- 27.2%), RH (- 29.6%) and LH (- 18.1%), ($p < 0.05$). Burst analysis demonstrated a significant decrease in burst duration for RH (- 31.9%), LQ (- 22.8%) and an increase for LH (29.1%), ($p < 0.05$). Burst amplitude significantly decreased for RQ (- 23.8%) and RH (- 20.2%), ($p < 0.05$). Burst rate showed a significant decrease only for RQ (- 20%). Inactivity time significantly increased for LQ (+ 10.8%) and LH (+ 35.6%), ($p < 0.05$). Low activity significantly increased for RQ (6.6%), ($p < 0.05$). Moderate activity time decreased for RH (- 17.9%) and LH (- 23%), ($p < 0.05$). Vigorous activity time was significantly reduced for RQ (- 31.3%), RH (- 37%) and LH (- 27.5%), ($p < 0.05$).

For the first time EMG was measured during an actual football match. It can be concluded that at the end of the match, EMG activity decreased, inactivity and low activity time increased while vigorous activity time decreased. These results suggest that a full 90 minutes football match reduces overall EMG activity. Further, at the end of the match EMG bursts were shorter and had a lower amplitude.

Key words: Fatigue, football, activity, inactivity, electromyography, textile electrodes embedded into shorts, MVC, threshold.

CONTENTS

1. INTRODUCTION.....	5
2. FOOTBALL INJURY INCIDENCE	6
3. FATIGUE: NEURAL AND METABOLIC ASPECTS	9
4. FOOTBALL SPECIFIC FATIGUE.....	12
5. EMG TO ASSESS NEUROMUSCULAR ACTIVITY.....	19
5.1 EMG AND FATIGUE.....	22
5.2 TEXTILE ELECTRODES	24
6. RESEARCH QUESTIONS AND HYPOTHESIS.....	27
7. METHODS.....	29
7.1 SUBJECTS INFORMATIONS	29
7.2 PROTOCOL	30
7.3 EMG RECORDING	31
7.4 EMG ANALYSIS.....	32
7.4.1 DATA CLEANING PROCESS	32
7.4.2 DATA NORMALIZATION AND ACTIVATION THRESHOLD.....	33
7.5 STATISTICAL ANALYSIS	34
8. RESULTS.....	35
8.1 LABORATORY TESTS	35
8.2 FIELD TESTS	36
9. DISCUSSION.....	41
10. REFERENCES	48
11. APPENDIX.....	56

LIST of ABBREVIATIONS

aEMGmvc = Averaged normalized EMG to maximal voluntary contraction

EMG = Electromyography

EMGmvc = Normalized EMG to maximal voluntary contraction

H = Hamstring

LH = Left hamstring

LQ = Left quadriceps

MN = Motor neuron (motoneurone)

MVC = Maximal voluntary contraction

POST = Last 15 minutes of the game

PRE = 1st 15 minutes of the game

Q = Quadriceps

1. INTRODUCTION

Fatigue has been defined as any exercise-induced reduction in the ability to generate muscle force or power (Gandevia 2001). In sport, the cause of muscle fatigue is complex and not completely understood (Garcia-manso et al. 2011). Many factors related to the central nervous system and/or peripheral factors within the skeletal muscles lead to muscle fatigue (Gibson & Edwards 1985; Westerblad & Allen 1998).

Krustrup et al. 2003 showed that football players experienced a specific neuromuscular fatigue, which (1) can lead to injury (Davis & Bailey 1997) and that (2) there is an increased risk of injury in the 2nd half, especially during the last 15-minutes (Hawkins et al. 2001). An injury is occurring as the result of participation in official football activities, with one or more of the following effects, (1) reduction in player's activity, (2) the need for advice regarding treatment and (3) adverse social or economic effects (Jung & Dvorak 2000). Rahnama et al. 2003 reported that a decrease in muscle strength might increase the susceptibility of a player to injury, particularly as incidents intensify towards the end of the match. The reduction in muscle force related to fatigue is likely to be due to a decrease in the number of fibers that can be recruited to generate force as fibers already recruited begin to fail (Bangsbo 1994). The most common injury affecting football players is hamstring strain. Decreased hamstring strength, increased imbalance between hamstring and quadriceps (H/Q), and transient as well as long-term fatigue are recognized factors to increase hamstring strain injuries (Delextrat et al. 2010).

The purpose of the literature review is to present research related to neuromuscular fatigue and its relation with football specific fatigue. This paper will also examine studies in relation to monitoring and recording of the neuromuscular activity during football specific fatigue. The experimental part of this thesis examines the influence of football induced fatigue on the neuromuscular activity using electromyography.

2. FOOTBALL INJURY INCIDENCE

Football is the world's biggest team sport and attracts new players every year (Ekstrand et al. 2004) with an estimate of 265 million players (90% males and 10% females). It is a complex contact sport with high technical and tactical and physiological demands at the elite level and the risk of injury is considerable (Carling et al. 2010). Injuries are a recognized problem and soccer is known to be associated with a relatively high injury rate, with the overall level of injury to professional football players being shown to be approximately 1000 times higher than that for industrial occupations generally regarded as high risk (Hawkins et al. 1999). Studies on football's injuries risk shows that 65% - 95% of the players have an injury during the season (Ekstrand et al. 2005). The level of play is an important factor when studying the injury risk. Studies show that risk increases with the level of play, number of matches and trainings. It has also been shown that the risk of injury is greater during training session (Ekstrand et al. 2004). Injury has also been associated with fatigue, 42 % of hamstring strain in English professional football occurred during the final 15 min of each half and same trends was observed with sprains and contusions (Fig.1) (Ekstrand et al. 2011).

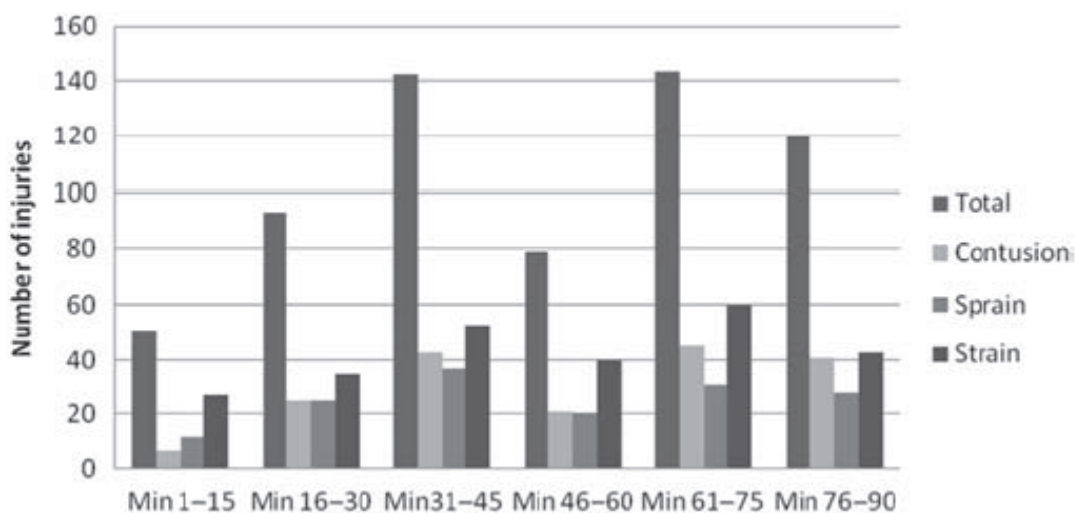


FIGURE 1. Injury incidence during football matches. (Ekstrand et al 2011).

The impact of injuries in a football match includes financial losses due to medical fees and increased insurance premium and lower incomes. Severe injuries may have long lasting consequences for a player (e.g. osteoarthritis or gonarthrosis) (Hawkins et al. 2001).

In female football, knee injury including anterior cruciate ligament (ACL) tear (this ligament ensures joint stability and thus has a mechanical function) is one of the most common injury. Quadriceps and hamstrings are functionally important to control stability of the knee joint complex. Studies on ACL injury mechanisms have suggested that the hamstring muscle has a crucial role in protecting the ACL during the movements of the tibia relative to the femur (Gehring et al. 2009). Nyland (1999) demonstrated that hamstring fatigue produced transverse plane dynamic knee-control deficits. Fatigue is an important factor that may influence stabilizing control and thus cause ACL injuries. Neuromuscular fatigue may play a major role since a significantly higher incidence of ACL injuries was found in professional female football players between the 75th and 90th minutes of the game (Hawkins et al. 1999). In addition, peripheral muscle fatigue was shown to reduce stretch reflex activity (Avela & Komi 1998).

Concerning male football, it appears that thigh muscle strain injuries are among the most common injuries and account for 10% to 23% of all acute injuries (Caine et al. 2010, 214-215). The same conclusion were drawn by Lutjhe et al. (1996) who investigated 12 teams playing in the highest competition level in Finland and found that thigh injuries accounted for 22% of all injuries. Among the group of thigh injuries, the injury with the most prevalence is the hamstring strain, it account for 12-16% of total injuries. Hamstring is bi-artrodial muscle that includes the biceps femoris, the semitendinosus and the semimembranosus (Fig 2) (Wen et al. 2008). It undergoes lengthening over two joints simultaneously during the latter part of the swing phase of the gate cycle and strain is most likely to occur at this point whilst working eccentrically to decelerate the limb and control knee extension. Alternatively, injury may occur during the latter part of the stance phase when the muscle shortens forcefully to extend the hip during take-off, potentially inducing a concentric contraction injury (Small et al. 2009). Sprinting is the primary mechanism for hamstring strain being responsible for 57% of all hamstring injuries (Small et al. 2009).

High activities such as sprinting are crucial in football and often involve decisive moment of the game. Sprinting speed during high level game can reach values around 32 km/h (Bangsbo et al. 1994; Mohr et al. 2005). Strength decrease induced by fatigue seems also to have an important role in the development of hamstring strain. Strength deficits or imbalance have been suggested to increase hamstring injury risk (Croisier et al. 2008). Football specific fatigue has been associated with decreased eccentric strength and nearly half of the H injuries occur during the last 15 minutes of each half (Delextrat et al. 2010). The imbalance between the strength developed by H and Q has been identified as a potential predisposing factor for hamstring strain, as well as anterior cruciate ligament. It has been shown that fatigue resulted in increased imbalance and decrease H/Q ratio (Delextrat et al. 2010).

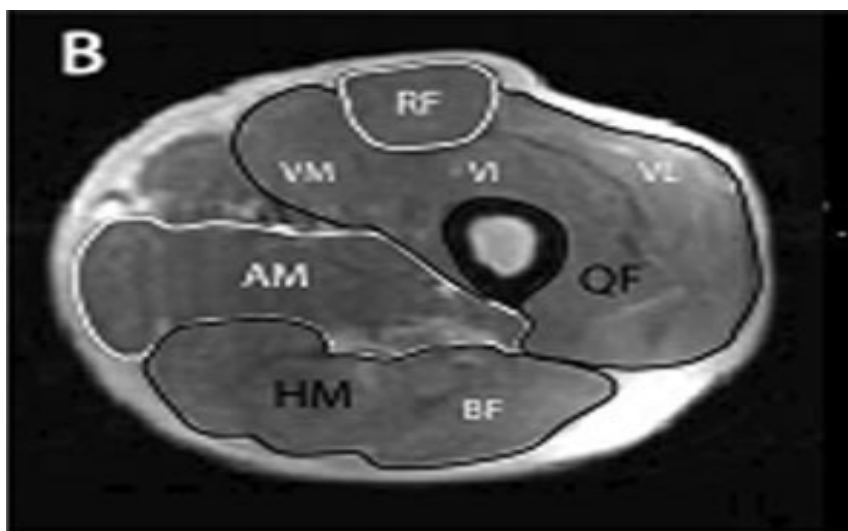


FIGURE 2. Mid-tigh axial plane image showing the quadriceps muscle group including RF (Rectus femoris), VM (Vastus medialis), VI (Vastus intermedialis) and VL (Vastus lateralis); the hamstring muscle (HM) including the biceps femoris, the semitendinosus and the semimembranosus; and the adductor muscles (AM). (Wen et al. 2008).

The causality associated with the above mentioned injuries is extremely complex and dynamic in nature. (Caine et al. 2010, 218-224). It seems that a great amount of studies associate football injuries with fatigue and the consequences of such condition. Therefore it is important to develop methods, techniques to assess and monitor football specific fatigue as accurately as possible.

3. FATIGUE: NEURAL AND METABOLIC ASPECTS

Fatigue is a complex phenomenon that may involve factors at different levels contributing to overall drop in performance. These may include a decrease in the ability of muscle fibers to generate force, a decrease in the efficacy of neuromuscular synapses, a changes in the activity of certain peripheral receptors leading to changes in their reflex effects, a changes in the patterns of firing (recruitment patterns) of alpha motoneurons, changes at any level of the hypothetical process of generation of a motor command and psychological factors (motivation) (Latash 1998, 204).

The sensation related to fatiguing contractions are derived from both feed-forward and feedback signals (Gandevia 2001). Whereas feedback signals from the periphery (alpha motoneurons, III-IV afferents and Ia afferents) inform the CNS (central nervous system) about changes in the involved muscles, feed-forward signal from supraspinal centers provide both an activation signal for the spinal cord and a source of information that is used to assess the effort associated with the physical activity (Fig. 3) (Enoka et al. 2011).

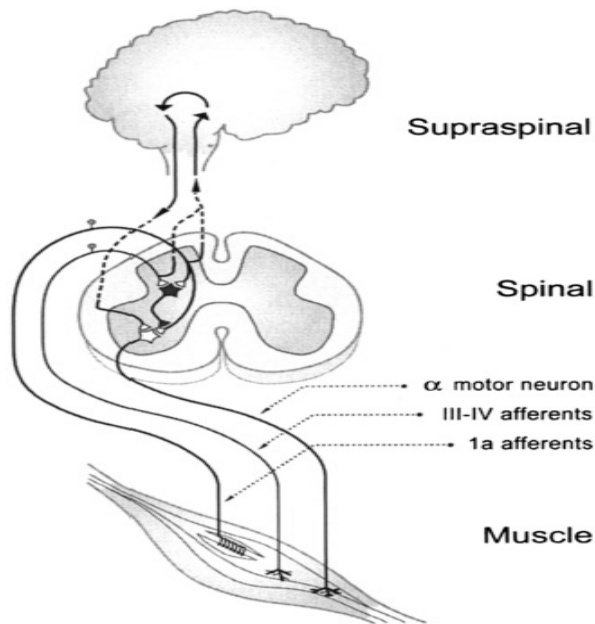


FIGURE 3. Feedforwards from CNS and feedbacks from periphery (Heargraves 2008)

Failure in force development may occur at various sites along the pathway. Reduced energy stores, the build-up of metabolic by-products and reduced central drive are suspected to be a primordial causative factor during fatiguing exercise (Fig. 4) (Westerbald & Allen 1998).

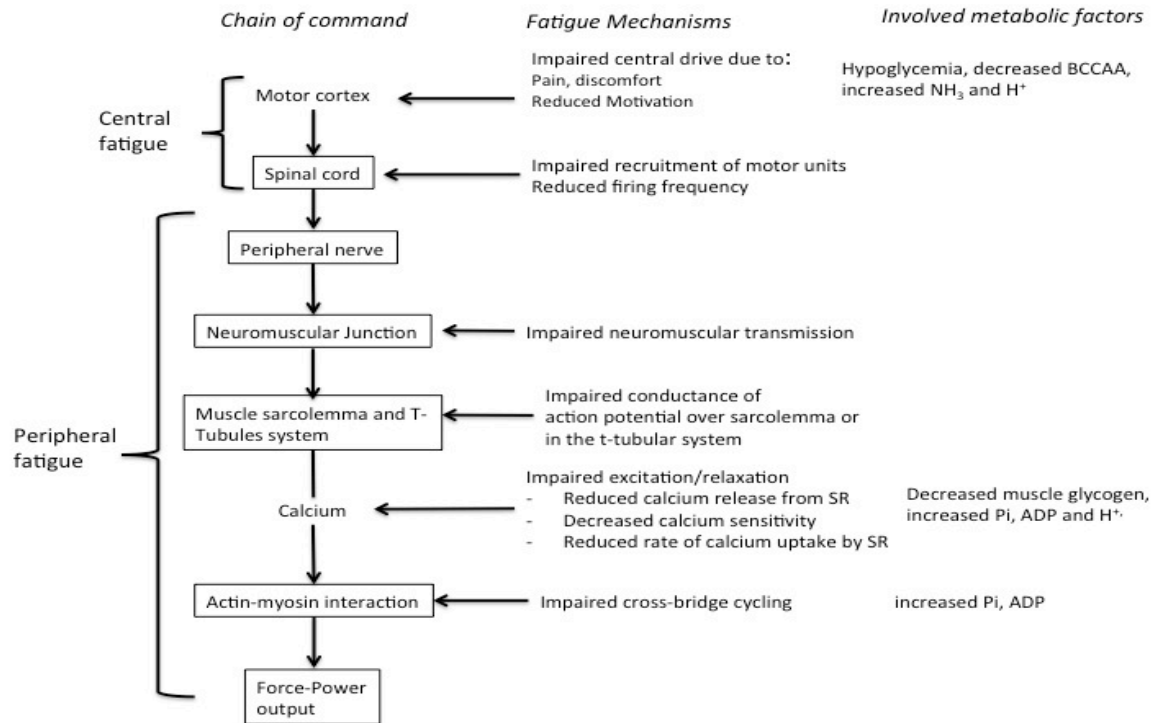


FIGURE 4. Distinction central and peripheral fatigue and possible sites of impairments (Hargreaves & Spriet 2006)

Fatigue's site of impairments also depends on the activity being performed. This effect is known as the task dependency of muscle fatigue. According to this principle, there is not only one cause of muscle fatigue and the dominant mechanism is specific to those processes that are stressed during fatiguing exercise (Enoka et al. 2011). The task variables that will affect the distribution of stress among the processes includes, the level of subject motivation, the neural strategy (pattern of muscle activation and motor command), the intensity and duration of the activity, the speed of the contraction, and the extent to which an activity is sustained continuously (Gandevia 2001).

During submaximal isometric activity, subjects are able to increase motor unit (MU) recruitment to oppose the decreased force output occurring with fatigue. However during maximal isometric activity, an individual is able to increase MU recruitment and alterations in firing strategy to individual MU are needed to modify force output. One hypothesis to explain the decline or increase in MU firing rate is the muscular wisdom theory. It proposes that motor neuron firing rate decline to match the muscle's contractile speed (Gandevia et al. 2001).

It is important to differentiate central and peripheral fatigue site of impairment (Fig 4). Central fatigue is a reduction in neural drive or motor command to the muscle resulting in a decline in force development of the entire muscle (St Clair Gibson et al. 2001). It is related to the CNS and includes the motor cortex and α -MN in the spinal cords. Strong evidence of depressed of neural drive comes from studies employing twitch interpolation technique. Transcranial magnetic stimulation (TMS) using both single and paired-pulse techniques, has also provided insight in understanding the balance of excitation and inhibition within the corticomotor system during maximal and submaximal exercise (Gandevia et al. 2001).

The development of fatigue is also related with changes within the muscle (Enoka 2002, 384). Fatigue induced by these changes is known as peripheral fatigue. It includes, relative lactate level increase, pH decrease and associated proton accumulation, ATP and creatine phosphate depletion, ADP, ionosine monophosphate and inorganic phosphate accumulation, skeletal muscle Na/K ATPase pump changes, sarcolemmal, T-tubule and sarcoplasmic reticulum functional changes described as excitation/contraction coupling failure (St Clair Gibson et al. 2001). Peripheral fatigue results in decrease in the number of MU recruited and decline in firing frequency during contraction (Hargreaves and Spriet 2006, 163-164).

4. FOOTBALL SPECIFIC FATIGUE

Football is an intermittent sport with a change of activity every 4-6 seconds (Mohr et al. 2003). Time-motion analysis has shown that elite players usually cover a total distance of 9-12 km during a game (Krustrup et al. 2003). Heart rate (HR) measurements indicate that the average oxygen uptake is around 70% of VO₂ max and international top-class player performs approximately 1350 activities during a game, including 220 runs at high speed (Mohr et al. 2003).

Numerous studies have demonstrated that number of sprints, high-intensity runs and distance covered are decreased in the 2nd half and in the end of the 1st half of the game (Mohr et al. 2003) (Fig. 5 and 6). This may suggest that performance is reduced in the 2nd half of the game and that fatigue occurs towards the end of the game.

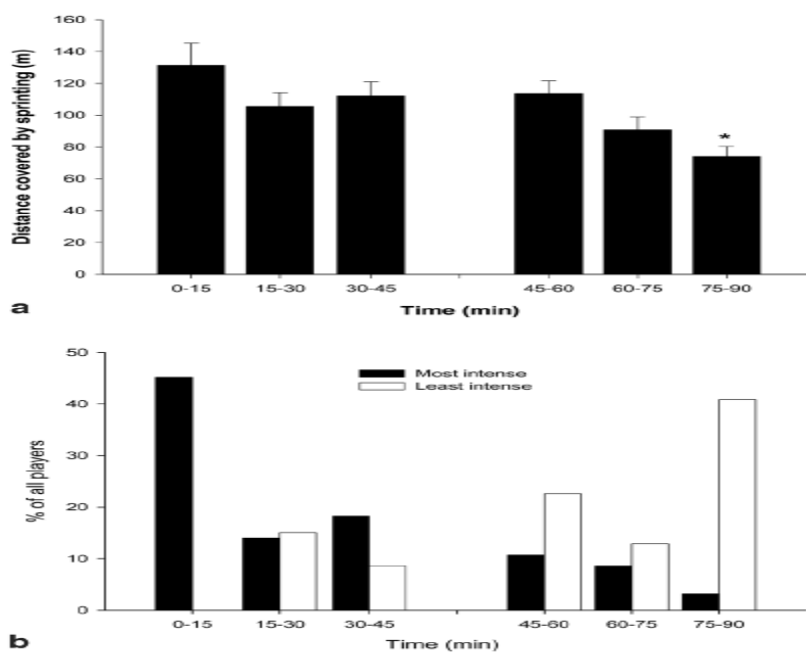


FIGURE 5. Distance covered sprinting during a 90 minutes football match (a) - Comparison between the least and most intense period of the match (b). (Mohr et al. 2003)

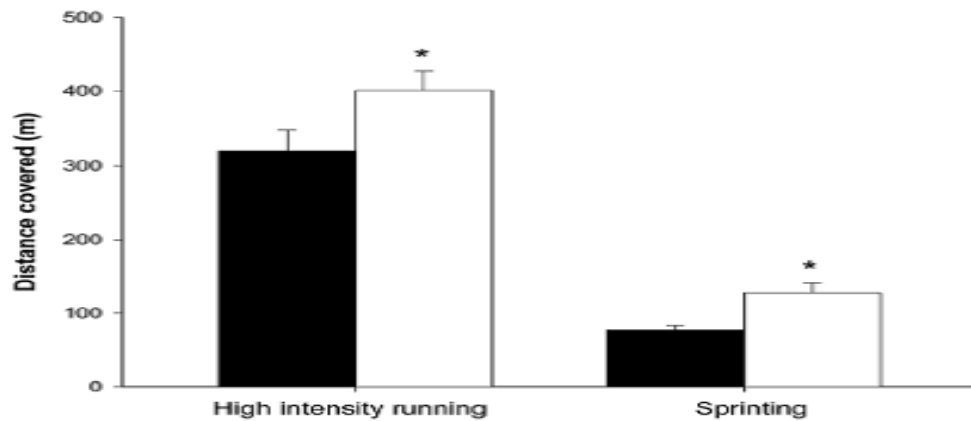


FIGURE 6. High intensity running & sprinting in the final 15 min of the game for elite players playing the entire match (black) and elite substitute (white). (Mohr et al. 2003)

Mohr et al. (2003) showed that football players experienced temporary fatigue during the game. The study showed that the amount of HI running in the 5 minutes period immediately after the most intense 5 minutes interval recorded during the game was observed to be less than the average of the entire game (Fig.7).

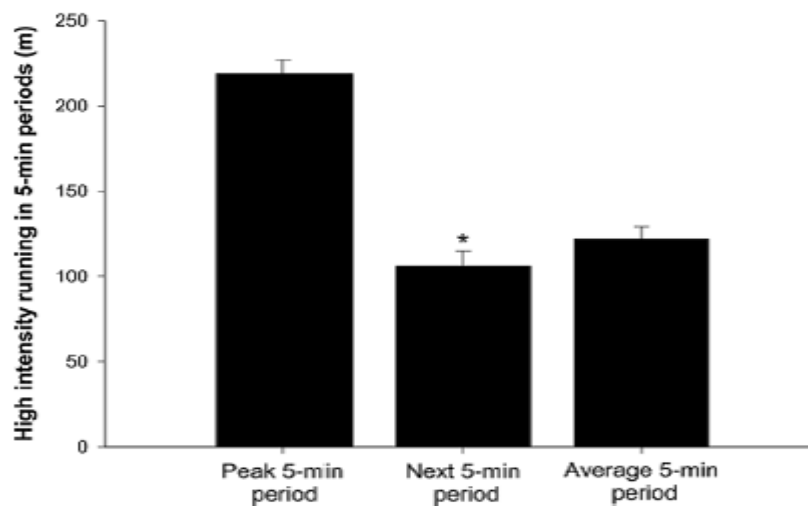


FIGURE 7. Temporary fatigue experienced by football players. (Mohr et al. 2003)

It is also important to keep in mind that football specific fatigue, can also arise from repetition and accumulation of matches within a short period. A period with a congested match calendar can lead to fatigue, increasing the risk of injury and poor performance during the following period. Ekstrand et al. (2004) have shown that 60% of the players who had played more than 1 match a week before the World Cup incurred injuries or underperformed during tournament. Elite soccer players take part in national championship matches, league cup matches, national cup matches, UEFA (Union of European Football Association) Champions League and/or UEFA Cup matches, and finally international matches. For these players, it is common to play 2-3 games per week (Saturday or Sunday + Tuesday or Wednesday) over several weeks. Ispiridis et al. (2008) showed that it took 96 to 120 hours after the match to achieve initial values for 20-m sprints and squat performance (Fig.8).

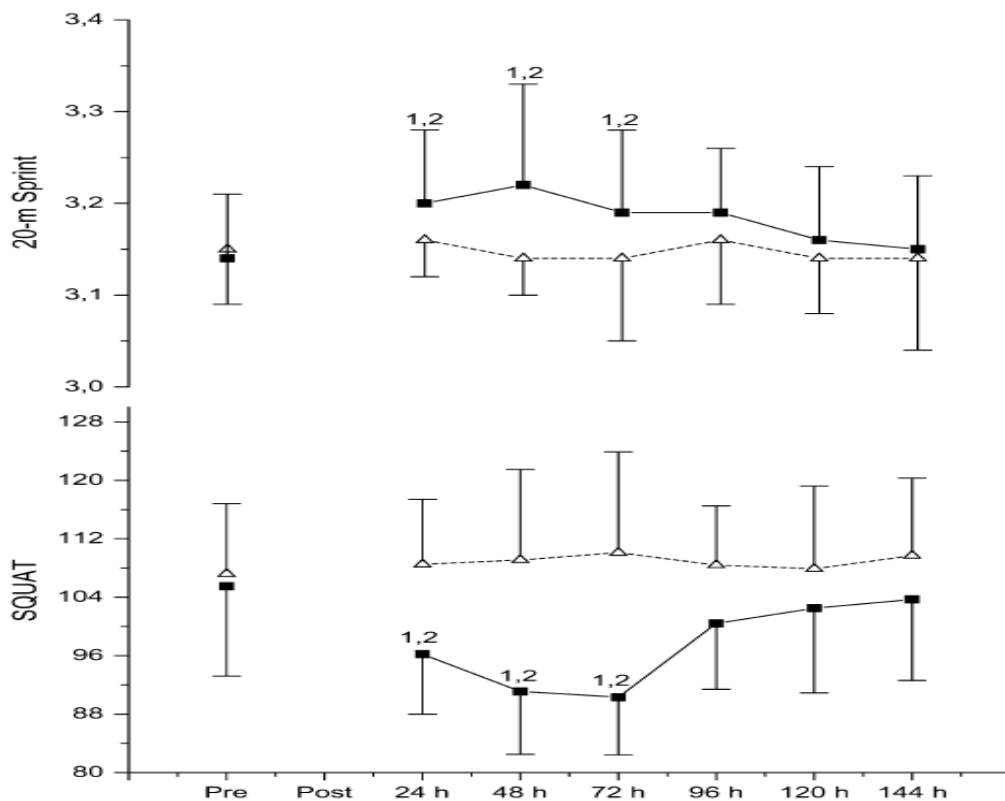


FIGURE 8. 20-m sprint and squat performances pre (white triangle) and post (black square) match. Ispiridis et al. (2008)

Listed below are different metabolic by-products and metabolic conditions that have been associated with muscular fatigue development and football specific fatigue.

Lactic acid. Muscles that are used in high intensity activity generally have inappropriate capacity for oxidative metabolism and rely on anaerobic glycolysis, where the end product is lactic acid. During repetitive activity muscle pH usually decrease due to the increase of lactic acid. Two further reactions which can contribute to the variation of pH are the breakdown of PCR (creatine phosphate) which absorbs a proton and the breakdown of ATP which occurs when fatigue is severe and release a proton (Amorena et al. 1990). The variation of pH is variable depending on the fibers type. Type II fibers have a much smaller pH than type I fibers. An intracellular acidosis only occurs if the rate of proton production exceeds the rate of removal (Gandevia et al. 1995, 57-66). The decrease in pH has been associated with several effects including; failure of calcium release from the sarcoplasmic reticulum; reduction of maximal isometric force; decreased myofibrillar calcium sensitivity; slower rate of relaxation; reduced shortening velocity and affect general metabolism (e.g. Acidosis reduce the glycogenolytic rate by inhibiting both glycogen phosphorylase and phosphofructokinase) (Roos & Boron 1981). Reduced pH has also shown to increase the ability of the fibers to resist stretch presumably by making the myosin cross bridges adhere more firmly to the actins filaments during activity (Curtin & Edman 1994).

Lactic acid and pH variation have been studied by Krstrup et al. (2003). They observed average blood lactate concentration of 3-10 mmol during football game. These values suggest that the rate of lactate production is high during intense period of the game. In concert, muscle acidosis was markedly elevated after these intense sequences. They also reported a weak correlation ($r = 0.41$) between muscle lactate and decrease sprinting performance after an intense period. Therefore it could be suggested that temporary fatigue might be linked to high muscle lactate concentration and/or muscle acidosis, since it has been shown in vitro that high lactate and low pH impair muscle performance during intense contractions. However, muscle lactate concentrations during the match were rather low (on average 20 mmol.kg⁻¹ dry weight) compared with those found at exhaustion after HI exercise (Brooks et al. 1994) and muscle pH is only slightly reduced (> 6.8) during the

game. Together these findings suggest that temporary football specific fatigue is not causally linked to high muscle lactate and acidosis (Krustrup et al. 2003).

Creatine phosphate. It has also been shown that after intense periods in the game, the decrease in muscle PCR is significantly correlated with impairment in sprint ability (Krustrup et al. 2003). Measurements of PCR in muscle biopsies obtained after intense-exercise periods during a game have shown average level around 75% of the level at rest, which is partly due to the fast recovery of PCR and the approximately 20 seconds delay in collecting the muscle biopsy in this study. Low concentration of PCR in the muscle might be responsible for temporary fatigue during the game because performance in intense intermittent exercise is elevated after a period of creatine supplementation (Krustrup et al. 2003).

Glycogen depletion. Lack of glycogen and depletion of glycogen stores have been associated with the development of fatigue during prolonged intermittent exercise (Balsom et al. 1999). Reduction of glycogen was also related to a decrease in sprint performance after the game. Krustrup has demonstrated that muscle glycogen concentration at the end of the game was reduced to 40 to 60 mmol/kg wet weight, indicating that there was still glycogen available. Histochemical analysis using PAS-staining technique revealed, however, that about half the individual muscle fibers of both types were almost depleted or depleted of glycogen. Nevertheless, it appears unclear what the mechanisms are behind a possible causal relationship between muscle glycogen levels and fatigue during prolonged intermittent exercise (Krustrup et al. 2003).

Potassium. Accumulation of potassium (K^+) in the muscle interstitium has also been suggested to take part in the development of fatigue during high intensity exercise (Bangsbo et al. 1996). At the point of exhaustion after short-term exercise (approximately 5 minutes), the interstitial K^+ concentration is elevated to around 12 mmol/l (Mohr et al. 2005). The accumulation of interstitial K^+ is closely related to the anaerobic metabolism which is significantly stimulated during the football match. It has been shown that the rate of accumulation of interstitial K^+ in exercising human leg muscle was significantly

increased when muscle pH was reduced due to intense arm exercise before the leg exercise. Thus football athletes may experience temporary fatigue as a consequence of accumulation of extracellular K^+ and the related electrical disturbances in the muscle cell (Mohr et al. 2005).

Dehydration. Dehydration and hyperthermia have also been suggested as agents responsible for the development of fatigue in the later stages of a football game (Reilly 1997). In normal thermal environment, players might lose more than 3 liters of fluid (Bangsbo 1994 and Reilly 1997), which might cause negative effect on the performance towards the end of the match (Saltin 1964) (Fig 9). In hot and humid environment, a decrease of 4-5 liters can occur and hyperthermia might become a key factor in the development of fatigue at the end of the game (Mustafa & Mahmoud 1979).

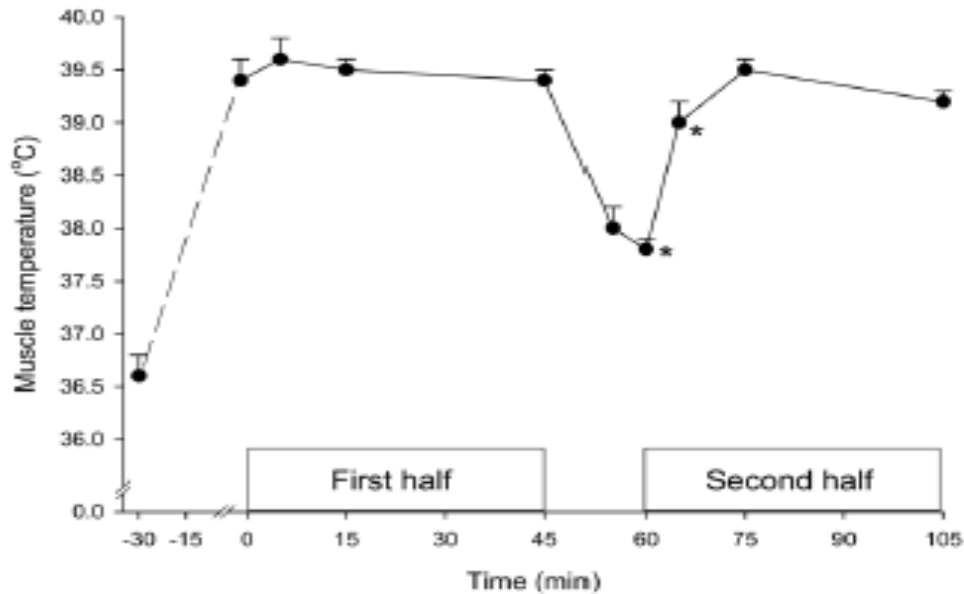


FIGURE 9. Muscle temperature during football match (Mohr et al. 2005)

Ammonia. Another metabolic by-product, NH_3 (ammonia) has also been pointed as possible cause of fatigue. NH_3 blood concentration increases during prolonged and intense exercise due to the catabolism of muscle adenine nucleotides or combustion of amino acids. As a potential neurotoxin NH_3 has been suggested that an increase in NH_3 concentration could affect the CNS function and contribute to the development of fatigue (Hargreaves & Spriets 2006, 173). During a football match, Krstrup et al. (2003) observed an increase in plasma NH_3 concentration, indicating an increase in the activity of enzyme AMP Deaminase. In addition, concentration of hypoxanthine and uric acid in the blood were significantly higher during the game than at rest, indicating a further breakdown of IMP.

5. EMG TO ASSESS NEUROMUSCULAR ACTIVITY

There is concentration gradient for sodium (Na^+), potassium (K^+) and chlorine (Cl^-) across the membrane and it creates an electrical potential. In a steady-state condition, this potential is referred to as resting membrane potential (RMP). In RMP, Na^+ - K^+ pump transports Na^+ outside the cell and maintains K^+ in the intracellular space. Cl^- will be held in the extracellular fluids due to attraction to Na^+ and repulsion of anions (A^-) (Fig. 10) (Enoka 2002, 241-243).

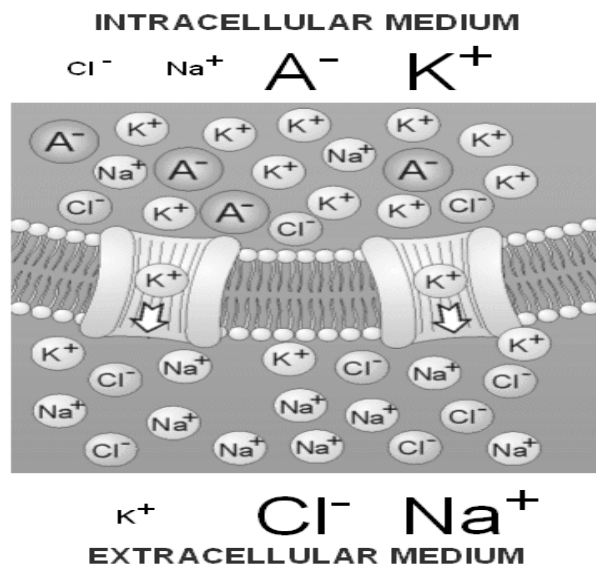


FIGURE 10. Excitable membrane in steady state condition. (<http://www.bem.fi/book/03/03.htm>)

The control of force by the nervous system (NS) is followed by electrical signals (action potential/AP) that are sent from the motoneuron to the muscle fibers. It will cause changes of ions movement across the membrane. AP can be induced chemically, electrically or mechanically and their propagation is divided in 4 phases: depolarization, overshoot, repolarization and hyperpolarization (Fig. 11). They are characterized by their waveform, amplitude, duration and velocity; all are depending on the activity of the ionic channels of the sarcolemma (Merletti 2004, 17-19).

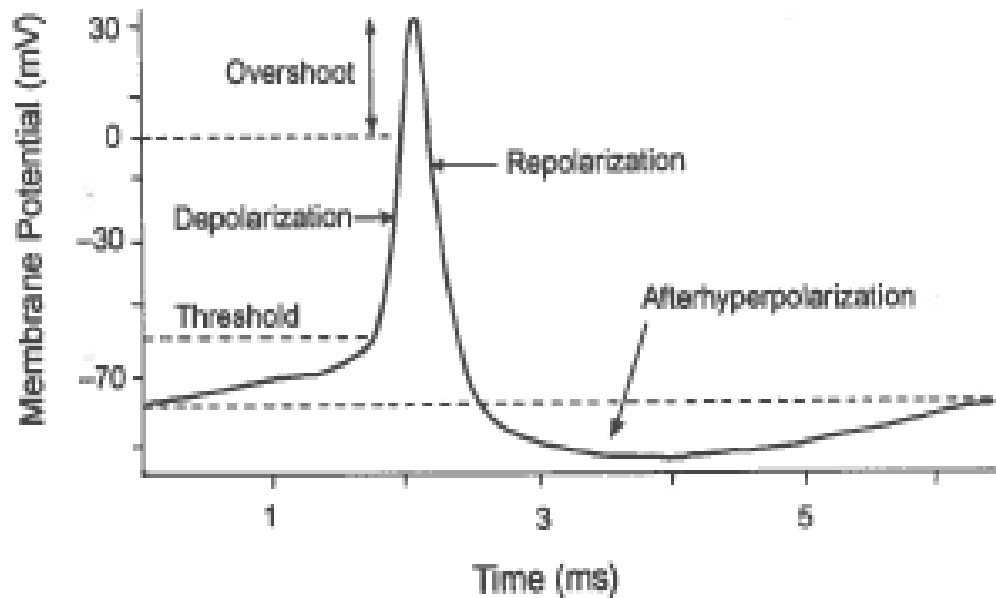


FIGURE 11. Graphical representation of AP. (<http://www.answers.com/topic/action-potential>)

A MU consists of α -MN in the spinal cord and fibers it innervates. There are different types of MU, with different physiological characteristics. Fast-twitch, fatigable (FF or type IIb); fast-twitch, fatigue resistant (FR or type IIa); and slow-twitch (S or type I), which are the most fatigue resistant. In voluntary contraction, force is modulated by MU recruitment and MU activation frequency; they depend on the level of force and speed of contraction. The greater the number of MU recruited and their discharge frequency, the greater the force will be. The recruitment of MU is based on the Henneman's size principle. During a muscle contraction there is a specific sequence of recruitment, small fibers size are recruited first and as force and/or speed of contraction increase, big sized fibers are then recruited (Merletti 2004, 2-7).

EMG is widely used to assess neuromuscular activity and consists of an experimental technique concerned with the development, recording, quantifying and analysis of myoelectric signals (AP). EMG measurements are made with electrodes (Fig. 12) (surface electrodes, subcutaneous and intramuscular electrodes), these measure the variation in voltage linked with the propagating AP. The recorded EMG can be quantified in different ways, and reflects a combination of the number of MU recruited and firing rate, also

referred as MU activation (Basmajian & DeLuca 1985). The EMG detection is affected by two groups of factors; (1) geometrical and anatomical factors (e.g.: electrode size, shape and location; thickness of the skin and subcutaneous layers) and (2) Physiological factors (e.g. muscle fiber conduction velocity, number of fibers, fiber type, temperature, intramuscular pH). The signal contains information about many physical and physiological factors whose contributions to the signal are not easy to separate (Merletti et al. 2001). One other aspect that should be considered is crosstalk (exclusively with surface electrodes) which is a signal detected over a muscle but generated by another muscle close to the first one. It is due to the volume conduction properties and it is one of the most important sources of error (Merletti 2004, 91).

Komi & Buskirk (1970) compared reliability between inserted wire electrodes and surface electrodes. They showed that the average test-retest of surface electrodes was 0.88 compared to 0.62 for inserted electrodes.



FIGURE 12. Surface EMG on vastus lateralis (VL) and vastus medialis (VM) of Q group. (<https://www.gofundme.com>)

Surface EMG presents some limitations, the measurements are still difficult to implement outside laboratory settings. The electrode placement with skin preparation requires careful handling and the measurements system includes lots a wires. Often the measurement devices are also quite heavy and clumsy to be carried during daily training activity (Finni et al. 2007).

5.1 EMG AND FATIGUE

During a sustained voluntary contraction, the EMG signal progressively changes its characteristics because of changes in muscle fiber membranes excitability and MU action potential propagation. These changes might lead to alteration of muscle metabolic conditions and failure to excitation-contraction coupling; resulting in the inability to sustain the required contraction level (mechanical fatigue). The above mentioned changes are believed to be related to shifts in ionic concentrations and are reflected by decrease in conduction velocity and spectral variables and increase in amplitude variable (Enoka & Stuart, 1992).

Rahnama et al. (2006), investigate EMG activity of lower limb using a programmable motorized treadmill protocol, that consisted of the different intensities observed during match-play (walking, jogging, running, sprinting), 6, 12, 15, and 21 km/h⁻¹. EMG activity was recorded from the rectus femoris (RF), biceps femoris (BF), tibialis anterior (TA) and gastrocnemius (GC). The measurements were made prior exercise, after the 15-minutes half time interval and immediately post-exercise. The amplitude of muscle activity during the run was indicated by the root mean square (RMS). Results showed with regards to RF, BA and TA, a significant main effect for condition (pre-game, half-time and post-game), speed (6, 12, 15, and 21 km/h-1) and interactions between condition and speed. The results reported by Rahnama et al. (2006), indicated that after a simulation of exercise intensity of football play, the EMG activity in major lower limbs muscles was less than before.

Oliver et al. (2008) also demonstrated a significant decrease in total EMG during a drop jump after a football specific intermittent exercise test. They showed that completing a football specific protocol reduced performance in all jump activity (Oliver et al 2008).

In another study, Thordlund et al. (2009) investigated the fatigue development in muscle mechanical properties with emphasis on rapid force capacity and neuromuscular activity during football match. Players were tested PRE and POST after football match for maximal knee extensor and flexor isometric strength (MVC) and contractile rate of force

development (RFD) with synchronous surface (EMG) recorded. Surface electrodes were placed on the dominant leg (vastus lateralis, rectus femoris, and semitendinosus). During EMG, recording of peak EMG amplitude within the entire contraction phase and the average EMG (mean average voltage, $MAV = \int EMG / \text{integration time}$) were obtained at time interval 0-30, 50, 100 and 200 ms relative to onset of EMG integration normalization to the peak EMG amplitude and mean average voltage in the 100 ms time interval leading up to maximal force. MVC and rapid force development were obtained using a dynamometer. MVC torque of the knee flexor and extensor muscle was measured at knee joint angle of 70°. Results showed significant decreases in post match MVC torque for the knee extensors (11%) and for knee flexors (7%). They also showed a decrease in RFD of 7-8% of the knee extensor from 0-50 and 200 ms and a decrease of 9% of the knee flexor from 0-200 ms. MAV in the first 100 ms before maximal force (MAV 100) was reduced 17% for the VL during maximal isometric knee extension. MAV 100 was reduced 31% for the BF during maximal isometric knee flexion and also a reduced MAV 100 for ST. ST MAV was reduced 29% in the 0-30 ms time interval. BF peak EMG during knee flexors MVC was reduced 30% while there was a tendency for a decline in ST after match play (Fig.13).

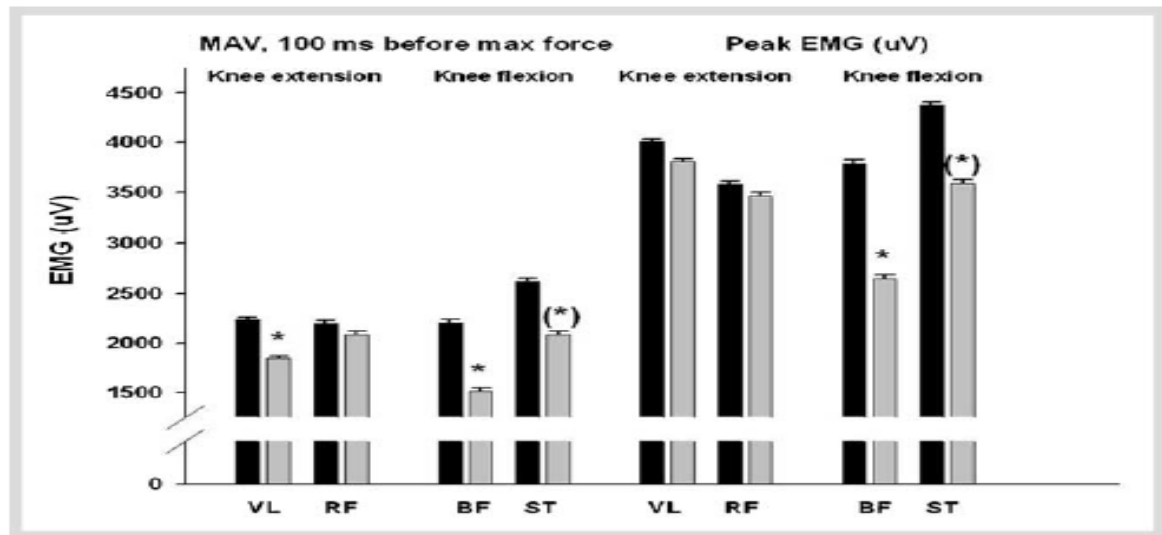


FIGURE 13. Mean average voltage (MAV) 100 before MVC and peak EMG during knee extensor and flexor MVC in the non-fatigued (black bars) and fatigue (grey bars) condition (Thordlund et al. 2009)

5.2 TEXTILE ELECTRODES

The development of washable textile electrodes has opened up possibilities to manufacture shorts, shirts and other clothing equipped with the textile electrodes that can record muscle activity during normal locomotion without skin preparation and wires hanging around the body (Lintu et al. 2005) (Fig.14).

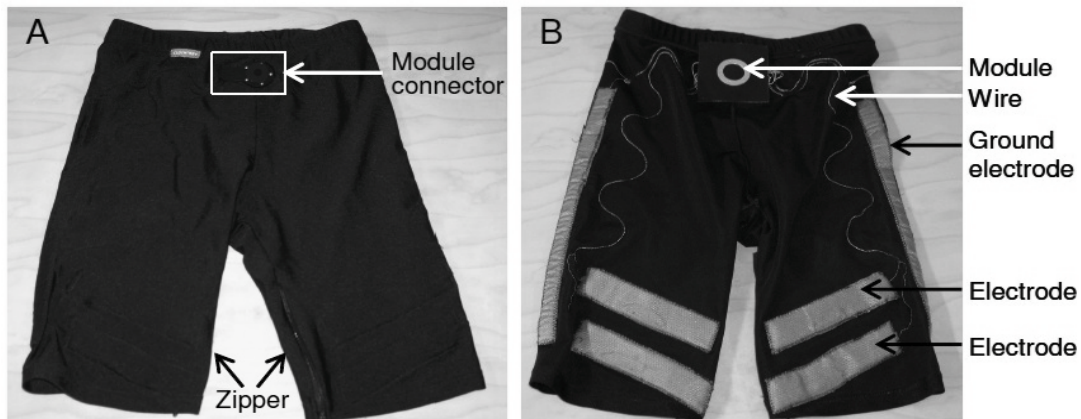


FIGURE 14. Textile electrodes EMG (Finni, et al. 2007).

To obtain the EMG signal the shorts are equipped with conductive electrodes and wire integrated into the fabric (similar to elastic clothing). Role of the electronic wires is to transfer the EMG signal from the electrodes to the module. There is a grounding electrode (size: 2 x 29-33 cm) placed longitudinally on the lateral side of the shorts over tractus iliotibialis. There are two different electrodes which are located horizontally on the shorts for right (RH) - left (LH) hamstring (size: 1.5 x 7.5-8cm) and right (RQ) -left (LQ) quadriceps (size: 2.5 x 9.5-14cm) muscle. The electrodes varied depending on the size of the shorts, which were adjustable with three zippers (1 on each leg and 1 in the back at waist level) and two elastic bands (1 on each leg). Conductive gel was used to facilitate the conductivity of electrodes (Finni et al. 2007).

The other important part of the EMG recording process is the electronic module (Fig. 15). The module contains signal amplifiers and A/D converter for each channel, microprocessor

with embedded software, interface to PC, data memory as well as wireless transmitter-receiver to enable storage and monitoring online.

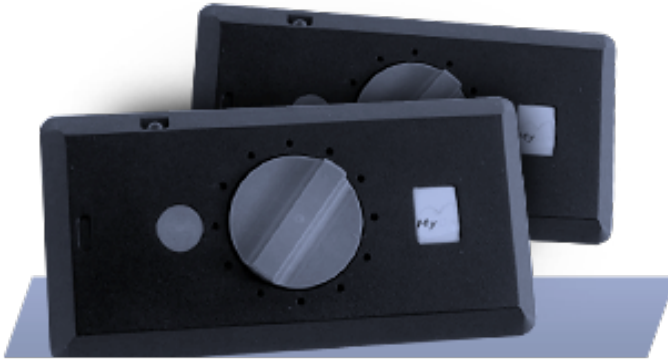


FIGURE 15. Electronic module. (www.myontec.com)

Typical surface EMG is based on measurement and analysis of individual muscle separately which is useful in basic science, however, manipulation and complexity of the system makes it not practical in field conditions. This new technology enables researchers to monitor the level of muscle activity from a group of muscle, typically from agonist and synergist muscle groups.

Finni et al. (2007) studied the validity and reliability of the textile electrodes during muscle strength tests, and their feasibility during maximal treadmill test. Validity was tested by comparing the signals from bipolar textiles electrodes and traditional bipolar surface electrodes during bilateral isometric knee extension with two electrodes locations. The study concluded that the textile electrode embedded into shorts is a valid and feasible method for assessing the average rectified value of EMG (Finni et al. 2007).

Similar research has been done and show similar conclusions as the one above mentioned. Lintu et al. (2005) have reported that the textile embedded EMG electrodes turned out to be better than with the traditional surface EMG method in dynamic work, because the short stayed in place despite sweating and motion. The integrated wires are an important positive aspect in long term measurements because signal artifacts resulting from many wires were decreased, and in the case the data were clearer and more reliable (Lintu et al. 2005).

This new technology will enable researcher to easily record and monitor neuromuscular activity during free live situation like a football match. No previous study has been able to use traditional EMG in real football situation. In the present study, textile electrodes were used during the whole game and burst analysis was used to describe EMG (Kern et al. 2001).

6. RESEARCH QUESTIONS AND HYPOTHESIS

The purpose of this research was to investigate the influence of football specific fatigue on the EMG activity and to determine the neuromuscular activity profile during a 90 minutes full football match. Measurements were done during the game using shorts embedded with textile electrodes, which measured the neuromuscular activity from quadriceps and hamstrings muscles.

Research questions:

1. Is there a difference in the average EMG activity, the number of bursts, mean amplitude of bursts, duration of bursts and burst rate in the first 15 minutes of the first half (PRE) compared to the last 15 minutes of the second half (POST) of the football game?
2. Is there a difference in the inactivity time, low, moderate and vigorous activity time in the last 15 minutes of the second half compared to the first 15 minutes of first half?

Research hypotheses:

Question 1:

We hypothesized that there will be a decrease in average EMG activity between the first 15 minutes of the game and the last 15 minutes of the second half. Rahnama et al. (2006) showed that exercise intensity comparable to a football match reduced the EMG activity (expressed as RMS). Rampinni et al. (2011) also showed that RMS was decreased by 12% after a football match. There are no data available related to burst analysis and football performance. However, previous study has shown that total distance covered and high intensity activity are reduced in the second half as compared to the first, in particular in the last 15 minutes (Mohr et al. 2003). We hypothesized that there will be a decrease in the number of bursts; mean amplitude of bursts; duration of bursts and burst rate in the last 15 minutes of each compared to the first 15 minutes of each half.

Question 2:

Bradley et al (2009) has shown that players spent longer time standing and walking in the second half and demonstrated that football player's activity will decrease during the 2nd half (Mohr et al. 2003; Bradley et al. 2009). Therefore, we hypothesized that there will be an increase in inactivity and low activity time; and a decrease in vigorous activity time in POST compared to PRE.

7. METHODS

Some of the methods and protocol used in this project have already been used and developed in a previous large study called: “*Muscle loading during physical activity and normal daily life (EMG24)*”, done in the University of Jyväskylä (Finland) between 2008 and 2010. And was also the subjects to several master’s theses (Haakana 2011 and Pesola 2011).

7.1 SUBJECTS INFORMATIONS

Seven voluntary male players from the professional football team JJK (Football Club Jyväskylä) took part in this project. Subjects were asked to come to the laboratory twice, once for familiarization with devices and anthropometric measures; and once for the actual measurements. During their first visit in the laboratory, subjects were asked to read and sign an informed consent. All the procedures in this project were done in accordance to ethics guidelines of the University of Jyväskylä. Table 1 presents the subjects anthropometrics data and player’s position and dominant foot.

Table 1: Subject anthropometrics and player’s position and dominant foot.

Subject #	Age	Weight (kg)	Height (cm)	% fat	Position	Dominant foot
1	18	72.2	180	11	Striker	Right
2	24	89.3	189	9.7	Striker	Right
3	27	81.2	180	12.2	Striker	Right
4	20	70.7	175	10.5	Central midfielder	Right
5	35	90.9	187	10.3	Central defender	Right
6	20	77.5	185	7.9	Central defender	Right
7	18	62.2	177	17.1	Lateral defender	Left
Mean±SD	23.1±6.1	78.4±10	181.8±5.2	11.2±2.8		

7.2 PROTOCOL

The protocol consisted of a laboratory test and a field test. In the *Laboratory test* subject height and weight were measured first. Then subject wearing the shorts embedded with textile electrodes (Myontec Ltd, Kuopio, Finland) performed two tests.

- 1) MVC of knee extension-flexion, using a knee extension-flexion device (DAVID SYSTEM-REHAB, David Health Solution Ltd, Outokumpu, Finland). Participants were seated on the machine in an adjustable chair, the upper body stabilization was achieved with a belt around the hips area, a resistance pad was also placed on the proximal part of the knee joint to localize the knee extensors and flexors. The axis of rotation of the machine was aligned with the axis of rotation of the knee articulation. The cuff of the machine's lever arm was fixed to the ankle, proximal to the malleoli. The subjects were asked to use the grips on both sides of the chair. Before MVC the subjects were asked to do a standardized warm-up. The warm-up consisted of 7 contractions at 60% 1 maximal repetition (RM); 5 at 70% of 1RM and 3 at 80% of 1 RM and 1 at 90% of 1RM, at a knee angle of 115 degree and subjects were given 1 minute 30 seconds rest between sets. MVC was performed at a knee angle of 115° and subjects were given 1 minute 30 seconds rest between repetitions. Participants were asked to perform 3 MVCs and were verbally encouraged during the contractions. The EMG values obtained from the MVC were used to normalize the football game measured data for the quadriceps muscle from knee extension and for hamstring muscle from knee flexion.

- 2) An incremental 3-stage treadmill test (OJK-1, Telineyhtymä, Kotka, Finland). The 3 stages corresponded to 3 different speeds (6 km/h=walking, 12 km/h=jogging and 16 km/h=striding) that are observed during a football match (Bangsbo et al. 1991; Mohr et al. 2003; Rampinni et al. 2007). All the stages were performed with a 0 degree inclination and lasted 1 minute each. During the treadmill test average EMG

from quadriceps and hamstring were monitored, the EMG values were determined during the last 30 second of the different stages.

The *Field test* consisted of the measurement of the LQ, RQ, LH and RH EMG activity during the football match. The measurements were done during three friendly games. Subjects were invited to wear the shorts embedded with textile electrodes and a module under their football uniform. Before each measurement a measurer checked the device and turned it on for recording. The measurer was also responsible for a log sheet in which start of the game, end of 1st half, start of 2nd half and end of the match were marked. At the end of the game, the measurer first turned off and removed the module, before the subject took off the shorts.

7.3 EMG RECORDING

Raw EMG data signal was recorded with 1000 Hz sampling rate and band-pass filtered with 50-200 Hz. Data were averaged and rectified over a 100 ms non-overlapping windows before storage to the module. The filtered, rectified and averaged data were downloaded from the module to MyonWearMowe software (Myontec Ltd, Kuopio, Finland). The downloaded data were then imported on Megawin software (Megaelectronics Ltd, Kuopio, Finland) for the analysis.

7.4 EMG ANALYSIS

7.4.1 DATA CLEANING PROCESS

As a first step, the imported raw EMG data were visually checked for artifact removal. In the presence of artifacts in one of the channels throughout the whole football match the data was considered as not reliable and was totally removed from the final analysis. After visual checking, raw data were rectified and averaged (Fig. 16).

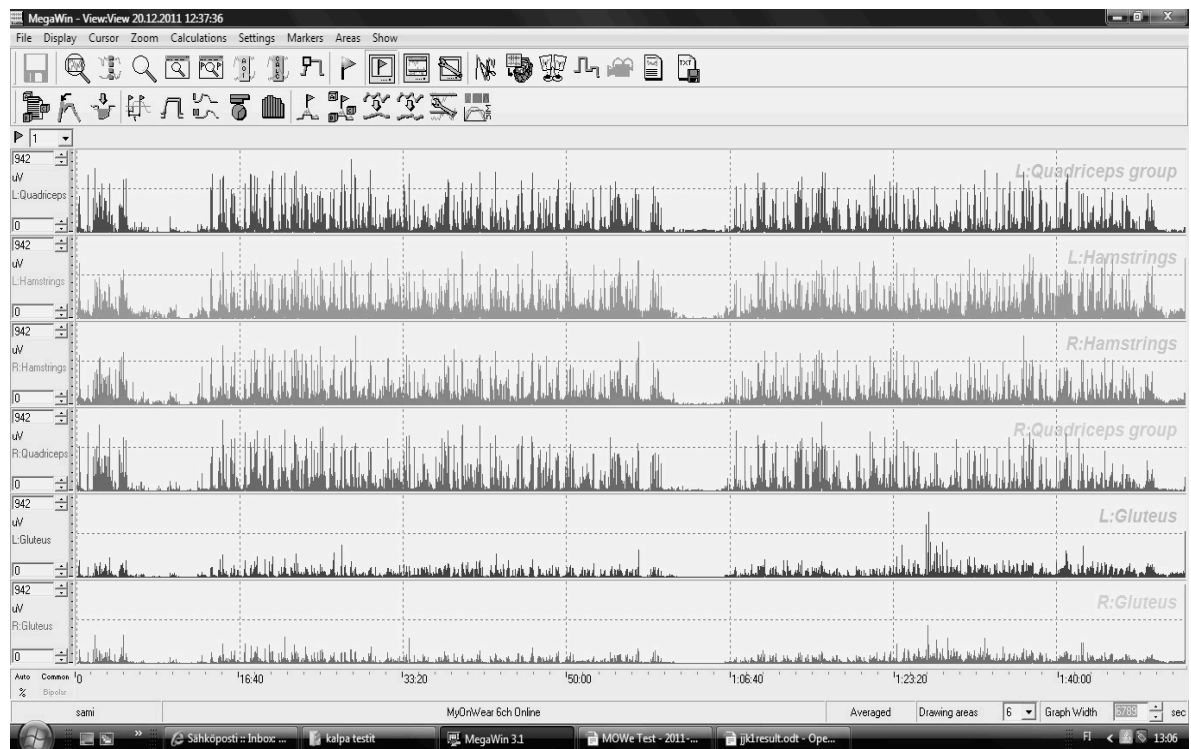


FIGURE 16. Example of average EMG data from the 90 minutes football match of Left and right quadriceps, hamstrings and Gluteus.

Average EMG (aEMG) data from the 1st 15 minutes and last 15 minutes of the game were identified and exported as an ASC file on excel (Microsoft inc. US). The exported ASC file was copied on an Excel sheet and converted to .csv file with a custom made excel macro. The .csv file were then analyzed by a custom made Matlab algorithm (Matlab, MathWorks, Massachusetts).

7.4.2 DATA NORMALIZATION AND ACTIVATION THRESHOLD

First, the individual normalization value (EMG_{MVC}) (measured during MVC test) and activation thresholds for inactivity-to-low, low-to-moderate and moderate-to-vigorous were calculated (measured during the 3 stages treadmill test). The inactivity was set as $<2\%$ of the EMG_{MVC} (Pesola 2011) therefore inactivity time analyzed in this study is equal to the percentage of the total recording time at an intensity corresponding to below 2% of EMG_{MVC} . Low activity is equal to the percentage of the total recording time at an intensity corresponding to EMG values obtained from stage 1 (6km/h) of the treadmill test; moderate activity is equal to the percentage of the total recording time at an intensity corresponding to EMG values obtained from stage 2 (12km/h) of the treadmill test and vigorous activity is equal the percentage of the total recording time at an intensity corresponding to EMG values obtained from stage 3 (12 km/h) of the treadmill test.

Then cleaned data was run through a Matlab script (Matlab, MathWorks, Massachusetts). The script used for this study is based on the one described by Kern (2001) and was previously used by Haakana 2011 and Pesola 2011. As a first step, the script normalized the EMG data from the football match with EMG_{MVC} . The Matlab script also provided a distribution of the muscle activity and inactivity at different percentages of EMG_{MVC} : 0-5, 5-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90, 90-100 and >100 . Burst was defined as an interval that had amplitude of $> 2\%$ of EMG observed during EMG_{MVC} (Klein et al. 2001). Many variables can be obtained from the busts analysis, below are the ones that we analyzed in our study.

- Average EMG: EMG values normalized to EMG_{MVC} mean from the 15 minutes periods.
- Number of bursts: Total number of bursts during the recording periods.
- Average duration of bursts (s): Mean duration of all bursts.
- Burst amplitude: Mean amplitude of bursts as percentage of MVC
- Burst rate per seconds (bps): Mean number of bursts per seconds

7.5 STATISTICAL ANALYSIS

Statistical analysis was performed using IBM SPSS STATISTICS 20 (SPSS inc. Chicago, Illinois, US) and Excel 2007 (Microsoft inc. US). Comparisons of the variables at two different period of time were done using the Wilcoxon signed rank test. Data is presented as mean \pm standard deviation (SD). Significance level was set as $p < 0.05$ * for all the tests.

8 RESULTS

8.1 LABORATORY TESTS

Table 2 presents results for MVC of both knee extension and flexion. Individual results of MVC are represented in appendix A. Means and SD from the treadmill tests are presented in Fig. 17. Individual results are presented in appendix B.

Table 2: Results MVC and aEMG for LQ, RQ, LH and RH

n=7	LQ (Kg)	LQ (uV)	LH (Kg)	LH (uV)	RQ (Kg)	RQ (uV)	RH (Kg)	RH (uV)
Mean	104.8	369.5	30.0	426.5	108.5	328.1	37.1	430.7
SD	20.1	141.7	4.09	93.5	16.1	171.1	8.8	169.5

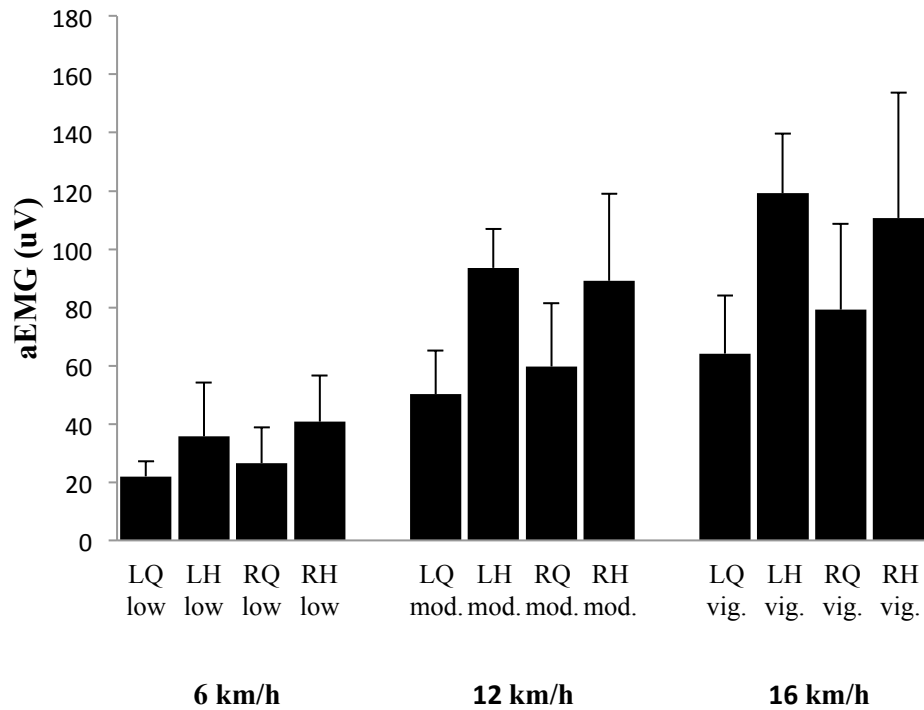


FIGURE 17. Mean aEMG during the three stages of treadmill test.

8.2 FIELD TESTS

Mean and SD of PRE and POST aEMG_{MVC} are presented in Fig.18. The EMG activity decreased by 27.2 % \pm 12 for RQ ($p < 0.05$); 29.6% \pm 8.8 for RH ($p < 0.05$); 27.9 % \pm 14.5 for LQ and 18.1 % \pm 11.9 for LH ($p < 0.05$).

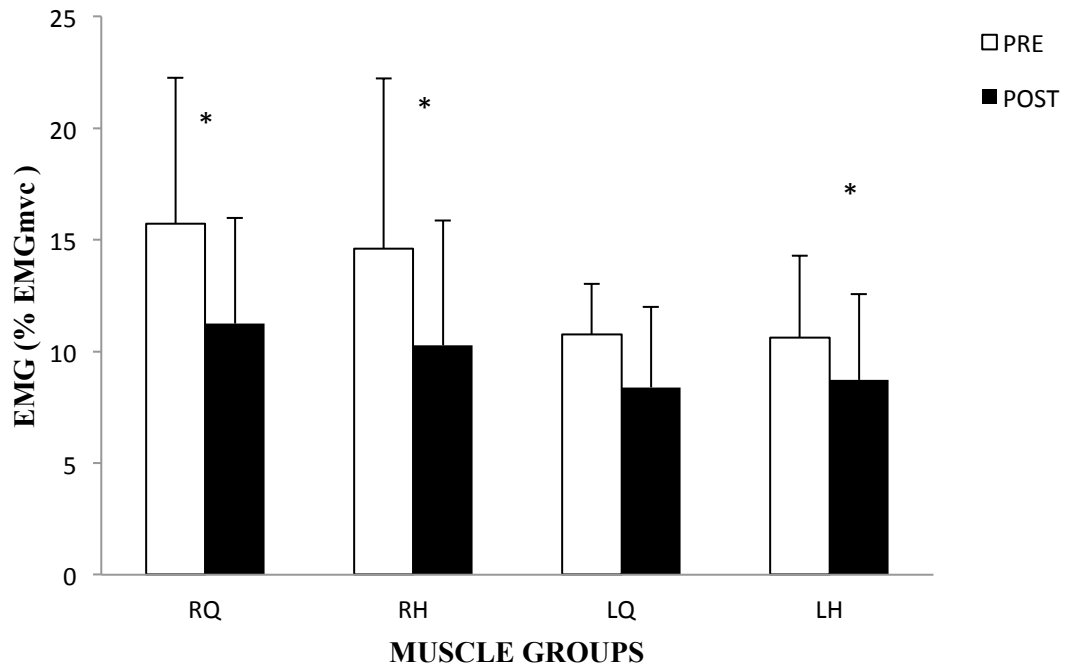


FIGURE 18. Comparison of mean of PRE vs. POST aEMG. * $p < 0.05$.

Table 3: Burst analysis, PRE and POST comparison

(n=7)	PRE	POST	% DIF.	Sig.
NUMBER OF B.	RQ 678.5 ± 407.2	942.5 ± 614.7	(+)20.6	0.068
	RH 739.6 ± 465.0	871.8 ± 478.2	(+)21.6	0.138
	LQ 1008 ± 783.9	1027.6 ± 743.2	(+)17.7	0.893
	LH 1005.8 ± 849.5	974.4 ± 758.1	(-)23.2	0.500
DURATION	RQ 0.63 ± 0.2	0.39 ± 0.8	(-)32.6	0.068
	RH 0.61 ± 0.3	0.36 ± 0.1	(-)31.9	0.043*
	LQ 0.57 ± 0.4	0.42 ± 0.2	(-)22.8	0.043*
	LH 0.73 ± 0.4	0.76 ± 0.4	(+)29.1	0.043*
AMPLITUDE	RQ 19.75 ± 11.1	14.43 ± 7	(-)23.8	0.043*
	RH 17.16 ± 6.8	13.61 ± 5.0	(-)20.2	0.043*
	LQ 13.23 ± 1.3	11.23 ± 2.7	(-)18.8	0.080
	LH 13.1 ± 2.9	12.05 ± 3.9	(-)12.3	0.138
B. RATE	RQ 1.16 ± 0.7	1.54 ± 0.8	(-)20.0	0.043*
	RH 1.65 ± 0.6	2.01 ± 0.4	(+)20.3	0.225
	LQ 1.75 ± 0.6	1.93 ± 0.5	(+)12.3	0.138
	LH 1.64 ± 0.7	1.78 ± 0.6	(+)18.5	0.500

The burst analysis revealed a difference in the aEMG activity between PRE and POST period of the measurements. Table 3 shows that the burst duration decreased for RH and LQ but increased for LH at the end of the game. Burst amplitude decreased for RQ and RH after the game. Burst rate showed lower value for RQ in the last 15 minutes of the game.

PRE vs. POST activity profile: Results showed a different muscle activity profile between the first and the last 15 minutes of the second half. All muscle groups showed similar patterns in the distribution of muscle activity (Appendix 3-5 and TABLE 4). The lowest intensity 0-5% is the only workload that shows an increase in POST. From 5% to > 100%, we observed a decrease in activity time in the POST. It also appears that the difference between PRE and POST condition is increasing proportionally to the activation level. The different muscle groups spent the majority of the time at activation percentage below 50% and only very small percentage of the time at the highest intensities.

Table 4: Examples of left hamstring's EMG activity PRE and POST. Values are Means \pm SD with calculated difference between PRE and POST.(n=7)

Activation %	PRE	POST	Av. % diff.	Significance
0-5%	50.6 \pm 20.2	59.7 \pm 19.1	(+)27.8	p= 0.043*
5-10%	17.2 \pm 5.09	15.6 \pm 6.3	(-)9.3	p= 0.138
10-20%	16.9 \pm 8.8	12.9 \pm 6.7	(-)17.6	p= 0.043*
20-30%	6.8 \pm 3.5	4.7 \pm 2.6	(-)23.9	p= 0.043*
30-40%	3.1 \pm 1.3	2.4 \pm 1.3	(-)25.2	p= 0.043*
40-50%	1.9 \pm 0.8	1.5 \pm 0.8	(-)22.5	p= 0.043*
50-60%	1.08 \pm 0.3	1.1 \pm 0.7	(-)27.4	p= 0.686
60-70%	0.7 \pm 0.3	0.7 \pm 0.5	(-)32.6	p= 0.893
70-80%	0.4 \pm 0.2	0.3 \pm 0.3	(-)25.2	p= 0.345
80-90%	0.3 \pm 0.1	0.2 \pm 0.1	(-)22.5	p= 0.225
90-100%	0.2 \pm 0.1	0.1 \pm 0.1	(-)27.4	p= 0.545
>100%	0.3 \pm 0.2	0.2 \pm 0.2	(-)32.6	p= 0.080

PRE vs. POST inactivity times are presented on Fig.19. EMG activity showed an increase of 33.8 % \pm 25.5 % for RQ, 30 % \pm 20.8 % for RH, 32.2 % \pm 10.8 % (p<0.05) for LQ, 35.6 % \pm 5.9 % (p<0.05) for LH, in POST period.

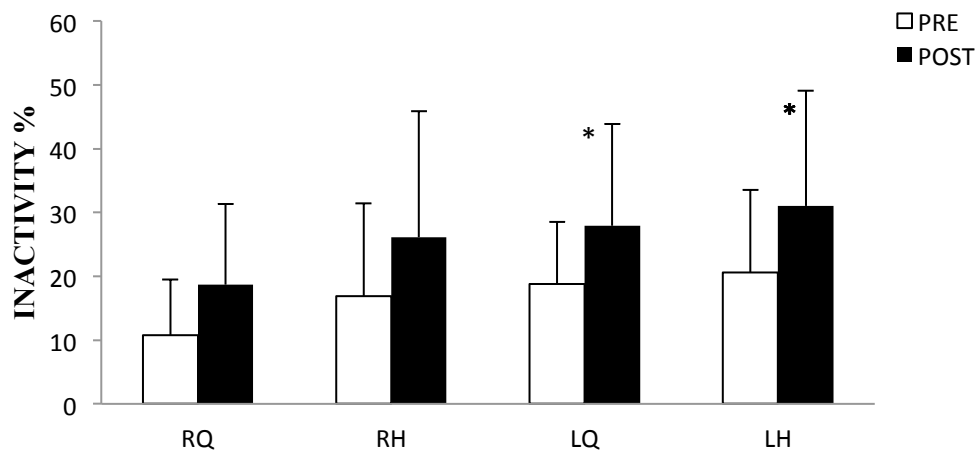


FIGURE 19. Comparison PRE and POST mean values inactivity RQ, RH, LQ and LH. *p<0.05.

PRE vs. POST low activity times are presented in Fig. 20. Data showed an increase between PRE and POST values of $6.6 \% \pm 7.8\%$ ($p < 0.05$) for RQ, $7.4 \% \pm 4.6 \%$ for RH, $7.9 \% \pm 6.5 \%$ for LQ, and a decrease of $14.1 \% \pm 5.7 \%$ for LH.

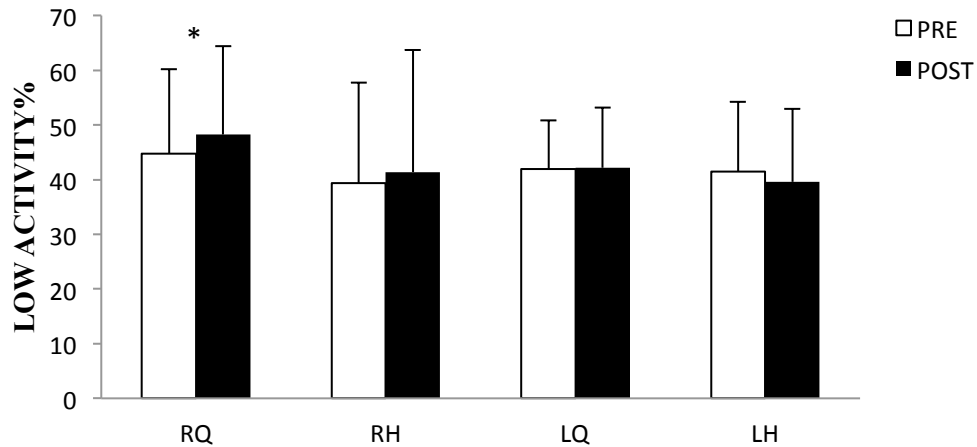


FIGURE 20. Comparison PRE and POST mean values low activity RQ, RH, LQ and LH. * $p < 0.05$.

PRE vs. POST moderate activity times are presented in Fig. 21. EMG activity showed a decrease of $21 \% \pm 14.1 \%$ for RQ, $17.9 \% \pm 8.3 \%$ ($p < 0.05$) for RH, $20.2 \% \pm 12.9\%$ for LQ, $23 \% \pm 6.85 \%$ ($p < 0.05$) for LH. The decrease in moderate activity was significantly in the hamstring muscle groups.

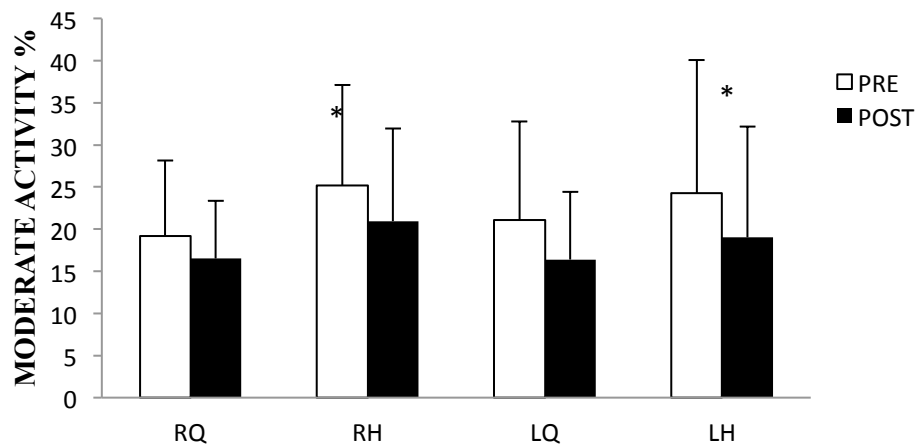


FIGURE 21. Comparison PRE and POST mean values moderate activity RQ, RH, LQ and LH. * $p < 0.05$.

PRE vs. POST vigorous activity times are presented in Fig. 22. EMG activity showed a decrease of $31.3\% \pm 14.8\%$ ($p < 0.05$) for RQ, $37\% \pm 10.3\%$ ($p < 0.05$) for RH, $26.5\% \pm 16.4\%$ for LQ, $27.5\% \pm 15.7\%$ ($p < 0.05$) for LH.

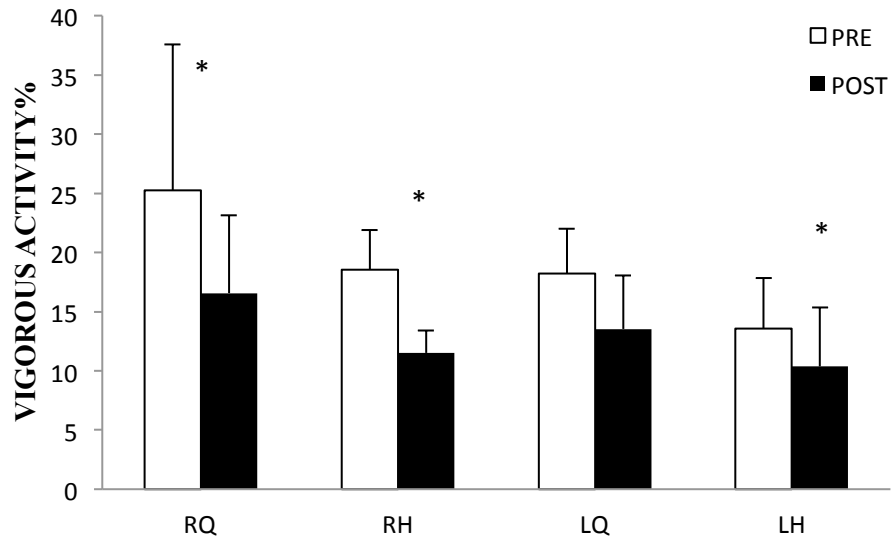


FIGURE 22. Comparison PRE and POST mean vigorous activity RQ, RH, LQ and LH. * $p < 0.05$.

9. DISCUSSION

The main findings of this study were the observed decrease in EMG during a football match. A 18-30 % reduction in aEMG was found between 1st 15 minute and last 15 minutes of the match. The reduced muscle activity is in accordance with previous studies of similar experimental design. In these studies, EMG activity was reduced after fatiguing protocols. The reduced EMG activity was also accompanied by a significant decrease in performances (Rahnama et al. 2005, Thordlund et al. 2008, Mendes-Villanueva et al. 2008).

The present study also showed a decrease in burst duration, bursts amplitude, burst rate and an increase in the number of bursts in POST conditions. Further, the distribution of muscular activity shifted towards lower intensities in the last 15 minutes of the game, except at the lowest intensity (0-5%). Inactivity and low activity time increased in POST period (except for LH) while moderate and vigorous activity time decreased in the last 15 minutes of the football match. The last important finding was that for all the studied variables we could observe different behavior between muscle groups.

These findings are suggesting that central and peripheral fatigue might have an effect on football specific performance. The inability of the muscle to maintain their pre-fatigue neuromuscular activity in submaximal and maximal fatiguing contractions can be explained by factors acting at spinal and supraspinal sites. At spinal level relevant factors include the intrinsic behavior of the MN, recurrent inhibition, reflex inputs reaching α and γ -MN and their presynaptic modulation, as well as neuromodulatory influences acting on MN and spinal circuitry. Conductivity of the electrical signal might also be altered by the buildup of metabolites induced by exercise. It has been demonstrated that accumulation of metabolites might stimulate group III and VI afferent, and as a consequence this would lead to pre-synaptic inhibition of group Ia afferents (Avela & Komi, 1998; Millet & Lepers, 2004). At supraspinal level, the output of descending (including corticospinal) paths to MN and the factors that control the output are likely to be important (Gandevia 2001).

At peripheral level, membrane excitability has been shown to be affected by metabolites generated during exercise. Excitability of the membrane can be decrease during maximal and submaximal fatiguing contractions due to activity-dependent modulations of the motoneuronal intrinsic properties and the input-output balance of the MN (Peirrerera et al. 2012). Reduced pH and accumulation of extracellular potassium (K^+) has been observed during high intensity activity such as football. This might affect the neuromuscular process by causing physical changes in the organization of membrane proteins and/or via electric field generated by their charge (Bass & Moore 1973). Moreover, the intermittent characteristics of football, requires the players to accelerate, decelerate and sprint, depending on the situation. These regular changes of rhythm might induce muscle damage, particularly to type II fibers that have been suggested to be more susceptible to damages than fibers I (Oliver et al. 2008).

All the variables studied in the burst analysis showed a difference in POST, however not all of them were statistically significant. Duration, amplitude and burst rate all showed a decrease in the last 15 minutes of the game and only number of burst showed an increase. Duration of burst showed a significant decrease. There is no previous data available related to the bursts analysis of such activity as football. However, we could speculate that the observed results are partly related to the recruitment strategy of the CNS. When workload increase or fatigue appears, CNS might modulate the rate coding (frequency of stimulation) to recruit more and larger MU in order to maintain or increase the force level required to sustain the effort and his strategy might be reflected as an increase in the average EMG activity (Gandevia 2001, 327).

Distribution of muscular activity demonstrated an inverse relationship between low and high activity. The time spent at lowest intensity (0-30 % a EMG_{MVC}) increased and time spent at the highest intensity (90- >100 % a EMG_{MVC}) decreased in POST. These data are in accordance with previous research studying the activity profile of football players. Rienzi et al. (2000) using video motion analysis showed that low activity counted for 80 % (50%: forwards and backwards walking + 30%: forwards, backwards and sideways jogging) of the total time. Striding and sprinting accounted for 4 and 1% of the time. The

remaining 15% of the total time was spent as static pause (Rienzi et al. 2000). In another study, Bradley et al. (2009), using video motion analysis, also confirmed the results. During the match, low intensity represented 85% (59.3% walking and 26.1% jogging). High intensity running represented 9% (8.4% striding and 0.6 sprinting) of total time and the remaining 5% players stood.

Another observation is that the time at lowest intensity (0-5% EMG_{MVC}) increased in POST. This was further confirmed with the analysis of percentage of inactivity, low activity (0-6 km/h), moderate activity (6-12km/h) and vigorous activity (12-16 km/h). Inactivity time increased in the POST condition for all the group muscle. Rienzi et al. (2000) showed that work rate was reduced in the second half of the game compared to first half and that it reflects the onset of fatigue as the games goes on. Further, Bradley et al (2009) showed that players spent longer time standing and walking in the second half.

Moderate and vigorous activity time decreases for all muscles in the last 15 minutes of the game. Krstrup et al. (2003) showed that distance covered by sprinting was significantly decreased in the second half. Bradley et al. (2009) showed a 21% decrease in the total distance covered by sprinting in the last 15 minutes of the game. Many studies using video analysis further demonstrate that the amount of high intensity exercise decreases towards the end of the game (Bangsbo, 1994; Bangsbo et al. 1991; Mohr et al. 2003 Reilly and Thomas, 1976). Mohr et al. (2003) also demonstrated that only 3% of the players would experience their most intense period in the last 15 minutes of the game and more than 40% of players had their least intense period in the last 15 minutes (Mohr et al. 2003).

The study revealed a different EMG activity mean values between muscle groups. Only one of the seven participants of this study was left footed. In the laboratory MVC and treadmill tests, we observed a difference between the same muscle group of opposite limb and muscle group in the same limb. Mean values of RH and LH aEMG mean were higher than than aEMG mean values of RQ and LQ. We also observed that aEMG increased as speed increased during the laboratory 3 stages treadmill test, which was also observed by Kyröläinen et al. (2005). Data from the football matches showed that right leg muscles had higher PRE and POST aEMG mean values during the game than the left side muscle

groups. We could also see difference between quadriceps and hamstrings, with quadriceps having larger PRE and POST aEMG mean values than hamstrings. Sagnier et al. (2007) had also noted a similar observation in a study with 27 professional players where torque of the quadriceps was significantly higher than that of the hamstrings, and in comparison in the same muscle group did not show significant difference. Sagnier et al. (2007) and Delextrat et al. (2009) showed that the hamstring muscle force seem to be affected by fatigue the most.

Burst analysis further emphasizes this difference. Number of bursts was higher for LQ and LH in PRE and POST periods compared to RQ and RH and LH having the highest percentage decrease (23%). Burst duration was high in LH, showed the highest value and it is the only muscle group increasing POST burst duration value. Burst amplitude was higher in PRE and POST conditions for RQ and RH compared to LQ and LH. LH showed the lowest percentage decrease in POST condition (12%). Burst rate showed a difference between LQ and RQ.

The reasons for the different behavior between muscle groups during the football match are multiple. One important reason is that, hamstrings and quadriceps are constituted of different fiber type proportion. Based on size, speed and fatigability, MUs can be classified in two major groups: large, fast and fatigable or small (type I), slow and fatigue resistant (type II). Larger, fatigable MU are normally reserved for brief and forceful contractions, based on the Henneman' size principle that demonstrated that small MUs are recruited first and as intensity of exercise increase larger MUs are then recruited (Henneman et al. 1965). Hamstrings and quadriceps have both types but with different proportions. Garrett et al. (1984) demonstrated that hamstrings have a larger proportion of type II fibers compare to quadriceps. The higher proportion of fast fatigable fiber II, makes the H more vulnerable to during long duration exercises (Garrett et al. 1984). This difference in fiber types might be an important factor in the divergence in neuromuscular activity between the two muscle groups (Clarckson et al. 1982).

Another reason might be the muscle architecture (muscle length, pennation angle etc.). Muscle force potential is related to the amount of parallel sarcomeres (physiologic cross-sectional area) and its velocity potential is linked to the sarcomeres that are in series (muscle length). Quadriceps, which is an antigravity muscle at the knee, has a higher physiologic cross sectional area than H (Ikai & Fukinaga, 1968). Kaufman et al. (1991) compared the physiological cross sectional area between Q and H. They demonstrated that Q's CSA can range from 65.5 to 86.73 cm² and H's CSA from 43.5 to 47.88 cm². According to Kaufman et al., this suggests that more force is needed to produce a flexion torque than an extension at knee joint. Consequently, this will probably have an influence on the different neuromuscular activity observed in quadriceps and hamstrings when exposed to fatigue. Kearns et al. (2001) showed that football players tended to have a thicker dominant leg and that thickness was associated with a longer fascicle length of the dominant leg. This might explain the different behavior of non dominant and dominant muscle group when they are subject to fatigue. Limb dominance has been suggested to be an intrinsic risk factor of injuries, because it is preferentially used for kicking and passing. However, the association between dominance limb and injuries remains controversial (Murphy et al. 2003).

The last factor that might explain the different EMG activity between left and right muscle groups is the specific task of the limbs and muscle during the football match is the different function of the dominant and non-dominant leg. One has a function of pushing, tackling, landing, jumping and kicking leg (dominant leg), the other has the function of support and act as pivot around which the rotation of movement occurs (non-dominant leg). Most football players have a preferred kicking limb and this is likely to put differential demand on the lower extremities given the difference in muscle activation seen in the kicking limb compare to the support limb (Brophy et al. 2010). During a 90 minutes football match, a player will have 51 contacts with the ball and approximately 50% of these contacts are made with the preferred foot (Whiters, 1982). During that contact with ball, the Q of the dominant leg contract in concentric mode and push the leg forward. The hamstrings, which act as antagonists, contract in eccentric mode to absorb energy and reduce the translation of the tibia (Sangnier et al. 2007). The role of hamstring during leg extension is to assist the

anterior cruciate ligament in preventing anterior tibial drawer forces (More et al., 1993) by enhancing the posterior pull, increasing joint stiffness and decreasing anterior laxity force during quadriceps loading to oppose its force (Baratta et al. 1988). It will help to prevent overextension by decelerating the leg prior to full extension (Coomb et al. 2002).

The unique feature of the present study was that for the first time, we had an accurate picture of the electrical muscular activity during an actual football match, and most importantly how the workload induced by this physically demanding sport will affect the activity of two important lower limb's group of muscle, quadriceps and hamstrings. No previous study has ever had the opportunity to use electromyography during a game. However, the results need to be interpreted with precautions. EMG activity cannot be considered as a steady parameter, because even during the same stage, the characteristics of each burst or active period can vary concurrently depending on the task being performed, temperature, type of contraction, angular position, intensity of workload, frequency and length of the stride (Alber-Kajee et al. 2011; Kellis et al. 1998) and those could unfortunately not be controlled during the football match. The validity and accuracy of the EMG measurement is depending on the recording procedure, factors such as amplification and rectification of the signal. Selection of the smoothing technique and EMG parameter during data process influence EMG results (Basmajian & DeLuca 1985, 163). During the match, players would do different types of contractions (eccentric, isometric, concentric and stretch shortening cycle) with a different velocities depending on the situations. We normalized our EMG values with isometric contraction of hamstring and quadriceps, at an angle of 115 degree. MVC is widely used and has been shown to be a efficient method of normalization but other methods, more specific to activities and contractions type encounter during the football match should be tested.

A major problem during this study was the number of subjects available and the extremely tight schedule. We only had a few participants at our disposal and this had an influence on the statistical analysis. Many players were not too enthusiastic to wear an unusual device while they are performing; some of them complained that the shorts felt a little bit too tight. Size of the shorts, is an important methodological concern to consider because if the shorts

are too large, electrodes might lose contact with the skin and EMG signal would be contaminated by artifacts. The shorts should be tailor made, to perfectly fit the shape of the subject. Feedback from the players also revealed that the module on the waist was also a source of concern as they could feel it moving up and down while running and the fear of not damaging it, add more stress during the game. The strict schedule, made it difficult for us to familiarize players with the different interventions. For many players it was the first time that they had to perform a MVC, so the result of the MVC used for the normalization might have been influenced by the participant's lack of familiarity with the leg flexion-extension machine. Finally, MVC were performed at different time of the day, and this might have an influence on the results (Sedliak et al. 2008).

Future studies should be long term and include more subjects. It would be useful to combine measurement with other devices (e.g. video analysis, accelerometer, heart rate monitors, GPS systems etc.) or with a specific training program (e.g. concentric, eccentric plyometric etc.). It would also be interesting to use the EMG shorts to have a better understanding of the injury onset mechanisms.

In conclusion, we demonstrated that there is a difference between the EMG activities in the first 15 minutes compare to the last 15 minutes of the game. EMG activity has a tendency to decrease during fatigue at the end of the game. These fluctuations in the neuromuscular activity will probably have an impact on force generation of the muscles and indirectly cause injuries. The present finding represents an important step in injury prevention, rehabilitation and conditioning field. Thanks to the development of the textile electrodes we were able to monitor the changes in the neuromuscular activity of two important muscles, in fatigue conditions. Our results give a promising starting point for using EMG in studying performance and preventing injuries during intensive sport activities such as football.

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11. APPENDIX

Appendix 1: aEMG for LQ, RQ, LH and RH during incremental 3 stages treadmill test.

Stages	1	2	3	4	5	6	7	Mean±SD
aEMG-LQ (uV) - 6km/h	22	20	26	21	15	19	31	22±5,16
aEMG-LH (uV) - 6km/h	37	24	44	41	0	55	49	35,71±18,5
aEMG-RQ (uV) - 6km/h	26	19	51	25	12	22	31	26,57±12,3
aEMG-RH (uV) - 6km/h	39	23	25	38	41	70	49	40,71±15,7
aEMG-LQ (uV) - 12km/h	82	48	44	50	48	34	45	50,14±14,9
aEMG-LH (uV) - 12km/h	107	86	86	105	110	85	76	93,57±13,4
aEMG-RQ (uV) - 12km/h	67	42	44	77	47	98	43	59,71±21,6
aEMG-RH (uV) - 12km/h	125	74	86	100	122	39	78	89,14±29,8
aEMG-LQ (uV) - 16km/h	103	59	53	55	78	44	57	64,14±19,9
aEMG-LH (uV) - 16km/h	143	114	89	112	149	114	113	119,14±21
aEMG-RQ (uV) - 16km/h	95	59	48	90	73	133	56	79,14±29,4
aEMG-RH (uV) - 16km/h	171	94	87	104	162	48	109	110,71±43

Appendix 2: Results MVC and aEMG for LQ, RQ, LH and RH

Subject #	1	2	3	4	5	6	7
MVC-LQ (kg)	81,88	120,98	86,43	123,01	126,14	112,41	82,95
aEMG-LQ (uV)	286	397	260	637	342	446	219
MVC-LH (kg)	28,23	36,80	24,04	31,30	32,91	29,54	27,66
aEMG-LH (uV)	391	565	306	448	324	505	447
MVC-RQ (kg)	101,81	117,57	120,55	120,65	124,52	89,57	85,34
aEMG-RQ (uV)	212	384	150	619	151	348	433
MVC-RH (kg)	41,72	53,18	34,44	32,50	41,16	29,53	27,44
aEMG-RH (uV)	539	552	239	585	162	541	397

Appendix 3: Right quadriceps's EMG activity PRE and POST. Values are Means \pm SD with calculated difference between PRE and POST.(n=7).

Activation %	PRE (%)	POST (%)	Av. % diff.	Significance
0-5%	44.48 \pm 12.42	56.27 \pm 8.8	(+)23.79	p= 0.080
5-10%	16.58 \pm 2.18	15.5 \pm 3.25	(-)15.43	p= 0.500
10-20%	16.32 \pm 4.78	13.83 \pm 3.77	(-)21.59	p= 0.138
20-30%	6.94 \pm 2.51	5.28 \pm 1.19	(-)20.74	p= 0.043*
30-40%	4.43 \pm 1.87	2.89 \pm 0.99	(-)32.08	p= 0.043*
40-50%	2.89 \pm 1.46	1.9 \pm 0.78	(-)38.84	p= 0.138
50-60%	1.96 \pm 1.24	1.2 \pm 0.75	(-)39.36	p= 0.080
60-70%	1.33 \pm 1.09	0.78 \pm 0.63	(-)43.28	p= 0.080
70-80%	1.06 \pm 0.9	0.54 \pm 0.47	(-)40.29	p= 0.080
80-90%	0.77 \pm 0.69	0.38 \pm 0.37	(-)39.75	p= 0.043*
90-100%	0.55 \pm 0.55	0.29 \pm 0.27	(-)35.57	p= 0.068
>100%	2.68 \pm 3.07	1.07 \pm 1.4	(-)50.71	p= 0.068

Appendix 4: Right hamstring's EMG activity PRE and POST. Values are Means \pm SD with calculated difference between PRE and POST.(n=7).

Activation %	PRE	POST	Av. % diff.	Significance
0-5%	43.36 \pm 14.07	55.06 \pm 16.04	(+)21.62	p= 0.043*
5-10%	16.93 \pm 1.83	16.64 \pm 2.98	(-)9.71	p= 0.500
10-20%	18.15 \pm 5.23	14.11 \pm 6.32	(-)24	p= 0.043*
20-30%	8.57 \pm 3.56	5.78 \pm 2.92	(-)33.77	p= 0.043*
30-40%	4.43 \pm 1.8	2.96 \pm 1.76	(-)36.39	p= 0.043*
40-50%	2.59 \pm 1.52	1.85 \pm 1.49	(-)35.55	p= 0.043*
50-60%	1.96 \pm 1.24	1.2 \pm 0.75	(-)40.66	p= 0.043*
60-70%	1.11 \pm 0.95	0.79 \pm 0.76	(-)41.60	p= 0.080
70-80%	0.87 \pm 0.73	0.53 \pm 0.50	(-)45.22	p= 0.043*
80-90%	0.56 \pm 0.54	0.34 \pm 0.39	(-)50.28	p= 0.043*
90-100%	0.32 \pm 0.40	0.19 \pm 0.22	(-)52.69	p= 0.225
>100%	1.3 \pm 2.36	0.55 \pm 1.17	(-)57.12	p= 0.043*

Appendix 5: Left quadriceps's EMG activity PRE and POST. Values are Means \pm SD with calculated difference between PRE and POST. (n=7).

Activation %	PRE	POST	Av. % diff.	Significance
0-5%	55.6 \pm 12.4	64.25 \pm 13.52	(+)17.57	p= 0.080
5-10%	16.18 \pm 3.33	14.86 \pm 4.78	(-)25.33	p= 0.345
10-20%	13.16 \pm 5.62	9.66 \pm 3.52	(-)27.01	p= 0.043*
20-30%	6.23 \pm 3.38	4.62 \pm 2.64	(-)25.31	p= 0.043*
30-40%	2.87 \pm 0.69	2.27 \pm 1.04	(-)24.86	p= 0.080
40-50%	2.02 \pm 0.66	1.47 \pm 0.75	(-)30.53	p= 0.080
50-60%	1.21 \pm 0.24	0.99 \pm 0.52	(-)33.66	p= 0.225
60-70%	0.80 \pm 0.14	0.62 \pm 0.47	(-)43.88	p= 0.500
70-80%	0.50 \pm 0.86	0.27 \pm 0.13	(-)45.68	p= 0.043*
80-90%	0.40 \pm 0.15	0.28 \pm 0.26	(-)44.99	p= 0.225
90-100%	0.23 \pm 0.13	0.16 \pm 0.16	(-)51.93	p= 0.225
>100%	0.71 \pm 0.58	0.42 \pm 0.68	(-)46.59	p= 0.225