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The effect of maximum strength training vs. combined strength/plyometrics training on strength and sprint performance in elite women's football.

Monitoring of training load and recovery

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Preface

This last year has been a long and educational process and the project is eventually completed. It has been tough, but thanks to all the people that have helped and supported me, I succeeded. This could not have been done without you all.

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Markus Vagle

Abstract

This study consisted of two projects conducted in parallel. The aim of project I was to investigate the effect of, and difference between, two strength-training regimes over 10-weeks in female football players. The aim of project II was to investigate relationships between different load monitoring techniques, level of recovery and ratings of performance.

Eleven players from a Norwegian elite female football club was included in project I, and ten players in project II. Participants in project I were split into two groups, plyometric (PLY, n=6) and maximum strength (MAX, n=5). Both groups performed two strength-training sessions a week for 10-weeks. MAX performed two maximum strength sessions, and PLY performed one maximum strength session and one plyometric session. Players was tested for 1 repetition maximum (1RM) strength in squat, bench-press and pull-down, as well as performance in 10- and 30-m sprint, countermovement jump (CMJ) on force platform, repeated sprint (6x30-m), Yo-yo intermittent recovery level 1 (Yoyo IR1) and muscle architecture pre- and post to the training period. For project II, load-monitoring data were collected through a series of methods including session rate of perceived exertion (sRPE), pre training wellness questionnaire (PTW), neuromuscular fatigue jump test (NMF), and coaches votes (CV).

Both groups had a substantial increase in 1RM squat (PLY = 10.4±7.1 kg effect size; ES=0.80, MAX = 18.1±7.7 kg ES=0.80; mean ± 90% confidence limits; CL), a moderate effect was found between groups being greater for MAX (ES = 0.85, 94% likely). MAX showed an increase in 10-m sprint time (0.04±0.03 s, ES = 0.41, 89% likely), but no other change was found for sprint or jump tests. A small increase in muscle thickness (PLY = 0.21±0.10 cm, MAX = 0.10±0.21 cm) was found for both groups, however the effect between groups was considered unclear (ES = 0.26). An increase in fascicle length was also evident (PLY = 0.60±0.89 cm, MAX 0.43±1.90 cm), but the between groups difference was trivial and unclear (ES = 0.19). Trivial difference was found in training load between groups throughout the period (ES = 0.17), and no consistent relationships were evident between the load monitoring techniques.

Both maximum strength- and combined maximum strength and plyometric training increases 1RM performance, but seem to have little effect on sprint and jump performance directly. Long familiarization periods seems to be necessary in order for the load monitoring data to be valuable and useful as a management system to assure development, and reduce the risk of injury.

Contents

1. Introduction

Football is one of the most prevalent sports in the world. It has been played for centuries, and there are several different modes of football, such as American football, Australian rules football, and European football. This thesis concerns European football, also known as association football or soccer (hereby referred to as football). The game is played by millions of people every day, and at several different levels of professionalism. The requirements are somehow equal among the different levels, but the demands increase with the increased level of play as high-level players often show superior abilities compared to lower-levels (Bangsbo, Mohr, & Krustrup, 2006; Gabbett, 2010; Haugen, Tonnessen, & Seiler, 2012). For high-level footballers great technical and tactical skills are required, as well as physical abilities. The game involves several different actions like sprints, change of direction, jumping, and high-intensity running. Each of these has been reported to improve through specific training and it has been reported that match physical performance is improved as a result (Impellizzeri et al., 2006; Ronnestad, Kvamme, Sunde, & Raastad, 2008; Tonnessen, Shalfawi, Haugen, & Enoksen, 2011). Aerobic conditioning has been shown to improve VO_2 max, distance covered during matches, the amount of high-intensity running, and number of sprints (Helgerud, Engen, Wisloff, & Hoff, 2001). Specific sprint and jump training, as well as strength training, has been shown to increase players' ability to accelerate, jump higher, and increase maximal speed (Cormie, McGuigan, & Newton, 2010; Ronnestad, Nymark, & Raastad, 2011; Tonnessen et al., 2011). Increasing these abilities is suggested to be critical to the outcome of the game (Haugen, Tonnessen, Hisdal, & Seiler, 2014). One of the most important factors for acceleration and sprint is power. The two main components of power are maximal force and velocity, and thus maximal strength and power training are necessary to improve these factors. Football clubs often focus on speed and power training instead of strength training when developing these abilities. This is probably due to its ease of transition to gameplay like situations, and the on field practicability of this type of training. However, since maximal force is one of the two main factors, strength training should be implemented as well. A case study conducted over 8-weeks with one of the worlds best club teams reported to improve sprint and jump performance by 5.2% and 3.2% ($p < 0.001$) respectively after maximal strength training (Helgerud, Rodas, Kemi, & Hoff, 2011).

In elite football, players execute a great amount of training, and tracking the intensity and volume is recommended to assure appropriate development of both individual and team fitness (Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004). Especially as high training loads (TL) are associated with injuries, and thus monitoring may contribute to reduce the risk of injury (Gabbett & Jenkins, 2011). As success is measured over several months, a top condition is required throughout the season. In order to manage this every player has to be "properly trained", and recover in-between matches. This requires high-level analysis, planning and monitoring. Several methods exists for monitoring of TL. Monitoring of heart rate, kg lifted, distance ran, and new more sophisticated methods such as semi-automatic video analysis and global positioning systems tracking is some of them. However, most of these methods are very expensive and technical knowledge and expertise for analysis is required to use and interpret the results. In high-level elite football, such as the Barclay's Premier League, and La Liga this is usually not a problem. In the Norwegian elite female football league, however the economics and availability of expertise is limited. Several easier to use, and inexpensive methods exists for quantification of TL, and measurements of performance e.g. session rate of perceived exertion (sRPE), pre training wellness questionnaire (PTW), and coaches votes (CV). All of these methods are considered reliable and valid, and could thus be a simpler and cheaper alternative in order to monitor intensity and TL (McLean, Coutts, Kelly, McGuigan, & Cormack, 2010; Mooney, Cormack, O'Brien B, Morgan, & McGuigan, 2013; Scott, Black, Quinn, & Coutts, 2013). In addition to this, measurements of neuromuscular fatigue (NMF) via countermovement jumps (CMJ) has been suggested as a valid method for assessing recovery and thus may contribute to decrease injuries and help in maximizing performance (Cormack, Newton, McGuigan, & Cormie, 2008b; Coutts, Reaburn, Piva, & Murphy, 2007).

1.1 Purpose

This study includes two projects which has a goal of elaborating the effect of strength training on speed and acceleration (project I), and assess the usefulness of different load monitoring techniques for quantifying internal load, recovery and performance in female football (project II). The main aim of the study, project I, was to investigate the effect of, and difference between, two strength-training regimes on sprint and acceleration qualities amongst female footballers. The effects were assessed through a wide range of tests, including 10- and 30-m sprint, 6x30-m repeated sprint, CMJ on force platform, half squats, bench-press, pull-down, and Yo-yo intermittent recovery level 1 (Yo-yo IR1). Furthermore, muscle architecture measurements were undertaken to analyze if the possible effects are reflected in changes in muscle architecture. The purpose of project II was to investigate different load monitoring techniques and to assess whether they are related to each other and/or performance.

1.1.1 Research questions

I) Is it possible to detect differences in the development of strength, speed, explosive power in sprint and jumps, and muscle architecture between maximum strength vs. maximum strength and plyometric training two times per week for 10 weeks?

II) Is there relationships between measurements of TL via sRPE, and the level of recovery and performance measured via PTW, CV and NMF?

2. Theory

Football is a team sport where the main goal is to score more, and concede less, goals than the opponent. Each team has eleven players on the field during a game, including the goalkeeper. The field size is regulated by international standards, and the goal lines (the short ends) can be a minimum of 64 and a maximum of 75 m, and the touchlines (the long sidelines) a minimum of 100 and a maximum of 110 m (Fédération Internationale de Football Association, 2013; Norwegian Football Association, 2014). Matches are scheduled for 90 minutes plus overtime, usually 1-3 min, that occur due to delays in the game, such as injuries and substitutions. Each team can conduct up to three substitutions during a game, meaning that most of the players have to play the full 90 minutes.

2.1 Match analysis and physical demands in football

Football consists of prolonged, high intensity, intermittent exercise and the game contains repeated activities such as accelerations, decelerations, sprints, jumping, and tackles (Bradley et al., 2009). The differences in these specific activity demands, between players, are based on position, tactics, and physical capacity. Stolen, Chamari, Castagna, and Wisloff (2005) published a review based on 181 research papers on football. They stated that field players at an elite level cover 10 – 12 km per match, and that goalkeepers cover approximately 4 km. Midfielders cover the greatest distances and professional players run longer than non-professionals. This is also supported by Mohr, Krustrup, and Bangsbo (2003) who stated that top-class players perform 28% more high-intensity running and 58% more sprints than players at lower levels. However, more recent studies have reported that players in the lower level Championship league in England cover greater total distance (effect size; ES = 0.38), and perform more high intensity running (ES = 0.22) compared to the Premier league players (Di Salvo, Pigozzi, Gonzalez-Haro, Laughlin, & De Witt, 2013). Furthermore, 80 – 90% of total distance is covered by low intensity activities (<14 km/h), with moderate and high intensity activities (>15 km/h) constitutes 10 – 20% (Andersson, Randers, Heiner-Moller, Krustrup, & Mohr, 2010; Krustrup, Mohr, Ellingsgaard, & Bangsbo, 2005; Mohr, Krustrup, Andersson, Kirkendal, & Bangsbo, 2008). Female players sprint 160 – 460 m in a game (Andersson et al., 2010; Krustrup et al., 2005; Mohr et al., 2008), and for male players the sprint distances have been reported to be between 222 and 1181 m (Stolen et al., 2005). The big differences between males and females in sprint distances have been discussed and it has been suggested that the high limits for what is categorized as sprint, >25 km/h (Bradley et al., 2009; Mohr et al., 2008) is too high for females, leading to a great amount of sprinting being omitted (Vescovi, 2012). Each player performs 1000 – 1500 activities of varying lengths during a game, which is equal to an activity change every 4 – 6 S (Krustrup et al., 2005; Stolen et al., 2005). According to Stolen et al. (2005) a sprint bout occurs approximately every 90-s during a game, and high-intensity bouts approximately every 70-s. For English premier league players the mean recovery time between high-intensity running is 72 S in the first half and 77 S in the second half (Bradley et al., 2009). This suggests that there is limited time for recovery between each high-intense action, thus the aerobic capacity is important. Gabbett, Wiig, and Spencer (2013) reported that sprints and high intensity running is often repeated in blocks throughout a game. In their paper, a repeated sprint was defined as three or more sprints with less than 20 S recovery in between. They found that blocks with two sprints was much more common than blocks with repeated sprints. The mean number of blocks with repeated sprint in a game was five, and the mean number of blocks for high-speed running was thirty-one. Depending on positions, technical- and tactical aspects, number of sprints and blocks vary a lot from game to game, and between players (Di Salvo, Gregson, Atkinson, Tordoff, & Drust, 2009; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007). Gregson, Drust, Atkinson, and Salvo (2010) have reported a 15.1 ± 9.1% and 29.1 ± 16.1% match to match variation in high speed running distance and total sprint distance respectively. In rugby the importance of the ability to maintain and perform high speed/high intensity activity and blocks of repeated sprints is suggested to be critical to the outcome of the game (Gabbett, Jenkins, & Abernethy, 2012; Gabbett, Polley, Dwyer, Kearney, & Corvo, 2013). There is reason to believe that this also applies to football, as the demands of the game are fairly similar (Coutts et al., 2007). According to these data there is great demands of endurance in football and the ability to perform sprints at high speeds (>25 km/h). 96% of the sprints in a football match is shorter than 30-m and 49% is shorter than 10-m (Stolen et al., 2005). This indicates that acceleration could be more important than top-speed, although it should be taken into consideration that sprints rarely starts from a stationary position. Using Pro-Zone multi camera video analysis, Di Salvo et al. (2010) registered the number of sprints performed during European champions league and UEFA cup matches. They found that approximately 100 of 133 sprints (~75%) were commenced from a high-speed running activity. The remaining sprints 33 of 133 (~25%) was categorized as explosive sprints, and started from a standing, walking, jogging, or low speed running activity. This indicates that players are likely to reach top-speed several times during a match and thus top-speed is equally important as acceleration. Haugen et al. (2012) has reported 30-m sprint results that showed distinct differences between Norwegian national team, first- and second division Norwegian female football; 4,35s , 4,43s, and 4,58s respectively. They also reported a peak top-speed of ~28 km/h, which suggested that elite female football players are capable of reaching a relatively high top-speed.

In addition to sprints and repeated sprints, change of direction is also considered an important parameter in football. A study by Bloomfield, Polman, and O'Donoghue (2007) found that players performed and average of 727 ± 203 change of directions during a match. Acceleration, top-speed, jumping and change of direction are all dependent on strength (Chaouachi et al., 2012; Di Salvo et al., 2010; Gabbett et al., 2012; Haugen et al., 2012; Keiner, Sander, Wirth, & Schmidtbleicher, 2014; Ronnestad et al., 2008; Wisloff, Castagna, Helgerud, Jones, & Hoff, 2004). Change of direction movements are usually performed on one leg, and can involve large amounts of forces.

A recently published review (May 2014) on physiology of female football report similar results as the above mentioned studies on total distance covered (~10 km), number of activity changes during a game (~1350), amount of high-intensity running and sprinting (~15-20%) (Datson et al., 2014). Moreover, it conforms with the suggestion that top-level players perform more high-intensity running and sprinting than lower-level players, 28% and 24% respectively (Datson et al., 2014).

2.2 Speed, strength and performance

To achieve the goals of the game every individual must acknowledge their position in the team, their abilities, and skills. Together these terms form performance. An increase in performance is achieved through strengthening of physical-, technical-, and/or tactical abilities and through injury prevention.

2.2.1 Speed

Speed is defined as an athlete’s ability to accelerate their body with maximal effort, thus sprint (Enoksen, Tonnesen, & Tjelta, 2007). Speed consists of two main parameters, stride length and frequency (Tonnesen, Alnes, & Aasen, 2009). These two parameters are influenced by factors such as sprinting technique, rate of force development, anaerobic capacity, and maximal strength. Speed training is usually performed when athletes are fully rested and the intensity should be >95% of the maximal speed (Haugen et al., 2014; Tonnesen et al., 2009). However, it has been reported that sprint performance can be increased with intensities as low as 90% (Vittorri, 1996). The recovery periods between sprint efforts are considered to be of high importance in order for the athlete to be able to perform repeatedly at such high intensities (Abt, Siegler, Akubat, & Castagna, 2011). Several experiments has been conducted in order to clarify optimal recovery periods for sprint training in soccer, and sprint-to-rest ratio recommendations ranges from 1:6 – 1:10 for short sprints (=<15 m) to 1:20-1:30 for longer sprints (~30-40 m) (Abt et al., 2011; Balsom, Seger, Sjodin, & Ekblom, 1992; Haugen et al., 2014; Little & Williams, 2007). Tonnesen et al. (2009) has suggested even greater recovery periods, the same in minutes as the work length of the sprints in seconds (i.e. 4-s sprint = 4 minutes rest). Although it has been suggested that football players should perform some sprint training with lower rest intervals to make the training more specific and gameplay like (Tonnesen et al., 2009).

2.2.2 Strength

Football players need to have a well-developed endurance, strength and speed to be able to perform at their best at the elite-level (Helgerud et al., 2001; Hoff, 2005). The level of development of these abilities vary with the level of competition (Bradley et al., 2009; Stolen et al., 2005). A study conducted on top level Norwegian football players, who had recently participated in the champions league, reported correlations that was almost perfect and very large between 1 repetition maximum (1RM) squats, 10-m ($r=0.94$, $p<0.001$) and 30-m sprints ($r=0.71$, $p<0.01$), and CMJ ($r=0.78$, $p<0.02$), respectively (Wisloff et al., 2004). Helgerud et al. (2011) conducted a case study, without any control group, in which top level champions league players performed maximal strength training for 8-weeks and showed a substantial increase in 1RM squat (60 kg, ES=2.40), performance in 10-m (-0.06-s, ES=0.93) and 20-m (-0.06-s, ES=0.52) sprint, and CMJ (3.1 cm, ES=0.60). Haugen et al. (2012) also presented large correlations between CMJ and sprint from 0-20 m ($r=0.63$, $p<0.001$) and 20-40 m ($r=0.64$, $p<0.001$) on Norwegian female elite and sub-elite players. Helgerud et al. (2011, p. 680) described the importance of strength training in football succinctly; *”Football play is dominated by acceleration and braking, and Newton’s second law of motion (F=m*a) establishes that for a given* *mass (the player's bodyweight), acceleration is proportional to force magnitude"*. This suggests that strength requirements in football are very important and should be presented as relative to bodyweight and not as absolute values, as this will provide a better indication of the players ability to move their own body and perform change of direction, jumps, and sprints. To get an indication of the requirements we can look at the demands previously presented in chapter 2.1. It has been reported that players that run 10 m at approximately 1.79 S have a relative strength >2.0 (1RM/body weight) in half squats, and that these players are also among the highest scorers at CMJ, ~60 cm (Helgerud et al., 2011; Wisloff et al., 2004). Based on these results there is reason to believe that maximal strength is an important factor and that there is a strong correlation between maximal leg strength, jump and sprint performance.

2.2.3 Adaptations

The adaptations of strength training will vary depending on the resistance and frequency as well as the set-up of sets, repetitions and recovery length in between sets. Different approaches will result in different responses to muscle thickness (hypertrophy), pennation angle, fascicle length, capillary density, neural adaptations, tendon adjustments, and skeletal changes like bone mineral density (Arampatzis, Karamanidis, & Albracht, 2007; Blazevich, Cannavan, Horne, Coleman, & Aagaard, 2009; Campos et al., 2002; Kraemer et al., 2002; Tsuzuku, Shimokata, Ikegami, Yabe, & Wasnich, 2001). The choice of approach is dependent on the demands of the sport, and should be adapted to meet each individual's shortcomings and goals (Kraemer & Ratamess, 2004).

Novices in strength training can expect relatively large effects, up to 1% gain in strength per session, and after several years of strength training, the adaptations slow down. Powerlifters at a top-level can only change their maximal force by a few percent every year (Raastad, Paulsen, Refsnes, Rønnestad, & Wisnes, 2010). During an isometric contraction, force is proportional to the muscles cross sectional area. Neural adaptations also occur, but may be of greater importance in development of power rather than in maximal force development (Raastad et al., 2010).

According to a position stand from American College of Sports Medicine 1-12 repetitions in 3-6 sets with >70% of 1RM resistance will lead to increased hypertrophy. The training should be split in blocks throughout a period with e.g. 6-12 and 1-6 repetitions, and have a progressive approach to give the best result. Recovery in between sets should be 1-2 minutes (Kraemer et al., 2002).

For development of maximal strength, it is necessary to use fewer repetitions, 1-6 over 3-6 sets at >80% 1RM and with >3 min recovery in between (Kraemer et al., 2002). Hypertrophy and maximal strength training have several similarities due to the close relationship between muscle cross sectional area and strength.

Muscular endurance is usually developed by using a resistance between 40-60% of 1RM and >15 repetitions for 2-5 sets. Recovery in between sets should be 1-2 minutes (Kraemer & Ratamess, 2004).

Development of power is closely related to maximal strength, as force x velocity = power. However power is often expressed as explosive strength and associated with lighter loads and faster execution. This type of training is usually performed with loads of 0-60% of 1RM, 1-6 repetitions and 3-6 sets. Maximal effort and velocity is a necessity for power training and therefore longer recovery in between sets is utilized, often 2-3 minutes (Kraemer et al., 2002; Kraemer & Ratamess, 2004). A more in-depth description of power is presented in chapter 2.2.4.

In general, when developing strength programs there are a couple of other aspects to consider as well as the number of repetitions and sets. Power training should be performed before heavier strength exercises, due to the aforementioned necessity that maximal effort is required in power training. Large muscle groups and multi-joint exercises should come before small and/or single-joint exercises, as well as high-intensity before low-intensity, e.g. exercises with 80% 1RM load before exercises with 50% 1RM load (Kraemer & Ratamess, 2004).

Periodization is an important factor to consider if you want the best results. According to Kraemer and Ratamess (2004) there are three principles of progression; progressive overload, variation and specificity. Therefore, exercise programs should always alter either the load, repetitions, rest intervals, volume or any combination of these factors to maintain the stress, and force the muscles to adapt to meet the higher demands. A change in exercises could also be used as an alternative variation. The principle of specificity means that the training should involve similar muscle actions as the specific exercise, a similar force-velocity relationship, and maybe even the same range of motion (Kraemer & Ratamess, 2004). Based on this information a good approach to develop jump and sprint performance could be; block 1 – hypertrophy focus (due to the cross-sectional area being an important factor of maximal strength), block 2 – maximal strength focus (due to the importance of maximal strength in power), block 3 – explosive strength (to optimize the force-velocity relationship and neural adaptations), block 4 – specific jump and sprint exercises.

Several studies has investigated the effect of strength training on competitive athletes, meaning that much of the research also had to deal with the issue of concurrent training. It is well known, and has been reported by several, that concurrent endurance training can impair the adaptations to strength training (Dolezal & Potteiger, 1998; Gergley, 2009; Ronnestad, Hansen, & Raastad, 2012a), and thus this needs to be taken in to consideration when analyzing and interpreting the effect of strength training in concurrently training athletes. However, several studies has reported substantial improvements in strength although they performed concurrent football or endurance training (Dolezal & Potteiger, 1998; Faude, Roth, Di Giovine, Zahner, & Donath, 2013; Helgerud et al., 2011; Millet, Jaouen, Borrani, & Candau, 2002; Mjolsnes, Arnason, Osthagen, Raastad, & Bahr, 2004; Ronnestad et al., 2008; Sedano, Marin, Cuadrado, & Redondo, 2013; Storen, Helgerud, Stoa, & Hoff, 2008). Some even report an increase in endurance after the training period (Faude et al., 2013; Losnegard et al., 2011). Based on this there is reason to believe that it is fully possible to enhance strength performance despite concurrent endurance training.

2.2.4 Power

The relationship between force and velocity defines power, as force x velocity = power. Neural adaptations may play an important part in power/explosive exercises in addition to maximal strength (Cormie et al., 2010; Kraemer & Ratamess, 2004). Muscle activation is controlled by the nervous system through motor unit recruitment, frequency of action potentials and synchronization of action potentials (Cormie, McGuigan, & Newton, 2011). For sports in general, there is often required great forces at great velocities to produce maximum power over as little time as possible. This is true also for team sports like rugby, Australian rules football and football, which require great abilities of speed, acceleration, change of direction, and jumping. Power is measured in Watt and is greatest when both force and velocity is at approximately one third of the maximal (Cormie et al., 2011). The inverse relationship of force and velocity is illustrated in Figure 1.

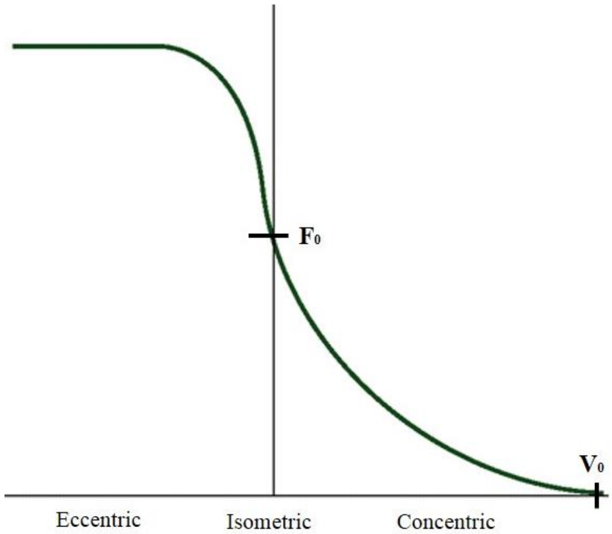


Figure 1: *A schematic presentation of the force-velocity curve (Hill's curve) where F = force, and V = velocity. Highest force is achieved through eccentric actions, highest velocities through concentric actions (Adopted from, Cormie et al., 2011)*

According to Kraemer and Ratamess (2004) it should be emphasized that the range of motion and force-velocity relationship is as similar as possible to the true exercise when performing them in training. Due to the strong relationship between maximal strength and power, it is assumed that athletes need to possess a high level of strength, in order to produce great power (Cormie et al., 2011; Manson, Brughelli, & Harris, 2014). A study conducted over 10-weeks of training investigated the effect of, and difference between, a maximal strength protocol and a ballistic (power) training protocol. They found that both groups increased their performance significantly in peak power output (10 W/kg) and sprint performance (-0.06 ± 0.07 S at 30-m for strength group, and -0.16 ± 0.10 S for power group), although only the maximal strength group increased their 1RM (30%) (Cormie et al., 2010). They also found that the effects of the training was similar for weak athletes regardless of training protocol. More recently, Faude et al. (2013) reported an increase in strength (25.2 kg 1RM in half-squat) and jump parameters (4.3 cm in CMJ) after combined strength and power training. This is in line with previous research by Cormie, McCaulley, and McBride (2007) who reported a significant increase in peak power for groups training only power and for the group training both power and strength. Although the power only group seemed to increase jump height and maximal power only at loads close to body weight, i.e. body weight + 20 kg and body mass + 40 kg, and the strength and power group increased at all loads. However, there was no difference between groups, indicating that both training regimes were effective in increasing power.

2.3 Muscle architecture

Muscle architecture is closely related with muscle strength and power as the muscles cross sectional area is proportional to its maximal force, and sarcomere length has a large influence on the velocity of muscle contraction and thus power (Cormie et al., 2011). Pennation angle can influence on both strength and power as an increase in pennation angle leads to an increase in the number of sarcomeres in parallel and thus facilitates for a higher force production. A greater pennation angle may also results in the muscle operating closer to its optimal length and thus produce greater force. However, increase in pennation angle is associated with slower contraction velocities, and thus may decrease power (Cormie et al., 2011).

Previously it has been reported a significant increase ($p<0.001$), measured by ultrasound, in muscle thickness (6.9%), fascicle length, and fascicle length/limb length (10.3% and 10.5% respectively) after 13-weeks of high-velocity resistance training (<60% of 1RM) (Alegre, Jimenez, Gonzalo-Orden, Martin-Acero, & Aguado, 2006). No change was found in pennation angle but a significant increase in maximal rate of force development (~23%, $p < 0.01$) was reported, indicating an increase in power. These findings are in line with the suggestions made by Cormie et al. (2011) that load up to 50% of 1RM could be used in development of power. However, the subjects in this study were not specifically trained before the start of the study and thus these changes in muscle thickness, strength, and power might be reduced if a similar training protocol was applied to athletes.

To my knowledge, only one study has investigated the effect on muscle architecture after power training and combined strength and power training. Blazevich, Gill, Bronks, and Newton (2003) conducted a study on competitive athletes, both men and women, where they measured changes in muscle architecture via ultrasound. They found a significant decrease (-3.1°, $p < 0.01$) in pennation angle at m. vastus lateralis distal after 5-weeks of power training, performed four times a week, containing 20- and 30-m sprints and CMJ jumps. Two other groups performed 2 sessions of the same power training in addition to two strength-training sessions consisting of either squats or front hack-squats. These two groups showed no significant change in pennation angle for m. vastus lateralis in either the proximal or distal part. Although a significant difference ($p < 0.05$) was found between the change in mean at m. vastus lateralis proximal between the power training group (-0.6^{o}) and the two combined power and strength groups (1.3^{o} front hack-squat, 1.5^{o} squat). The power group tended to decrease pennation angle and the strength/power groups tended to increase pennation angle. For all groups the muscle thickness increased significantly ($p < 0.05$) at m. vastus lateralis proximal (0.7 mm for power training group, 2.3 mm for front hack-squat, and 2.6 mm for squat) and m. rectus femoris (2.3 mm for power training group, 3.1 mm for front hack-squat, and 0.2 mm for squat). This indicates that an increase in muscle thickness is possible through only power training as well. For fascicle length the power group increased significantly ($p < 0.05$) at m. vastus lateralis distal (51.6 mm) and m. rectus femoris proximal (41.6 mm). The squat training group increase fascicle length at m. rectus femoris both distal (37.4 mm) and proximal (98.2 mm) (Blazevich et al., 2003).

Later it has been reported similar changes after both strength and power training. Cormie et al. (2010) found a significant ($p < 0.05$) increase in muscle thickness (~12%) and pennation angle (~9%) after 10-weeks of heavy (>75% 1RM) back squat training. The power-training group that performed jump squats at lighter loads (0-30% 1RM) also increased pennation angle significantly (~7%, $p < 0.05$).

Muscle architecture variables have also been shown to relate to sprinting, with fascicle length reported to have a medium to large correlation with sprint performance ($r= -0.43$ $p < 0.01$, and $r= -0.51$, $p < 0.01$ for males and females respectively) (Abe, Fukashiro, Harada, & Kawamoto, 2001; Kumagai et al., 2000). A cross sectional study that investigated the differences in fascicle length between elite sprinters and distance runners, as well as recreational controls, found that elite sprinters had significantly longer fascicle length in m. vastus lateralis, and m. gastrocnemius medials than both distance runners and controls ($p < 0.01$)(Abe, Kumagai, & Brechue, 2000). This is likely due to more sarcomeres in series, which facilitates for higher velocity contractions and thus increases power.

These findings for changes in muscle thickness, pennation angle, fascicle length are also in line with other studies that have investigated the effect of strength and/or power training on such parameters (Aagaard et al., 2001; Chilibeck, Calder, Sale, & Webber, 1998).

2.4 Nutrition

Nutrition is of great importance as it is very closely related to health, performance, training adaptations as well as recovery (Rodriguez, Di Marco, & Langley, 2009). Nutrition is often given the most attention pre and post matches, due to its importance for performance and recovery. However, the importance of nutrition in everyday training deserves considerable attention, especially during periods of high training loads. A good diet is recommended to enhance the adaptations of training (Garthe, Raastad, Refsnes, & Sundgot-Borgen, 2013), and before starting training it is recommended to have maximized glycogen storages in order to reduce fatigue and maximize performance (Rodriguez et al., 2009). The adaptations to strength training is strongly affected by the diet (Kreider et al., 1996; Rodriguez et al., 2009; Rozenek, Ward, Long, & Garhammer, 2002), as an increase in strength is closely related to hypertrophy and a certain amount of protein and energy seems to be necessary in order to maximize strength and hypertrophy gains (Rozenek et al., 2002). Several studies has investigated the amount of protein needed, and it seems that between 1.2 – 1.8 gram per kg body weight per day is enough to optimize muscle protein synthesis, although simultaneously intake of energy, ~44 – 50 kilocalories per kg body weight, seems to be equally important (Lemon, 1998; Stark, Lukaszuk, Prawitz, & Salacinski, 2012; Tipton & Wolfe, 2004). A good diet will also affect the immune system in a positive manner and take part in the prevention of sickness. In addition, it is suggested that a 2-3% drop in hydration can decrease performance (Rodriguez et al., 2009). Together this increases the risk of injuries and supports the opinion of nutrition being taken seriously in everyday training as well as pre-, during, and post- match (Rodriguez et al., 2009).

2.5 Injury prevention

"... the world's best training program or the world's best coach will have little influence if the athletes are continually injured." (Translated from, Raastad et al., 2010, p. 119). This quote describes the importance of preventing injuries for athletes. An injured player will have limitations in the execution of training, and thus injuries are a setback for development of individual performance factors (i.e. strength, speed, and technical abilities). In general muscle- and ligament injuries are among the most common injuries,

and the injury incidence is higher in matches than in training (Arnason et al., 2004; Hawkins, Hulse, Wilkinson, Hodson, & Gibson, 2001; Walden, Hagglund, & Ekstrand, 2005). Strength training is an important factor in the injury prevention process, and load monitoring may also contribute in order to reduce TL. It has previously be reported that the risk of strain injuries will be lower if the difference in strength between m. Hamstrings and m. Quadriceps is decreased (Arnason, Andersen, Holme, Engebretsen, & Bahr, 2008; Mjolsnes et al., 2004). The knee and ankle areas are exposed to injury as well, and strength training is an important contributor to prevent injuries in these areas (Mandelbaum et al., 2005; Myklebust et al., 2003). A newly published study by Nilstad, Andersen, Bahr, Holme, and Steffen (2014) found that only a greater body mass index (BMI) was related to lower extremity injuries. The study involved 173 female football players from the elite league in Norway, and they underwent a screening and a test battery, which consisted of assessment of isometric quadriceps and hamstring strength, hip abductor strength, 1RM leg press, star excursion balance test, drop jump, joint laxity and foot pronation. No intrinsic factors were associated with knee injuries but new injuries in the lower leg and/or foot were related to previous knee injuries (Nilstad et al., 2014).

Mapping, planning, execution and evaluation of training is important to find the balance that gives every individual the optimum foundation for development, recovery and injury prevention. Every individual has different foundations and shortcomings, and the requirements are different for each position. Based on this it is obvious that not all players will have the same experience of training, and valid and reliable methods for load monitoring and/or risk factor assessment could be of importance to reduce the risk of injuries both individually and for the team.

2.6 Load monitoring

For men a regular competitive season is 8–9 months, containing over 50 official games, even up to 70 including international qualification and tournaments. Thus, an average of one game every 5–6 days, with 2–6 days of recovery in-between. For women there are 30–40 official games spread over 6–7 months, this gives approximately the same average as for men, resulting in a high physical load with short periods of recovery. In Norwegian women’s football, most of the players are occupied with full-time jobs or studies, in addition to playing football. Therefore, high standards of preparation, monitoring and follow-up is required. It is desirable to combine recovery training, technical-tactical training and physical training to maintain and develop the player's capacity as well as being prepared for the next game. With little time for recovery, it is almost impossible to completely satisfy all parameters. Too large amount of training loads can lead to poor performance and injuries (Coutts et al., 2007; Gabbett & Jenkins, 2011), and too small amounts can reduce the physical capacity and thus lead to impaired performance (Rhea, Lavinge, Robbins, Esteve-Lanao, & Hultgren, 2009).

There are several ways of collecting information about physical load and performance. Well-known methods are monitoring of heart rate, distance, speed, resistance and lactate. However, there are several relatively new methods, such as: sRPE, PTW, NMF, CV, video analysis (e.g. ProZone), global positioning systems (e.g. Catpult minimax) and radio frequency based systems such as the Norwegian system called ZXY. These new methods are intended to provide a more accurate estimation of the total load on the muscular system caused by high intensity actions such as accelerations, decelerations, sprints, jumps, and change of direction efforts. The subjective methods like sRPE, PTW and CV are often used because of their ease of use and cost efficiency.

The sRPE method developed by Foster et al. (2001) involves a subjective rating on a category scale ranging from 0 – 10 where 0 = rest and 10 = maximal effort. The rate of intensity is then multiplied with the duration of the session and quantified as the internal load for the particular session. This kind of load monitoring has previously been reported as a reliable measurement for both strength, endurance and team sports (Alexiou & Coutts, 2008; Day, McGuigan, Brice, & Foster, 2004; Impellizzeri et al., 2004; Singh, Foster, Tod, & McGuigan, 2007). In comparison with heart rate based methods, there has been shown very large correlations with the sRPE method ($r = 0.71$) (Impellizzeri et al., 2004). As there is really no good, and yet reliable, automatized methods to quantify the internal load of short and very high intensity work like resistance training, sprints, jump, change of direction etc. sRPE is considered a valuable method (Alexiou & Coutts, 2008; Impellizzeri et al., 2004). It is also cost effective, and the gathering and analysis of data is quite simple. Which also makes sRPE an "easy to understand" method which does not require a high-level of expertise to gather and analyze, and it is not as time consuming as analyzing individual heart rate values (Alexiou & Coutts, 2008). In addition, heart rate transmitter belts and global positioning system units are usually not permitted during official games, which is a limitation for these methods, and favors a method like sRPE.

The fact of having one system for quantification of load is beneficial in the context of comparing different types of training stresses like resistance training, technical- tactical training, and gameplay. It makes it easier to calculate a joint load for a whole period i.e. one training week. Two other target values can be calculated as well, monotony and strain. Monotony is the product of the average daily TL within one week divided by the standard deviation for that week. Providing an indication of the variation in TL within one week. Strain is calculated by multiplying the monotony with weekly load (Foster et al., 2001). This could indicate if the training becomes too habitual which is unfortunate (Foster et al., 2001) and could possibly be detrimental (Gabbett & Jenkins, 2011).

The PTW method from McLean et al. (2010) consists of a questionnaire where players rate different physiological and psychological parameters to assess the wellness and freshness from day to day or week to week. The rating consists of questions about fatigue, soreness, sleep, stress and mood, and is rated on a scale from 1-5 where 1 = terrible, 3 = normal and 5 = excellent. In the study from McLean et al. (2010) they found a significant reduction of overall wellness one day after match for all three microcycles, 9, 7 and 5 days between matches respectively ($p = < 0.01$, ES = -1.64). Two days after match the overall wellness was reduced in the 9 and 7 days microcycles but not in the 5 days microcycle. This difference in time to recovery was evident despite that the exact same training was conducted the following day in all three microcycles. They suggest that the optimal recovery is connected to a series of variables such as adaptation to previous training, and the extent of damage from the match, and not only limited to training load in the days before the match. More recently, it has been shown large correlations ($r = 0.50 – 0.70$) between changes in high intensity running performance and changes in wellness score during an intense off-season training camp for Australian rules football players (Buchheit et al., 2013).

One other method used in load monitoring settings is a rating of the players performance conducted by one or more coaches (Mooney et al., 2013). The method involves each coach rating each players performance on a 1-5 scale where 1 = poor and 5 = excellent. The study from Mooney et al. (2013) involved 17 professional Australian Rules football players from the elite level. Each player was assessed with testing pre and post to 1-4 matches and their performance was rated in the same matches. A >8% reduction in objective performance parameter assessed through a CMJ also resulted in a lower load per minute score given by an accelerometer (located inside the global positioning system unit) and a lower CV perceived by the coaches. This load per minute score is derived from the sum of all triaxial changes of inertia like jump and accelerations measured by the accelerometer (Boyd, Ball, & Aughey, 2011; Mooney et al., 2013). The accelerometer samples at 100 Hz and thus it is capable of detecting subtle movements (Mooney et al., 2013). A couple of other studies has also used similar ratings conducted by coaches (Franks & Miller, 1986; Heasman, Dawson, Berry, & Stewart, 2008). Heasman et al. (2008) found what they categorized as relatively high correlations between rating of player's performance from one coach and the city's major newspaper rating, as well as with a derived impact rating based on the number of a specific different positive and/or negative involvements during an Australian rules football match. However in the study by Franks and Miller (1986) they concluded that votes conducted by coaches was considered unreliable and suggested that coaches might be biased by certain players.

According to Bigland-Ritchie and Woods (1984) in McLellan, Lovell, and Gass (2011, p. 1030) NMF has been defined as *"... any exercise induced reduction in the maximal voluntary force or power produced by a muscle or a muscle group...*". Cormack, Newton, and McGuigan (2008a) introduced a method for monitoring of NMF by CMJ on a force platform. The method involves detecting two main variables of the jump, flight time (FT) and contraction time (CT). FT equals the time the subject is in the air in seconds, and CT equals the time from countermovement is initiated to toe-off. FT is then divided by CT, giving the researchers a ratio that can provide information on each player's recovery. Cormack et al. (2008a) found a substantial reduction in the ratio between FT and CT 48 hours pre vs. post-match (-7.5%; ES = 0.32), furthermore the reduced ratio was maintained 24 hours after the match (-7.8%; ES = 0.33). The reduction immediately post-match was even larger when compared to pre-match, (-16.7% reduction; ES = 0.65) and the reduction was also evident 24 hours after match (-17.1%; ES = 0.67). Seventy-two hours post-match the FT:CT ratio had only a trivial change compared to 48 hours pre, and pre-match (5.0%; ES = 0.20, and -3.7%; ES = 0.14 respectively). For measures 96 and 120 hours post-match the changes were also considered trivial when compared to pre-match. Cormack et al. (2008b) also conducted a study where they assessed changes in the FT:CT ratio during a whole season of Australian rules football. The FT:CT ratio showed a substantial reduction at 60% of all time-points and most of the measurements were performed 72-96 hours post-match indicating an incomplete recovery. They suggest reducing training load to enhance recovery and thus performance (Cormack et al., 2008b).

Other studies have used similar protocols and found a reduction in FT and CT variables, which also directly affected CV (Mooney et al., 2013). McLellan et al. (2011) found that rugby players were recovered 48 hours post-match for variables such as peak force development and peak power assessed through a CMJ. These findings are also in accordance with the findings of McLean et al. (2010) who found that CMJ from the FT variable was significantly reduced 24 hours post-match, and that players on average had their highest values 4 days after the match. These results were also in compliance with changes in the psychological measurements conducted via the wellness questionnaire.

Based on the aforementioned data, it is suggested that different variables assessed through CMJ can predict NMF and thus incomplete recovery, and possibly also a higher risk of injury (Cormack et al., 2008a; Cormack et al., 2008b; McLean et al., 2010; McLellan et al., 2011; Mooney et al., 2013). These variables, in general, also correlate well with the amount of training load and performance perceived by coaches (Alexiou & Coutts, 2008; Foster et al., 2001; Impellizzeri et al., 2004; Mooney et al., 2013).

2.7 Summary

In general the demands in football are complex, but the ability to perform sprints at great speed (>25 km/h) as well as change of directions and jumps are considered to be of high importance (Bradley et al., 2009; Datson et al., 2014; Stolen et al., 2005). In order to accelerate, decelerate, jump and perform change of directions, it is required to be able to produce high force, at high velocities over short time periods (Cormie et al., 2011; Manson et al., 2014). For athletes to tolerate these stresses, strength and power training is necessary. As strength and power are so closely related, a combination of exercises might be the most effective in order to develop specific actions that demand both strength and high velocity (Kraemer et al., 2002). Few repetitions at high intensity (>85% 1RM) over 3-6 sets is considered to be the best way to influence maximal strength, although in untrained athletes almost every strength training approach will affect maximal strength (Kraemer et al., 2002; Raastad et al., 2010). For power training a combination of exercises that involves the same range of motion and force-velocity relationship as the original exercise (e.g. a sprint, jump etc.) with lighter loads (0-30% 1RM) appear to be the best for development (Kraemer & Ratamess, 2004). Although intensities ranging from 0-50% 1RM are also reported to increase the power output (Cormie et al., 2011). Concurrent strength and endurance training might reduce the effect of the strength training, however several studies has reported substantial strength gains, end even gains in endurance parameters, while performing concurrent training (Faude et al., 2013; Helgerud et al., 2011; Losnegard et al., 2011; Ronnestad et al., 2008)

Changes in muscle thickness and pennation angle might provide a good indication of athletes change in performance due to their influence on the muscle cross sectional area which is proportional to the muscles maximal force, and thus also inflict power (Cormie et al., 2011). Fascicle length of muscles can also provide a good indication of power because longer fascicle length is associated with more sarcomeres in series and thus higher contraction velocities (Kumagai et al., 2000). Muscle thickness, pennation angle, and fascicle length are likely to change based on the type of specific training performed.

Monitoring of TL is considered important in order to prevent injury, and optimize performance (Coutts et al., 2007; Foster et al., 2001). Although there is no definitive limits for what is too little or too much. Several methods such as sRPE, PTW, and CV correlate well with the assessment of performance. However, it is recommended to interpret the results on an individual basis in order to assess changes in TL and/or risk of injury (Alexiou & Coutts, 2008; Buchheit et al., 2013; Impellizzeri et al., 2004; McLean et al., 2010; Mooney et al., 2013). According to Cormack et al. (2008b) a ratio of FT:CT might be the most sensitive and valuable parameter to reveal NMF and thus indicate a decrease in performance.

3. Methods

The study was conducted as two parallel projects. The main aim of the study, project I, investigated the effects of, and the difference between, two-strength training protocols performed two times a week for 10 weeks. Project II consisted of load monitoring during a 10-week pre-season training period.

3.1 Design

A typical week schedule within the training intervention (project I) and the setup for the load monitoring (project II) is illustrated in Figure 2. The players performed the second strength session of the week on either Saturday or Sunday depending on if there was a match or not.

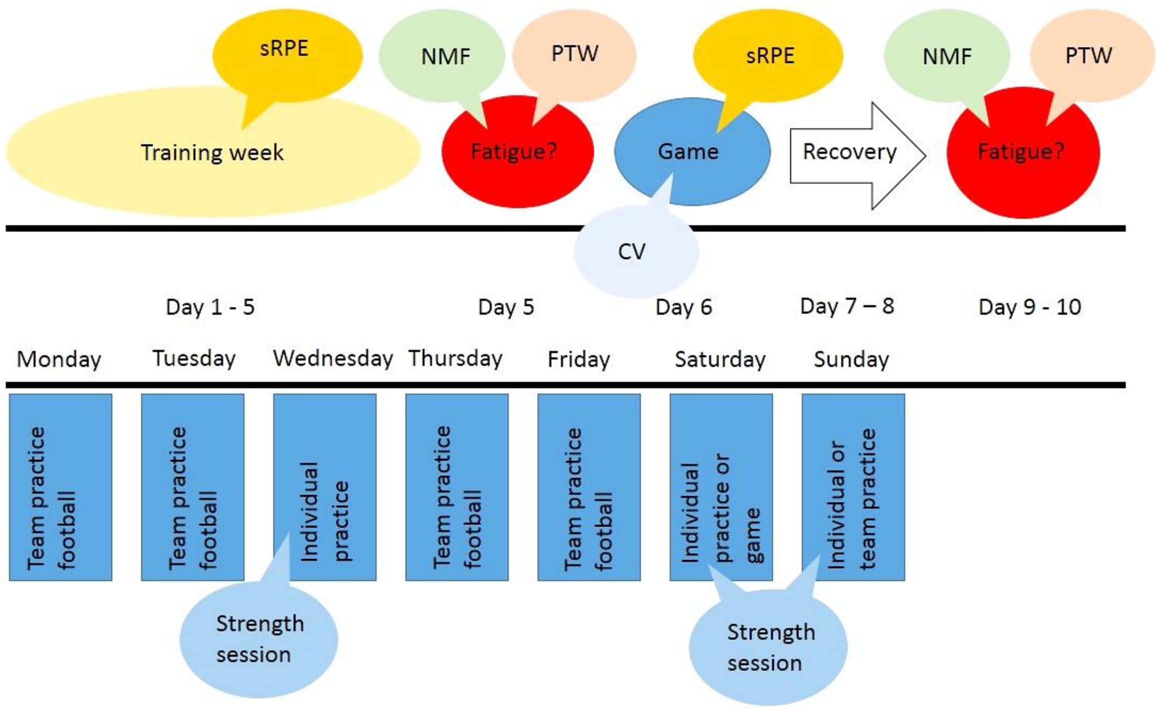


Figure 2*: Load monitoring and test of fatigue during a 10-day period, starting on Monday (day 1) with a game on Saturday (day 6). Key time-point for measurements of NMF is the day before match (day 5) and 48 – 72 hours after match (day 9 – 10), i.e. the following training week. Weekly schedule for the team with time-points for strength sessions marked. sRPE = session rate of perceived exertion, NMF = neuromuscular fatigue jump test, PTW = pre training wellness questionnaire, CV = coaches votes.*

3.2 Study schedule

The study started in the early pre-season period and was terminated 8-weeks before the first official match of the season. Both projects were conducted in the same time-period. Figure 3 shows an overview of the time-period.

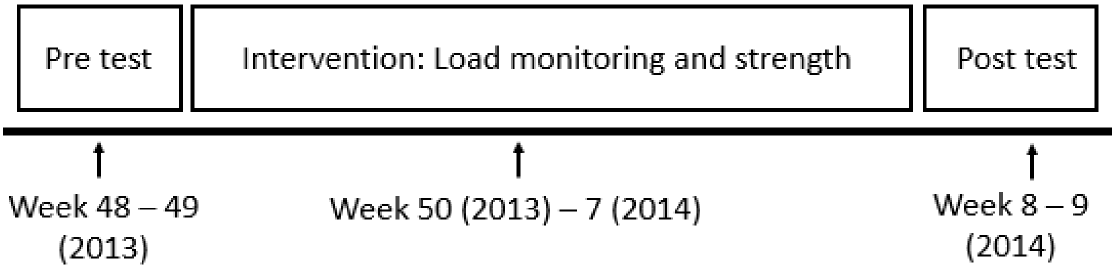


***Figure 3**: Overview of the study schedule.*

3.3 Subjects

A team from the Norwegian elite female football league participated as subjects in the study. It was a prerequisite that the players were free of injury at the time of the commencement of the project. Fifteen subjects were recruited to project I, and nineteen subjects to project II. The players took part in normal team practice and completed the strength sessions on the given days (Figure 2). To be included in the analysis of project I, the players had to complete at least 70% of the strength sessions (i.e. 14/20). Due to injuries (two players), club transfer (one player), and too few completed sessions (one player), four players was excluded from project I. A total of eleven subjects were included in the analysis of project I (Table 1). To be included in the analysis of project II, the players had to complete at least 70% of any combination of either the subjective ratings (sRPE and PTW) or the NMF jump test. The same four players that were excluded from project I was excluded from the analysis in project II. In addition, five other players were excluded due to too few completed NMF jump tests and subjective ratings. A total of ten subjects were included in the analysis for project II (Table 2).

Table 1*: Overview of subjects in project I, PLY n=6, MAX n=5.*

	Groups	Mean ± SD	Range	ES between groups	Qualitative inference
30-m (s)	PLY MAX	4.67 ± 0.18 4.76 ± 0.19	0.48 0.50	0.43	Small
Squat (kg)	PLY MAX	105 ± 11.1 89.4 ± 14.5	32.5 35	1.39	Large
Weight (kg)	PLY MAX	65.2 ± 3.6 66.2 ± 4.5	8.9 11.1	0.21	Small
Height (cm)	PLY MAX	171.3 ± 2.2 173.6 ± 6.3	6 16	0.85	Moderate
Age (year)	PLY MAX	20.5 ± 5.2 20.0 ± 3.0	13 8	0.05	Trivial
Years in elite-league	PLY MAX	3.8 ± 4.6 2.0 ± 3.4	12 8	0.17	Trivial

PLY = plyometric group, MAX = maximum strength group,

***Table 2**: Overview of subjects in project II, n=10.*

	Mean ± SD	**Range**
Weight (kg)	66.0 ± 3.9	13
Height (cm)	172.2 ± 4.6	16
Age (year)	20.5 ± 4.3	14
Years in elite-league	4.0 ± 4.2	13

3.4 Test battery

A comprehensive test battery was performed to measure physical capacity pre- and post-the strength training intervention (project I). In addition, a NMF jump was performed twice a week throughout the intervention (project II). The following tests were performed; Yo-Yo IR1, sprint (10-m and 30-m), CMJ on a force platform, repeated sprint 6 x 30-m on a 30 s cycle, ultrasonography of m. vastus lateralis, 1RM squats, bench press and pull down. All tests, with exception of the Yo-Yo IR1, were conducted within a two-week period ahead of the intervention. The Yo-Yo IR1 was performed in the first week of the intervention due to weather disruptions the previous week. The CMJ and sprint tests were conducted on two occasions to ensure the accuracy of the measurements, by calculating the typical error of these tests for this specific group of athletes. There was a minimum of 24 hours and a maximum of 5 days between the repeat tests for the CMJ and sprint assessments. Repeated sprint was performed as the last test on the second test day after completing the CMJ and sprint assessment. Subjects were instructed not to exercise the day before testing. The test schedule ensured that there was no testing, nor training, the day before ultrasonography and strength tests. However, one subject had to perform strength testing the day before the Yo-Yo IR1, during pre-tests, due to practical complications.

Table 3: *Overview of the typical error measurements for the different test. 10-m, 30-m and CMJ n=14, MT, PA and FL n=10.*

	Raw data			%		
Test	**Typical error**	**Lower 90% CL**	**Upper 90% CL**	**Typical error**	**Lower 90% CL**	**Upper 90% CL**
30-m (s)	0.06	0.04	0.08	1.2	0.9	1.7
10-m (s)	0.04	0.03	0.05	1.7	1.3	2.6
CMJ (cm)	0.87	0.66	1.29	2.8	2.2	4.2
MT (cm)	0.02	0.02	0.04	1.0	0.8	1.7
PA (^{0})	0.39	0.28	0.64	2.5	1.8	4.2
FL (cm)	0.15	0.11	0.24	2.0	1.5	3.3

MT = muscle thickness, PA = pennation angle, FL = fascicle length

3.4.1 Strength

Testing of squats was conducted as the first exercise, then bench press, and finally pull down. Warm-up was split in two parts, consisting of a general and a specific part. The general warm-up consisted of 10 min on a cycle ergometer (Bike 500, Technogym Selection, Cesena, Italy) of approximately 100 W. The specific warm-up consisted of several series before each exercise with increasing load based on an estimated 1RM. 10 repetitions with 50%, 6 repetitions at 60%, 3 repetitions at 80% and one submaximal repetition at 90 – 95%. Then single trials were performed with approximately 3 min recovery in between until 1RM was obtained. It was endeavored to adapt the load for all subjects to avoid more than three trials at 1RM.

Squats: 90^0 at the knee joint was measured using an analogue goniometer (Medi-nor AS, Oslo, Norway). Subjects were instructed to stand with approximately shoulder width distance between the legs and the feet angled slightly outwards, and leg position was marked with a measuring tape. An elastic band was set up for the subjects to hit at exactly 90^0 angle of the knee joint. There were two test supervisors in place at all time to ensure safety and to approve/disprove each attempt.

Bench press: For a lift to be approved gluteus and scapula had to be in contact with the bench during the whole lift. Lowering and push off had to be a controlled movement without bouncing the bar off the chest. A supervisor was in place at all times to ensure safety and to approve/disprove each attempt.

Pull down: A “lat machine” (Technogym Selection, Cesena, Italy) was used as the test apparatus. The height of the seat and thigh support were set for a natural seating position and a wide overhand grip was used. Subjects had to maintain an upright position defined, as 100 - 110^{o} hip extension (upright position defined as 180^{o} extension), during the whole lift and was not allowed to raise the body. To ensure that subjects started the lift from a «dead position» a supervisor assisted in lowering the bar so the subjects could reach it from a seating position. A lift was approved when the bar was lowered below the level of the chin.

3.4.2 Jump

CMJ was measured on a force platform (FP4 Hurlabs, Tampere, Finland), connected to a computer software (Hurlabs, Force platform software suite v. 2.63) that recorded vertical ground reaction forces. The warm-up protocol consisted of 2 min of jogging including high knees, heel flicks, and lateral movements as well as three submaximal practice CMJs. Before each subject stepped on the platform, zero measurements were conducted. Subjects performed three approved CMJs with hands placed on the hips and approximately 30 S of passive rest was required in between the trials. The subjects were instructed to jump as high as possible and the depth was self-selected. A jump was approved as long as the subjects kept their hands on the hip and went directly into a negative phase at the start of the jump (Figure 4). Results were saved to a customized Microsoft® Excel sheet. The two best results each day was summed and averaged and the best result of these two was listed as baseline.

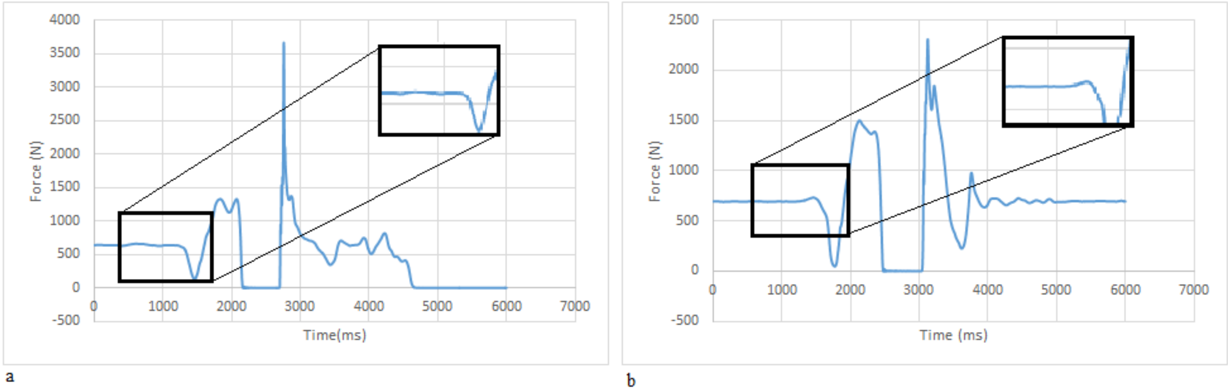


***Figure 4**: Example of an approved and disapproved CMJ.* ***a**: correct execution.* ***b**: jump disapproved due to the upward movement before the negative phase.*

3.4.3 Sprint (10- & 30-m)

After the CMJ and before the sprint test a more comprehensive warm up was performed. This consisted of 5 min of jogging, the FIFA 11+ part 1 (appendix IV), and two gradient runs up to approximately 70% and 90% of maximal speed. The test was performed on a flat, indoor surface (PULASTIC SP Combi, Gulv og Takteknikk AS, Norway) using the Brower Speed Trap II TC wireless timing gates system (Draper, Utah, USA). Each subject performed three trials, with 3 min rest between trials. Subjects started from a stationary position, 30 cm behind the first gate. Timing gates were placed approximately 1.0 m above the ground. Results were saved to a customized Microsoft® Excel sheet for analysis. The two best results each day was summed and averaged and the best result of these two was listed as baseline.

3.4.4 Repeated sprint

Repeated-sprint ability was undertaken 5 - 10 min after the 30-m sprint test. This was performed on the same surface and with the same set up as the 30-m sprint test. The test consisted of 6 x 30-m maximal sprints on a 30-s cycle. Each sprint started from a stationary position, 30 cm behind the first gate. Subjects was instructed to run past two cones placed 1-m behind the last timing gate before decelerating, then turning around and jogging back to the start on the outside of two cones placed 5 m to the side of the track. Subjects received verbal feedback to ensure they returned to the start within the allocated time. Sprinting time of each effort was saved for analysis of total time and sprint decrement. These variables were listed as baseline.

3.4.5 Endurance

Endurance was measured with the Yo-Yo IR1. The test consisted of 2 x 20-m shuttle runs, out and back, with 10 S active recovery in between (Figure 5). The velocity increased progressively throughout the test. Players was not allowed to leave the outside line before the beep and had to reach back to the finish line within the next beep. First time a subject failed to reach the finish line in time they received a verbal warning and the second time the test was ended. Two testers were stationed on both lines and supervised the rules and decided when players did not reach the finish line in time. The total distance, including the last incomplete shuttle, was listed as the final test result. The test was performed outside on an artificial turf grass and the players wore football boots. The audio was broadcasted from an mp3 player through a set of speakers (Logitech speaker system Z320, Apples, Switzerland).

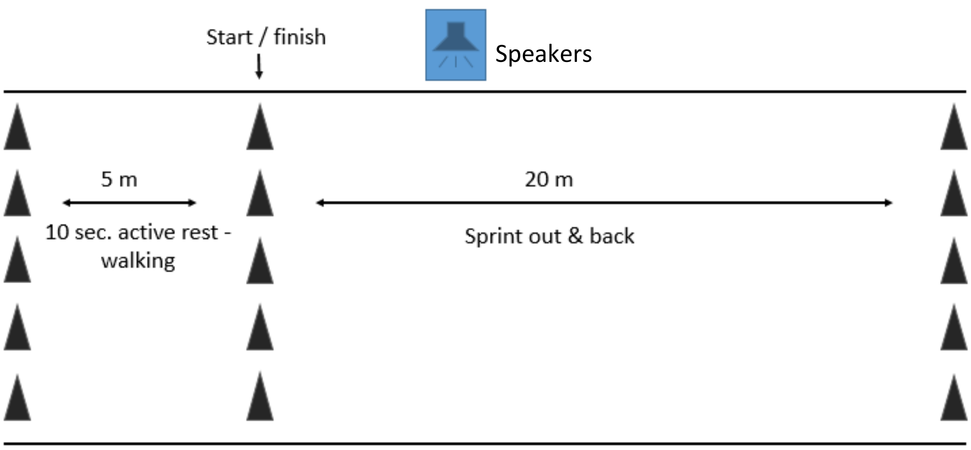


Figure 5*: A schematic overview of the course set-up for the Yo-yo IR 1 test.*

3.4.6 Ultrasonography

Muscle thickness and pennation angle of the m. vastus lateralis in the right leg of all participants were measured with ultrasonography (50 mm, 5–12MHz HD11XE, Phillips, Bothell, Washington, USA). The subjects laid down on an examination bench and were instructed to be fully relaxed during the measurements. Measuring point was determined by measuring the distance from the trochanter major to the fulcrum of the knee and the mark was set at 60% of this distance. For the muscle thickness measurements, m. rectus femoris was identified before sliding the probe laterally to the m. vastus lateralis. Three clear pictures were taken by repeating this procedure three times. For the pennation angle measurements, the same procedure was made with rotating the probe to be 90^{o} at the fascicle orientation. Three clear pictures were taken of the pennation angle. Results were saved on the machine, and exported to a USB-stick for analysis on an alternative computer. For the analysis, all pictures were analyzed using "ImageJ" (V.1.45s, National Institute of Health, Austin, Texas, USA). All three pictures were analyzed three times and the mean of the measurements for both thickness and pennation angle, was used as baseline. The results were plotted on a prepared Microsoft® Excel sheet for calculation of fascicle length, using the following equation;

$$Fascicle\ length = Muscle\ thickness/SIN(3.14\ x\ pennation\ angle/180)$$

3.5 Strength training

After testing and before the intervention started, the players were divided into two groups, plyometrics (PLY) and maximum strength (MAX). Matching was based on the 30-m sprint test with the aim of minimizing the difference in mean between groups. For the group matching process, an excel spreadsheet developed by (Hopkins, 2010) was used. The MAX group performed two maximum strength sessions per week and the PLY group performed one identical maximum strength session and one plyometric session. The maximum strength sessions consisted of a varied selection of exercises for both legs and upper body, with three to four sets with three to six repetitions (Appendix I). Resistance was always RM. For the plyometric session, a varied selection of explosive exercises with and without external resistance, 0 – 35% of 1RM, with three to four sets and three to six repetitions (Appendix II). Players kept exercise logs for every workout. All players were familiar with the exercises at the start of the project. Nevertheless, a familiarization session was given to ensure proper technique and correct resistance. Most of the sessions throughout the intervention period was monitored, however, due to time-management conflicts some subjects had to occasionally perform non-supervised sessions. Every strength session was performed at least 48 hours apart and no less than 24 hours before or after a match.

3.6 Load monitoring

All training was monitored via several methods for monitoring of the total load of the players. This consisted of a subjective rating on the intensity of every training session sRPE (Foster et al., 2001), a questionnaire for the physical and mental health PTW (Adopted from, McLean et al., 2010), and a jump-test on a force platform to assess NMF (Cormack et al., 2008a). In addition the coaches rated each player's performance in matches on a category rating scale, CV (Adopted from, Mooney et al., 2013). Each method is described in detail below.

3.6.1 Session rate of perceived exertion

Players rated the intensity of every training session during the 10-week intervention period on a scale from 0 – 10 where 0 = rest and 10 = maximal effort. They were instructed to conduct the rating within 30 min after each session. Players were also notified by SMS to complete the rating within the required time. In addition to the rate of intensity they also noted duration, type of exercise and where it was performed, e.g. Football field, gym etc. An example of the sRPE logbook is shown in appendix III. For the analysis, the rate of intensity was multiplied with the duration to form the daily TL. The daily TL were summed to form the weekly load. Calculations for monotony and strain were also documented.

$$Monotony = \frac{Average\ daily\ TL\ within\ one\ week}{Standarddeviation\ within\ that\ week}$$

$$Strain = \ Weekly\ traning\ load * Monotony$$

If, for any reason, a subject forgot to write down the duration of the session, the standard durations were used based on the type of session. Strength sessions had a planned duration of 65 min, and the football sessions of 90 min. The players were familiarized with the sRPE by conducting ratings in at least 3-weeks before the commencement of the study.

3.6.2 Pre training wellness

The PTW questionnaire was conducted via an internet page developed only for the club (illustrated in appendix V). Players had their own anonymized user ID and a self-selected password at the page. Only administrators, i.e. the researcher and supervisor, were able to see and obtain the data provided by the players. The data collection took place in the middle of the day, before practice. Players were notified by SMS to remember to conduct the assessment. It was reported two times per week, the same day as the main training session, and the day before the match or the same day as the second main training session. The questionnaire consisted of five categories rated from 1 – 7, fatigue, sleep quality, muscle soreness, stress, and mood. Due to restrictions from "The Norwegian Data Protection Authority", the sickness category from McLean et al. (2010) was exchanged with the mood category. The score from each category was summed and formed a daily wellness score. PTW ratings was commenced 2-weeks before the start of the study to familiarize the subjects with the scale and the routine.

3.6.3 Neuromuscular fatigue jump-test

The NMF jump-test was performed as a CMJ on a force platform (FP4 Hurlabs, Tampere, Finland), connected to a computer software (Hurlabs, Force platform software suite v. 2.63) that recorded vertical ground reaction forces. It was performed two times per week, the same days as the players conducted the PTW questionnaire. Testing was performed within 30 min before the start of each training session. The warm-up protocol was the same as for the jump test, two min of jogging including high knees, heel flicks, and lateral movements as well as three submaximal practice CMJs. Due to practical considerations players performed only one approved jump, the criteria for an approved jump are described in chapter 3.4.2 Jump. For the analysis, two sequences were identified, FT and CT. A ratio between these two sequences was calculated by dividing FT by CT (Cormack et al., 2008a). This ratio was compared to the ratio from the baseline (pre) tests. Players were considered to be in a fatigued state (i.e. not recovered) when a ratio fell below 92% of the baseline ratio. For the analysis and calculations, the MatLab software R2013a v. 8.1.0.604 (Mathworks, Natick, MA, USA) was used. Subjects that were unable to produce maximum effort due to acute injuries did not perform the test. This resulted in a varied number of data across the study period, 13 ± 3.5 (mean ± standard deviation; SD) tests per. subject (75% completion rate). Subjects were familiarized to the test through several familiarization sessions before the commencement of the study.

3.6.4 Coaches votes

As a second measurement of performance, two coaches individually rated each player's performance in matches. Performance was rated between 0 and 10 where zero = horrible and ten = exceptional (Mooney et al., 2013). In addition to the performance rating, the coaches also listed the playing time in minutes. The performance rating was conducted between 30 and 60 min after the game. The rating was the coaches subjective opinion of players performance, based on their role and instructions given by the coaches.

3.7 Validity and reliability

Validity and reliability of the measurements are considered to be of great importance for the results to be considered as correct and relevant. Validity concerns whether a test measures what it is supposed to measure, and reliability concerns the accuracy of the test results (Thomas, Nelson, & Silverman, 2011). To assure the reliability, it is common to do repeated measurements and calculate the typical error of the measurements. A test cannot be valid if it is not reliable (Thomas et al., 2011).

To assure the reliability in this study the typical error was calculated for the field tests 10- and 30-m sprint and CMJ, as well as for the ultrasound measurements (Table 3). Two pre-tests was performed to form the basis for the typical error calculations, and for the ultrasound repeated measurements were taken of moderately-trained subjects that were not involved in the study (n=10). The results of the test were listed in a prepared Microsoft® Excel sheet (Hopkins, 2000) for calculations of typical error.

Typical error needs to be taken into consideration in order for the magnitude of change in performance to be considered practically relevant, when analysing the data for one subject (i.e. the change in performance needs to be bigger than the typical error). Previously a typical error of 0.03-0.04 has been reported for 10- and 30-m sprint measured by timing gates (Duthie, Pyne, Ross, Livingstone, & Hooper, 2006; Woolford, Polglaze, Rowsell, & Spencer, 2013). However, in this study the typical error was slightly higher, possibly due to the fact that the timing gates were single-beam gates (Table 3). According to Duthie and colleagues (Duthie et al., 2006) the smallest worthwhile change of sprints over 10-m is <0.01s change in performance, which is considerably lower than the typical error. The 10- and 30-m sprint test are also in line with the recommendations for sprint testing (Duthie et al., 2006)

For ultrasound measurements both the reliability and validity is reported to be good (Kwah, Pinto, Diong, & Herbert, 2013). In a review including 36 reliability studies and 6 validity studies, it was stated that measurements of both pennation angle and fascicle length is considered to be reliable and valid, also for practitioners with less experience and/or formal training (Kwah et al., 2013)

In a review assessing the reliability and validity of strength and power testing both squat (coefficient of variation = <4.3%) and bench-press (coefficient of variation = <4.3%) tests with free weights were considered reliable (McMaster, Gill, Cronin, & McGuigan, 2014). Both tests are also generally accepted to be valid measurements of leg and trunk strength.

CMJ-tests performed on a force platform have been shown to be very reliable. Cormack, Newton, McGuigan, and Doyle (2008c) have reported the typical error of jump height to be as low as 0.023-0.024 with a coefficient of variation = 5.2%. For measurements of FT and FT:CT ratio the typical error is reported to be 0.017 and 0.056 respectively (Cormack et al., 2008c). Based on this also the NMF test is considered reliable and valid, which is also supported by several other studies (Cormack et al., 2008a; Cormack et al., 2008b; McLean et al., 2010; McLellan et al., 2011; Mooney et al., 2013)

In accordance to Gabbett (2010) the reproducibility (i.e. reliability) of repeated sprint tests are good in conjunction with analysis of total time (typical error = 1.5%). This is also supported by others, Spencer, Fitzsimons, Dawson, Bishop, and Goodman (2006) found a typical error of 0.7%. The test also proved to discriminate between high-level national players and state players on the total time parameter, and thus it is considered valid (Gabbett, 2010). For analysis of sprint decrement the test seemed to be much less reliable and valid, typical error = 19.5% (Gabbett, 2010) and 14.9% (Spencer et al., 2006).

The Yo-yo IR1 test is commonly used as a measurement of endurance in football. Krustrup et al. (2003) assessed the test-retest reproducibility in which the subjects performed two Yo-yo IR1 tests within 1-week, and found an almost perfect correlation of 0.98 ($p < 0.05$). In addition, a very large and significant correlation was evident between Yo-yo IR1 performance and VO2 max ($p < 0.05$ $r = 0.71$)(Krustrup et al., 2003). This is also supported by other studies (Bangsbo, Iaia, & Krustrup, 2008; Thomas, Dawson, & Goodman, 2006). Performance in Yo-yo IR1 has also been reported to have a very large correlation to the amount of high-intensity running in-game (Bangsbo et al., 2008; Krustrup et al., 2005; Mohr et al., 2003). This study follows the procedures suggested by (Krustrup et al., 2003).

In context with the purpose of this study, the validity of the tests is considered to be good. When the results are greater than both the smallest worthwhile change and the typical error it is considered a true change.

Use of the sRPE method to quantify internal TL is believed to be a valid method, and thus reliable (Foster et al., 2001; Impellizzeri et al., 2004). A couple of studies have investigated the reliability and validity of sRPE. It has been suggested a valid tool of quantifying internal load based on its very large correlation with heart rate based methods ($r=0.71$ $p<0.001$ (Impellizzeri et al., 2004))($r=0.83$ $p<0.05$ (Scott et al., 2013)), and in relation to distance travelled, high speed running and player load ($r=0.81$, 0.71, 0.83 respectively)(Scott et al., 2013). However, it has shown less reliability when comparing short bouts of intermittent running (coefficient of variation = 31.9% (Scott et al., 2013))(coefficient of variation = 28.1% (Wallace, Slattery, Impellizzeri, & Coutts, 2014)), indicating it is less reliable to detect small changes, although still suggested a valid method of quantifying internal load in team sports like football.

To my knowledge no studies have investigated the reliability and validity of PTW and CV. However, both methods are considered reliable and valid based on their significant relationships with changes in TL, intensity and performance (Heasman et al., 2008; McLean et al., 2010; Mooney et al., 2013).

3.8 Statistics

Calculations were made in prepared Microsoft® Excel 2013 sheets, developed by Hopkins (Hopkins, 2006; 2007). To reduce bias from potentially skewed data, log transformation was conducted before analysis. Descriptive statistics were presented as mean ± SD. Differences between pre- to post- measurements were presented as means ± 90% confidence limits (CL) and the ES was calculated using the aforementioned spreadsheets.

The magnitude of the difference is described using the Cohens d ES, <0,2 trivial; 0,2-0,6 small; 0,6-1,2 moderate; 1,2-2,0 large; >2,0 very large. The likelihood of the difference being beneficial, trivial or harmful was calculated. The effect was considered beneficial to athletic performance if the ES was greater than the smallest worthwhile change calculated as 0.2 x between-subject SD. The likelihood of the difference being beneficial, trivial or harmful were calculated and qualitatively assessed as follows =>25%, possible; =>75%, likely; =>95%, very likely; =>99.5%, most likely. In cases where the likelihood of having beneficial or harmful effects both > 5% (i.e. the CL of the ES spans both substantial positive and negative values) the effect was considered unclear (Hopkins, Marshall, Batterham, & Hanin, 2009).

Sprint decrement is calculated with a reliable and valid method suggested by Glaister, Howatson, Pattison, and McInnes (2008).

$$Total\ sprint\ time = Sum\ of\ all\ sprints$$

$$Ideal\ sprint\ time = Best\ sprint\ x\ no.of\ sprints$$

$$Sprint\ decrement = \ (100\ x\ (Total\ sprint\ time/Ideal\ sprint\ time)) - 100$$

For the load monitoring data, correlation analysis were made in Microsoft® Excel 2013, with the “Correl” function presenting Pearson R for the correlation between variables. The criteria for the magnitude of correlations was <0.1 trivial; 0.1-0.3 small; 0.3-0.5 medium; 0.5-0.7 large; 0.7-0.9 very large; >0.9 almost perfect (Hopkins et al., 2009).

3.9 Ethics

The project involved intense physical testing which may have been unpleasant for some subjects. There was also a risk of injury related to the exercises and game play. Qualified personnel, including coaches, physiotherapists and the physician, closely monitored the players during practice. In addition, the everyday life was monitored through the load-monitoring program. Ultrasonography is not known to lead to any discomfort, acute or sustained. As certain players are well known in public and among media, additionally demands to anonymity were required. From an ethical point of view, this project is important because of the information it can provide to form the base of guidelines connected to load, exercise and gameplay.

4. Results

4.1 Project I

Yo-yo IR 1 was performed at a separate day, three subjects missed either the pre- or posttest and their results are not included in the analysis for Yo-yo IR1. All included subjects (n=11) performed the sprint, jump and repeated sprint tests. The strength test was conducted on a separate day; one subject from the MAX group was not able to perform the post strength tests due to an injury. Table 4 shows changes within groups. For an overview of all tests that were completed for each subject, please see appendix VII.

Table 4: *Change pre- and post- training for both groups. Raw performance data are shown as mean ± SD. Change in performance as mean ± 90% CL. Sprint tests 10-m, 30-m, RS tt, and CMJ, PLY n=6, MAX n=5. Strength: squat, bench press, pull-down, PLY n=6, MAX n=4*

		Performance (mean ± SD)		**Change in performance (mean ± 90 % CL)**				
Test	**Groups**	**Pre**	**Post**	**Raw data**	**ES**	**Qualitative inference**	**% likelihood of difference being beneficial/trivial/harmful**	**Qualitative inference**
10-m	PLY	1.98 ± 0.07	1.97 ± 0.08	-0.01 ± 0.03	0.08	Trivial	27 / 62 / 11	Unclear
	MAX	2.01 ± 0.08	2.06 ± 0.08	0.04 ± 0.03	0.41	Small	1 / 10 / 89	Likely
30-m	PLY	4.67 ± 0.18	4.65 ± 0.15	-0.02 ± 0.05	0.10	Trivial	22 / 75 / 3	Unlikely
	MAX	4.76 ± 0.19	4.81 ± 0.18	0.05 ± 0.08	0.21	Small	3 / 44 / 53	Possibly
RS tt	PLY	29.88 ± 1.09	29.74 ± 1.06	-0.14 ± 0.37	0.11	Trivial	27 / 69 / 4	Possibly
	MAX	30.17 ± 1.01	30.20 ± 1.21	0.04 ± 0.68	0.03	Trivial	21 / 53 / 26	Unclear
CMJ	PLY	33.95 ± 3.94	34.12 ± 4.58	0.16 ± 0.64	0.02	Trivial	2 / 97 / 1	Very Unlikely
	MAX	30.61 ± 3.32	30.34 ± 3.51	-0.26 ± 1.08	0.07	Trivial	4 / 79 / 16	Unlikely
Squat	PLY	105 ± 11.1	115.4 ± 8.9	10.4 ± 7.1	0.80	Moderate	96 / 3 / 1	Very likely
	MAX	89.4 ± 14.5	107.5 ± 15.4	18.1 ± 7.7	0.80	Moderate	99 / 1 / 0	Very likely
Bench	PLY	48.3 ± 6.6	50.4 ± 8.0	2.1 ± 2.0	0.25	Small	64 / 35 / 1	Possibly
	MAX	48.8 ± 9.2	51.9 ± 9.7	3.1 ± 5.6	0.23	Small	55 / 40 / 5	Possibly
Pulld.	PLY	55.0 ± 5.0	58.3 ± 3.8	3.3 ± 1.1	0.54	Small	99 / 1 / 0	Very likely
	MAX	56.3 ± 6.0	60.0 ± 7.4	3.8 ± 5.1	0.41	Small	79 / 17 / 4	Likely

PLY = plyometric group, MAX = maximum strength group, RS tt = repeated sprint total time, CMJ = countermovement jump, Bench = bench press, Pulld. = pull-down

4.1.1 10- and 30-m sprint

Change in performance within groups is shown above in Table 4. Percent difference from pre- to post-test are shown in Figure 6. Between groups a moderate and likely (91%) difference in favor of the PLY group was found for 10-m sprint (ES = 0.61). For 30-m sprint a likely (92%) small difference was found in favor of the PLY group (ES = 0.51). Although only the change in 10-m sprint performance for the MAX group is above the typical error.

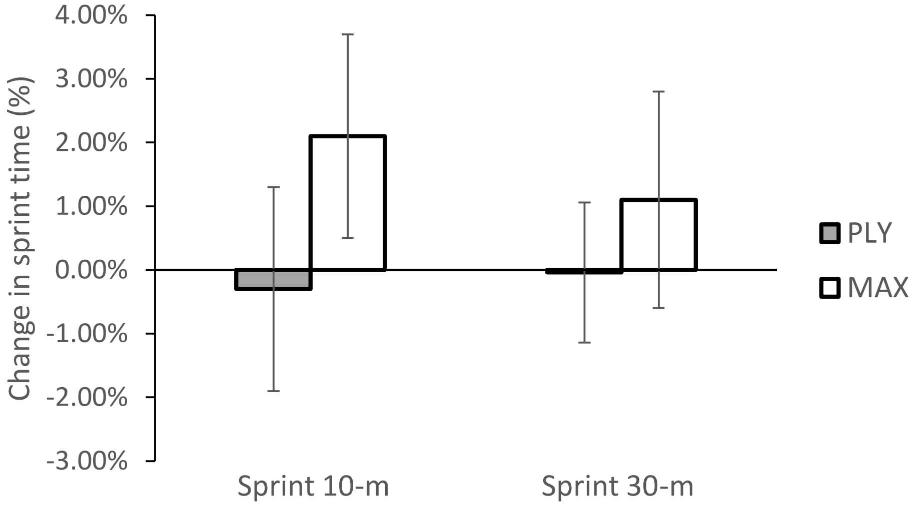


Figure 6: *Percent change in performance for 10- and 30-m sprint pre – post, results shown as mean ± 90% CL. PLY n=6, MAX n=5.*

4.1.2 Jump

Between groups a trivial difference (ES = 0.09) was found. It is unlikely (71%) that there was any meaningful difference between groups. Change in performance for each group is presented in Figure 7.

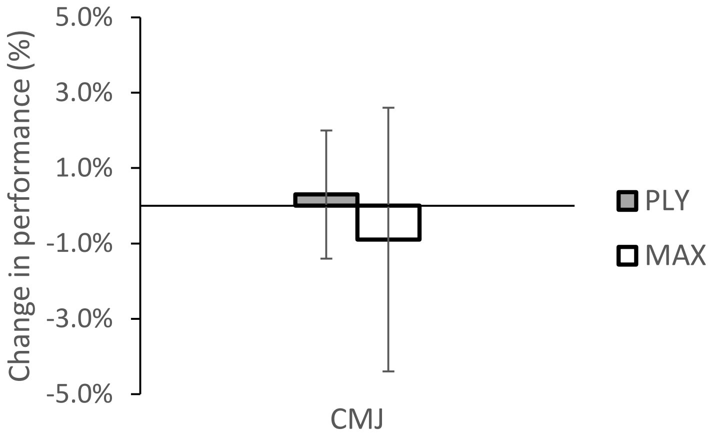


Figure 7*: Percent change in performance for CMJ pre – post, results shown as mean ± 90% CL. PLY n= 6, MAX n=5*

4.1.3 Squat

For 1RM squat a likely (94%) moderate difference (ES = 0.85) between groups, in favor of the MAX group, was found. Percent change in performance is presented in Figure 8.

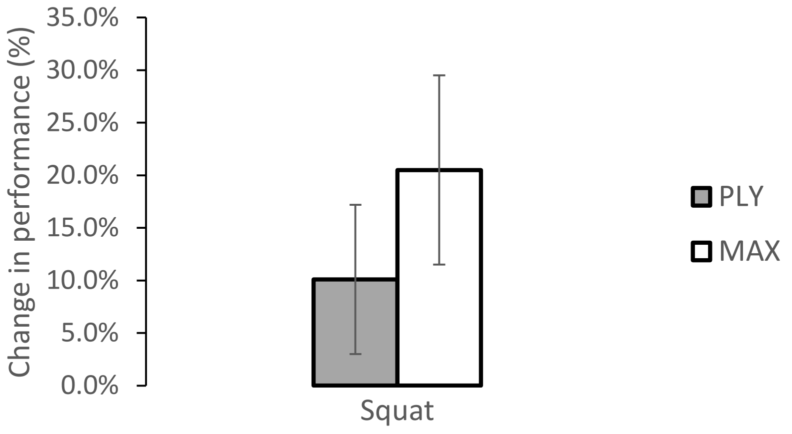


Figure 8*: Percent change in performance within groups (mean ± 90% CL). PLY n=6, MAX n=4*

4.1.4 Repeated sprint

Total time was used as the main parameter for repeated sprint. Changes within groups for repeated sprint total time is presented in Table 4. Between groups a trivial difference was found, -0.6 ± 2.3% in favor of the PLY group (ES = 0.16) and the effect was considered unclear.

For the repeated sprint test, sprint decrement in percent was also calculated. Between groups there was a likely (94%) difference (ES = 1.0) in favor of the MAX group. Within the PLY group, there was no change in mean 0.0 ± 1.4%, for the MAX group there was a -1.0 ± 1.2% change in mean.

4.1.5 Muscle architecture

Changes in architecture are presented in Table 5. Two subjects were not able to conduct the measurements due to time-management conflicts regarding work and football practice.

Table 5: *Change in muscle architecture pre- to post-test. Raw architecture data are shown as mean ± SD and change in architecture as mean ± 90% CL. PLY n=5, MAX n=4.*

		Mean ± SD						
	Groups	Pre	Post	Change in mean pre - post (mean ± 90% CL)	ES	Qualitative inference	% likelihood of the difference being beneficial/trivial/harmful	Qualitative inference
MT (cm)	PLY	1.98 ± 0.36	2.19 ± 0.35	0.21 ± 0.10	0.44	Small	96 / 4 / 0	Very likely
	MAX	2.32 ± 0.23	2.42 ± 0.35	0.10 ± 0.21	0.27	Small	58 / 31 / 11	Unclear
PA (⁰)	PLY	16.56 ± 2.57	17.00 ± 3.53	0.44 ± 1.57	0.09	Trivial	33 / 54 / 13	Unclear
	MAX	15.54 ± 1.87	15.24 ± 1.73	-0.30 ± 3.61	0.11	Trivial	32 / 23 / 45	Unclear
FL (cm)	PLY	7.00 ± 0.94	7.60 ± 0.94	0.60 ± 0.89	0.51	Small	80 / 15 / 5	Likely
	MAX	8.77 ± 1.38	9.20 ± 0.86	0.43 ± 1.90	0.25	Small	54 / 28 / 18	Unclear

PLY = plyometric group, MAX = maximum strength group, MT = muscle thickness, PA = pennation angle, FL = fascicle length.

Between groups a small but unclear effect (ES = 0.26) was found for muscle thickness. For pennation angle the difference was trivial and considered unclear (ES = 0.13). A trivial and unclear difference (ES = 0.19) was found also for fascicle length. Percent change in all ultrasound parameters is presented in Figure 9.

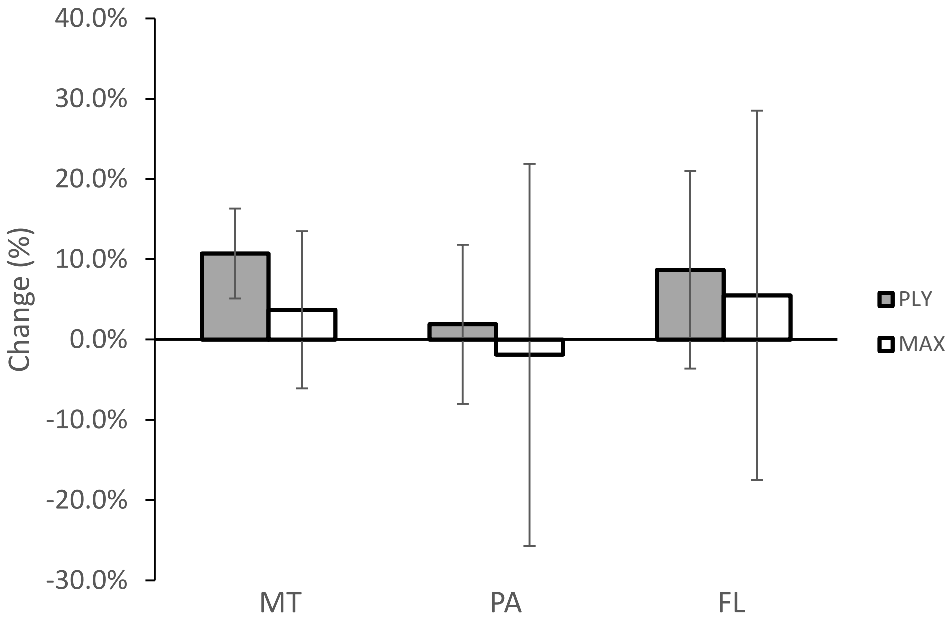


Figure 9*: Changes in muscle architecture from pre – post. PLY n=5, MAX n=4. MT = muscle thickness, PA = pennation angle, FL = fascicle length.*

4.1.6 Yo-yo IR 1

Three subjects from the MAX group missed either the pre- or post-test, and their results are therefore not included in the analysis. For this reason, an analysis of change in performance for the Yo-yo IR1 test was made with pooled groups. With groups pooled (n=8) a moderate change in performance (ES = 0.84) from 1055 ± 168 m to 1225 ± 140 m (mean ± SD) was found. Percent change in mean ± 90% CL = 16.8% ± 11.0. For the PLY group (n=6) a 22.6% ± 11.9 (mean ± 90% CL) change in mean was found, raw data change was 220m ± 94.8 (mean ± 90% CL), from 993 ± 144 m to 1213 ± 137 m (mean ± SD). The effect size was moderate (ES = 1.17), and the qualitative chance of a practically beneficial effect was very likely (99%). No analysis was made within the

MAX group due to too few subjects that completed either the pre- or posttest due to injuries.

4.1.7 Training load

Training load for each group, each week in project I is presented in Figure 10. One subject did not record enough sRPE data to be included in this analysis; average completion rate was 83 ± 8.5%. Only a trivial difference was found between the groups for mean training load for the whole period (ES = 0.17).

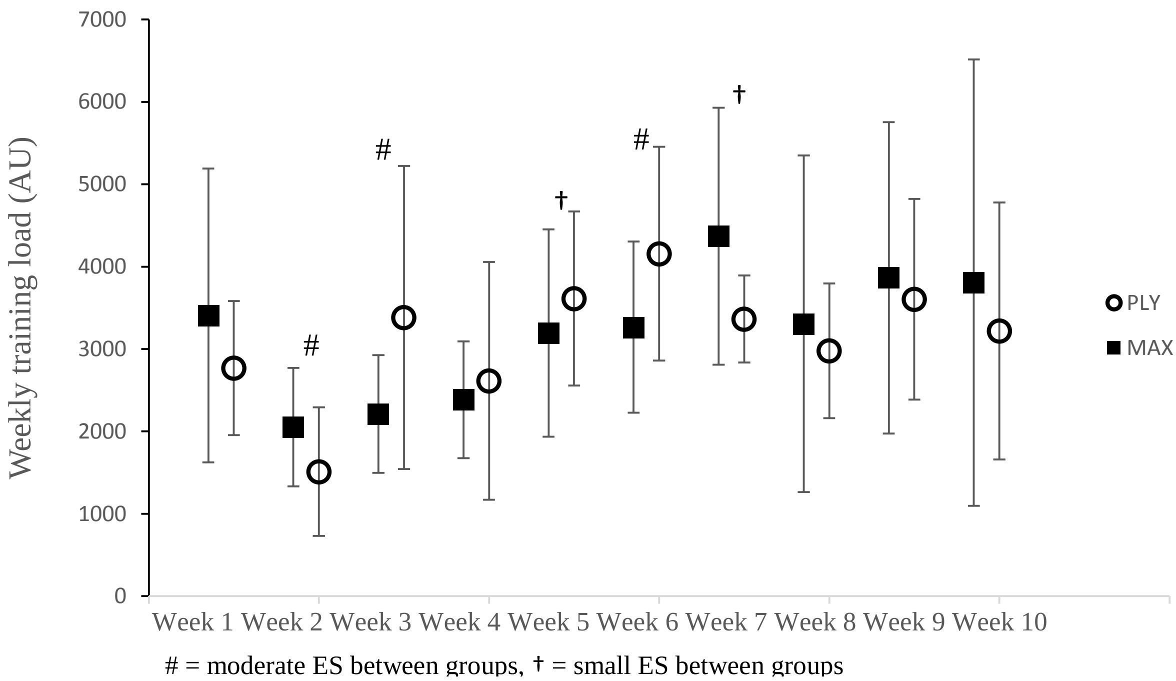


Figure 10: *Weekly training load (sRPE) between groups in project I. PLY n=5 and MAX n=5. Week 1, 4, 8, 9 and 10 trivial difference. Week 2, 3, and 6 ES=0.85, 0.78 and 0.89 respectively. Week 5 and 7 ES=0.55 and 0.33 respectively*

4.1.8 Number of sessions

There were some differences in the number of sessions completed between groups. The PLY group completed an average of 15.5 ± 1.2 sessions (range 14 – 17), and the MAX group completed 18.4 ± 1.8 sessions (range 16 – 20). Therefore, it was necessary to calculate if the number of completed sessions did influence the results. The subjects were divided into two groups based on number of completed sessions, 14 – 16 and 17 – 20 sessions completed, independent of the intervention groups PLY and MAX. For the 14 – 16 sessions group, 5 of 6 subjects belonged in the initial PLY group, and for the 17 – 20 sessions group 4 out of 5 subjects belonged in the MAX group. Three testing parameters had an ES>0.2 and thus a difference between groups 14–16 and 17–20 (Table 6). For the other parameters 30-m (ES = 0.16), RS tt (ES = 0.05), CMJ (ES = 0.11), and benchpress (ES = 0.02), no meaningful differences were found.

Table 6*: Difference in testing parameters within and between groups 14-16 completed sessions and 17-20 completed sessions. For sprint test (10-m) 14–16 group n=6 and 17–20 group n=5, for strength test (squat and pull down) 14–16 group n=6 and 17–20 group n=4. Difference within groups is presented as change in mean and percent difference. Difference between groups is presented as ES and the qualitative inference.*

		Mean ± SD					
Test	**Groups**	**Pre**	**Post**	**Change in mean pre - post (mean ± 90% CL)**	**% difference ± 90% CL**	**ES**	**Qualitative inference**
10-m (s)	14-16	1.95 ± 0.04	1.95 ± 0.07	0.0 ± 0.3	0.0 ± 1.6	0.24	Small
	17-20	2.06 ± 0.07	2.08 ± 0.06	0.02 ± 0.03	1.0 ± 1.6		
Squat (kg)	14-16	103.8 ± 12.1	112.9 ± 7.7	9.2 ± 5.1	9.2 ± 5.7	0.63	Moderate
	17-20	91.3 ± 15.5	111.3 ± 17.9	20.0 ± 8.7	22.0 ± 9.3		
Pulld. (kg)	14-16	56.7 ± 4.7	59.2 ± 3.4	2.5 ± 1.3	4.6 ± 2.7	0.39	Small
	17-20	53.8 ± 6.0	58.8 ± 7.8	5.0 ± 4.2	9.1 ± 7.0		

Pulld. = pull down

4.2 Project II

4.2.1 Load monitoring

Correlation analysis was conducted to investigate the relationships between the different methods for load monitoring, sRPE, PTW, NMF, CV (n = 10). The completion rate for the NMF test has been previously stated (chapter 3.6.3), for sRPE the completion rate was 82.8 ± 8.5%, and for PTW the completion rate was 85.5 ± 6.9%. The time points for the different rating and tests are shown in Figure 2.

No meaningful correlations were found between the different load monitoring methods. Correlation values crossed substantially positive and negative values for all categories. There was a tendency for meaningful negative correlations between the sum of sRPE one and two days before NMF assessment. However, two subjects presented large to very large correlations in the opposite direction and thus no consistent relationship could be determined. No meaningful relationships were evident between NMF and strain the past week, in addition to between NMF and PTW. Correlations spanned between medium to large of both positive and negative values. The relationship between PTW and sRPE were mostly small to medium correlations of both positive and negative values. Only two subjects showed a consistent negative relationship, however two subjects showed large positive correlations, and thus no meaningful relationship could be determined. Correlations of CV was not possible due to too few games and too much rotation of the squad.

5. Discussion

This study consisted of two projects conducted in parallel. The aim of project I was to investigate the effect of, and difference between, two strength-training regimes over 10-weeks in elite female football players. The effect was assessed through a series of field tests consisting of 10- and 30-m sprint, CMJ, repeated sprint, half squats, bench-press, pull-down, and Yoyo IR1. The aim of project II was to investigate any meaningful relationships between different load monitoring techniques and recovery and performance.

The main findings was that both groups had a substantial increase in lower extremity strength, however, no change was found in 10- or 30-m sprint, CMJ, and repeated sprint total time. Both groups also showed an increase in muscle thickness and fascicle length in m. vastus lateralis, but no change was found in pennation angle. No consistent relationships were found between the different load monitoring techniques.

As the subjects concurrently participated in football practice it is acknowledged that an influence from other training factors is possible. However, the only difference between groups in the weekly training was the strength training regimes. All other factors such as training mode and TL was similar for both groups, and therefore, should not influence the results.

5.1 Strength

The substantial increase in 1RM for both groups was somewhat unexpected. The PLY group performed only one maximum strength session per week and previous research has suggested that at least two maximum strength sessions is necessary to improve strength performance (Kraemer & Ratamess, 2004). It could be that the subjects were not properly trained at the outset of the study, although they were familiar with strength training and the type of exercises. A meta-analysis from 2003 suggested that individuals with less than one year of consistent strength training is to be considered untrained (Rhea, Alvar, Burkett, & Ball, 2003). Compared to competitive female cross-country skiers who did not perform regular strength training (108 kg and 90 kg 1RM half-squat for strength and control group respectively (Losnegard et al., 2011)) the subjects in this study was equally strong (105 kg and 89 kg 1RM for PLY and MAX respectively), and thus this supports the suggestion of the athletes being "weak", in terms of strength. It has been shown that large amounts of endurance training can elicit the adaptations to strength training (Ronnestad et al., 2012a). However, this might not be the same for weaker athletes, that may improve strength anyway (Kraemer et al., 2002; Kraemer & Ratamess, 2004). Others have also shown an increase in strength and power related parameters after strength training performed concurrently with endurance training (Millet et al., 2002; Ronnestad et al., 2008; Sedano et al., 2013).

The number of sets, repetitions, and recovery between sets in this study are in line with the recommendations and the program design should, thus be adequate enough to induce the expected strength and power parameters (Kraemer & Ratamess, 2004; Raastad et al., 2010; Rhea, Ball, Phillips, & Burkett, 2002). Several other exercises could have been chosen, e.g. Olympic lifts are shown to enhance power to an even greater extent than just maximum strength and/or power training alone (Channell & Barfield, 2008; Chaouachi et al., 2013; Hoffman, Cooper, Wendell, & Kang, 2004; McBride, Triplett-McBride, Davie, & Newton, 1999). However, due to the limited period that this study was conducted over, the required familiarization process of such exercises was too long to be considered.

The PLY and MAX groups respectively, completed an average number of 15.5 ± 1.2 and 18.4 ± 1.8 sessions over the 10-week intervention period. Four out of five subjects in the MAX group performed 17-20 sessions, compared to five out of six in the PLY group who performed 14-16 sessions. A moderate difference (ES = 0.63) in favor of the 17-20 (~MAX group) was found and this may partly explain the differences in change of strength shown between the PLY and MAX groups.

5.2 Sprint

The PLY group showed no meaningful change in performance for 10- and 30-m sprint after the intervention. For the MAX group a small effect size (ES = 0.41 and 0.21) was found for 10- and 30-m sprint times respectively. Nevertheless, the increase in 30-m sprint time was below the typical error and thereby not considered a true change. For the 10-m time however, a true change was found showing an increase in time. An increase of 0.04-s is the equivalent of a decrease of 20-25 cm during a 10-m sprint. This could be a game decisive reduction in terms of winning or losing a duel for the ball, creating a chance for the opponent (Haugen et al., 2014). There could be several reasons for the increase in time, but the most likely is the discrepancy between force and velocity. Previously it has been suggested that it is the intended rather than the actual velocity that is of importance for the training response, nevertheless velocity may also be inhibited by increased hypertrophy (Behm & Sale, 1993). Several studies have shown an increase in sprint performance after strength training interventions (Chelly et al., 2009; Helgerud et al., 2011; Ronnestad et al., 2008), but some have also reported no change (Kotzamanidis, Chatzopoulos, Michailidis, Papaiakovou, & Patikas, 2005; McBride, Triplett-McBride, Davie, & Newton, 2002; Wilson, Newton, Murphy, & Humphries, 1993). Strength gains may not be immediately transferred to increased sprint performance, due to the fact that the fast repeated kinematics of sprinting changes rapidly, and these movements cannot be reproduced entirely through resistance training (Kotzamanidis et al., 2005). Furthermore, one study that investigated the effect of strength training on kicking speed, suggested that players need time in order to transfer the increased strength to specific movements (Sedano, Matheu, Redondo, & Cuadrado, 2011). This may very well be the case in this study. This assumption can be supported by the principle of specificity, as most of the strength and power exercises are performed in the frontal (vertical) plane, and sprinting is performed in the sagittal (horizontal) plane. Kraemer and Ratamess (2004) stated that specificity through similar range of motion is important in order to enhance adaptations. This can also be evident in the present study, as the PLY group that had horizontal movements in their strength program, had no meaningful change compared to the MAX group who had an increase in sprint time. It might be that the PLY group were able to transfer their strength gains quicker due to the concurrent horizontal movements that replicate the repeated kinematics of sprint. It is possible that the MAX group may have required additional time with more specific range of motion exercises for this transfer to take place. It is fair to assume that the process is complex and that several different methods may be potentially optimal, based on players strength levels, familiarity with strength and/or sprint training, as well as specific velocity patterns.

For repeated sprint ability two parameters was calculated, total time and percent decrement. It has been consistently reported that the typical error for the decrement calculations is high (19.5%) (Gabbett, 2010; Spencer et al., 2006), and in this study no true change for sprint decrement was evident as it was not above the typical error reported.

The total time is considered the main variable for repeated sprint analysis as the typical error is much lower than for sprint decrement (0.7-1.5%). No meaningful difference was found in either group for total time. This is in line with previously reported results that neither explosive strength training or traditional heavy strength training improve repeated sprint ability (Buchheit, Mendez-Villanueva, Delhomel, Brughelli, & Ahmaidi, 2010; Shalfawi, Haugen, Jakobsen, Enoksen, & Tonnessen, 2013). Although some studies have shown improvements in repeated sprint parameters after resistance training (Bogdanis et al., 2011; Edge, Hill-Haas, Goodman, & Bishop, 2006).

5.3 Jump parameters

No changes were evident in CMJ performance in any of the groups. The calculated likelihood of changes suggested that it is unlikely to very unlikely that the MAX and PLY training approaches provided any beneficial effect. Although the mentioned principle of specificity, in terms of range of motion, is more in line with the specific action performed in both training and testing protocols, no changes were found. This is not in line with Cormie et al. (2010) who stated that one can expect an increase in jumping performance in relatively weak athletes after a period of strength and/or power training. Previous research report both changes (Cormie et al., 2007; Kotzamanidis et al., 2005; Ronnestad, Kojedal, Losnegard, Kvamme, & Raastad, 2012b) and no changes (Faude et al., 2013; McBride et al., 2002) in jump parameters following either resistance or combined resistance and power training. Other studies have reported effects on squat jump but not CMJ (Chelly et al., 2009; Maio Alves, Rebelo, Abrantes, & Sampaio, 2010). Several reasons has been proposed as to whether resistance training or power training will increase jumping abilities; initial strength of the subjects (Häkkinen & Komi, 1985), neuromuscular adaptations (Cormie et al., 2007), and the specificity in terms of stretch shortening cycle (Chelly et al., 2009). Specificity is applicable also in order of velocity and during loaded or one-legged jumps as the stretch shortening cycle is altered compared to on field training and thus the effect also may be different. In terms of neuromuscular adaptations, Cormie et al. (2007) suggests that the effects might be present due to the subjects nervous system adapting to the new movement pattern which may not be as familiar to all. However, jumping is a familiar movement for elite football players and thus the neural adaptations may be less important. As the subjects may be classified as initially weak in terms of strength, one should expect an increase in jump performance after the intervention. However, a duration of 10 weeks might not be enough (Cormie et al., 2007) and the possible greater effect from initially weaker strength players might be reduced by the lack of possible neural adaptations and velocity specificity.

5.4 Endurance

As several players were not able to perform the Yoyo IR1 test, due to injuries such as ankle sprains keeping them from performing their maximum effort, the groups were pooled for analysis of endurance. No substantial changes were expected in endurance as a result of the intervention. The increase in endurance level however, is in line with what others have reported during a pre-season preparatory period (Bangsbo et al., 2008). Some have also suggested that strength training can increase work economy and thus, increase endurance performance (Sedano et al., 2013; Storen et al., 2008). In light of this there is at least no reason to believe that the strength training would induce any negative effects on aerobic conditioning performance.

5.5 Muscle architecture

The changes in muscle architecture are in line with the changes in strength performance, considering that both groups increased in both 1RM squat and muscle thickness of the m. vastus lateralis. Although the PLY group had a greater increase in muscle thickness compared to the MAX group, the MAX group had the greatest increase in 1RM squat (20.5%). The greater increase in muscle thickness observed in the PLY group was somehow unexpected considering that the PLY group performed only one max strength session a week and the MAX group performed two max strength sessions a week. According to previous research, it is expected that the MAX group would have the greatest increase in muscle thickness as frequency of training has a great influence on hypertrophy (Cormie et al., 2010; Wernbom, Augustsson, & Thomee, 2007). It might be that the MAX group, who were initially weaker (ES = 1.39 in favor of PLY), had a stronger neural adaptation compared with the PLY group and, thus improved 1RM to a greater extent despite the difference in muscle thickness adaptations (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002; Seynnes, de Boer, & Narici, 2007).

Fascicle length has previously been reported to have a medium to large correlation with performance in sprinting (Abe et al., 2000; Kumagai et al., 2000). Nevertheless, no increase in sprint performance was found in the present study. According to Behm and Sale (1993), increased hypertrophy may inhibit velocity adaptations, and this may well be the case in this study. Another explanation might be that, as the fascicle length values are estimated through the equation, the increase in fascicle length is present only due to the change in muscle thickness and thus is not a true change.

Moreover, studies have also shown different adaptations in different parts of the muscles (i.e. proximal and distal parts)(Blazevich et al., 2003). In this study measurements were only taken at approximately the middle part of m. vastus lateralis (specifically, 60% of the distance from trochanter major to the fulcrum of the knee), and it might be that the PLY and MAX groups would have different adaptations more proximally and/or distally.

5.6 Load monitoring

No consistency was found in the specific relationships between the load monitoring methods. This is not in line with what has been reported in previous studies. McLean et al. (2010) reported large significant relationships between TL and PTW questionnaires, and Mooney et al. (2013) between TL and coaches votes. Similar relationships have also been found for TL and reduction in FT & CT ratio (Mooney et al., 2013). However, several possible reasons have been suggested to why meaningful relationships have not been found. For sRPE familiarization, fitness level and muscle damage from previous training has been proposed as possible explanations (Wallace et al., 2014). For this study, all subjects performed the same type and amount of training except for the difference in one strength session, but there was no meaningful difference in TL between groups for the whole period. Therefore, it is reason to believe that muscle damage from previous training sessions would be similar between groups and is not likely to be an interfering factor. Fitness level, familiarization and/or age could be factors that may partially influence these data. Younger players may experience an inferior fitness level than older, more experienced players (Bradley et al., 2014) and this may influence the experience of the session intensity. It is taken for granted that all subjects will improve their fitness level during the pre-season build up and thus, experience the same type of training differently in the beginning of the period compared to the end. This, however would also be detectable in the other methods for load monitoring and thus still be comparable. As increased fitness levels are also shown to increase the amount of high intensity running, sprints, total distance etc. (Haugen et al., 2012; Helgerud et al., 2001; Mohr et al., 2003) equal types of sessions might be given the same rating score regardless of fitness level as players perform even higher. Nevertheless, the subjects in the present study are top-level players and their fitness levels are believed to be quite good in the first place. Age alone could also influence the given rating as older players have more experience in differentiating the relative intensity and type of sessions, and younger players in general report a higher perceived exertion (Brink, Nederhof, Visscher, Schmikli, & Lemmink, 2010). Older players may even "train smarter" in order to benefit as much as possible, and still preserve energy to matches. Familiarization to the 10-category rating scale may be the most obvious reason, however Wallace et al. (2014) found that the coefficient of variation improved already from trial 2-3 compared to trial 1-2 in repeated sessions performed on cycle ergometers and thus, the subjects presumably familiarized quite early in the 10-week intervention. The subjects were also acquainted with the scale before the commencement of the study, and thus familiarization should not be an issue. It could also be that the sRPE measurements is quite reliable, as suggested before by many others (Foster et al., 2001; Impellizzeri et al., 2004; Scott et al., 2013), and that the non-meaningful relationships are due to disturbing factors associated with the other methods such as PTW, NMF and CV.

Even though PTW has shown small to large correlation with changes in TL (Buchheit et al., 2013; McLean et al., 2010), this is not the case in the present study. As mentioned above, this could be due to bias in collecting the "correct" TL, but it also might be due to the time point of collecting PTW data, as well as to little familiarization. PTW was reported in the middle of the day via an internet page developed for the club. The reason for choosing this time-point and not in the morning, as chosen by others (Buchheit et al., 2013; McLean et al., 2010), was that this time point was easier for the subjects to remember to conduct the reporting, taken in to consideration that they were not professionals. This time-point also made it easier to remind players through SMS to ensure that all players conducted the registration within the same time frame. A fair assumption to make is that more familiarization is needed in order for the subjects to be able to determine what "normal" really feels like. Especially young players will have less experience in quantifying this feeling and thus the results will be incorrect.

NMF tests (FT & CT ratio) have been shown to change in relation with TL and wellness measurements (Cormack, Mooney, Morgan, & McGuigan, 2013; McLean et al., 2010; Mooney et al., 2013). These assessments has been suggested to be reliable and to provide a good indication of incomplete recovery, and thus decreased performance and increased risk of injury (Cormack et al., 2008a; Cormack et al., 2008b; McLean et al., 2010; McLellan et al., 2011; Mooney et al., 2013). A possible consequence may be that the players performed only one approved jump. However, performing three approved jumps would have been too time consuming, and previously others have performed only one jump and still found reliable results (Cormack et al., 2008c). The lack of meaningful relationships to NMF may very well be due to too little familiarization, even though a familiarization period was conducted prior to the start of the intervention. Moreover, the pre-test was performed on two occasions and practice jumps were performed as well to minimize random effects. A possible explanation could be the level of professionalism of the subjects, as all were either working full-time or were full-time students. Influences from the work/school day may affect the NMF results independent of the recovery from training/match, and not only the match load and PTW prior to the match. Previous research reporting on these variables have been conducted on professional athletes, which usually use most of their time between training and matches to rest.

The use of CV during pre-season might not be necessary. In the present study, there was too few games, and too much rotation of the playing squad, that no player had enough ratings to compare these results against the other parameters. However, other studies has reported CV to be directly affected by the state of recovery assessed through CMJ jumps, as well as on field performance measured with global positioning systems and/or video technology(McLean et al., 2010; Mooney et al., 2013). Another issue to discuss is whether to use a 5-catergory rating or 10-category rating scale on such ratings. The study from (Mooney et al., 2013) used a 5-category rating scale and found significant correlations with several of the above-mentioned recovery and performance parameters. In the present study, a 10-category rating scale was used (Adopted from, Mooney et al., 2013). The reason was to make it a bit easier for coaches to differentiate between players performance, but this might also have influenced the possibility for a meaningful relationship to occur. As a difference from 3-4 will have a bigger impact if based on a 5-category rating scale compared to a 10-category rating scale. This should definitely be taken in to consideration for later studies. Smaller category rating scales might also force coaches to differentiate more between players performance.

Although this study found no meaningful correlations between these parameters, other studies have reported moderate correlations (Buchheit et al., 2013; Impellizzeri et al., 2004; McLellan et al., 2011; Mooney et al., 2013). Based on these previous studies presenting meaningful correlations, I still believe that there is good reason for collecting such information. At least on a professional level. Due to the fact that the methods has been reported to be both reliable and valid, and that it is so easily implementable, commercially available, and relatively easy to understand.

5.7 Limitations

Working with top-level semi-professional athletes could be difficult in terms of science. As there are always a few limitations that needs to be considered when conducting research on competitive athletes. In this study, the two most obvious limitations are the lack of a control group, and the low number of subjects (project I n=11, project II n=10). Both of these factors reduce the power of the statistical certainty. Moreover, all subjects were from the same team. This might be an advantage in order to equalize TL, preconditions etc. but it makes it harder to generalize the results as there is no guarantee that the teams ordinary training will not inflict the results of the study. Having subjects from different teams, as well as a control group, would have been preferable but this is not easily feasible when working with competitive athletes in general.

Another limitation for the statistical outcome is the unbalanced groups. This is more likely to occur due to the of the low number of subjects, as one drop-out easily can alter the group mean. The groups were matched after the pre-tests based on the 30-m sprint time, in order to minimize difference in mean between groups on this variable. However, due to the drop out of four players there was a small difference between groups for 30-m sprint time (ES = 0.43) at the start of the intervention.

Standardization approaching testing could also have been improved. Subjects was instructed not to exercise the day before testing, and urged to eat and hydrate well, however, no action was taken in order to control nutritional intake beyond this. All subjects reported that they felt fine during the testing, but as this is of great importance for performance, it should be accounted for in a more controlled manner. In addition, subjects had work and/or school on some of the test days, and stress related to this could have been different from pre- to post-test. Although, no difference was reported in PTW between the testing days. This influence could be of importance, and it should have been emphasized to test on the weekends in order to minimize influence from work and/or school.

Moreover, the familiarization to the load monitoring techniques might require more time than what was given in this study. Especially the NMF jump test require a lot of practice in order for the players to standardize their technique and to form the correct baseline for all players. It might be that the two sessions of dry training at practice in addition to practice jumps in the warm-up routine and the two pre-tests was not enough to form the correct baseline.

6. Conclusion

Both PLY and MAX protocols to training enhance 1RM squat performance. However, strength training alone does not seem to enhance sprint parameters directly despite the substantial increase in 1RM squat. Plyometric training in addition to maximum strength training may be more efficient than maximum strength training alone in order to optimize the transfer of increased strength to power movements such as sprints and jumps. Both groups had a beneficial adaptation in muscle architecture, increasing both muscle thickness and fascicle length, indicating an increased power and velocity specific adaptation as a result of both training methods. However, specific sprint and jump training appears to be advisable in addition to strength training to maximize enhancements.

No meaningful relationships were found between the different load monitoring methods in this study. However, it is likely that more familiarization is necessary in order to develop stable baseline measurements and implement standard routines.

7. Practical applications

The current data indicate that semi-professional female football players can obtain a moderate beneficial gain in strength through both maximum strength and a combination of maximum strength and plyometric training during a pre-season period. These effects appear to be evident despite performing 5 to 6 weekly football sessions. A combination of maximum strength and plyometric training may improve transfer of strength to sprint performance as it better replicates the kinematics of sprinting.

Further research should focus on how load monitoring methods could be better implemented for semi-professional athletes and investigate the time frame for the delayed enhancement of sprint performance via maximum strength training.

The football team involved in this study finished 8^{th} in the domestic league last season. This pre-season was the first with a well-developed strength/plyometric program and as of now; this team is unbeaten and holds the top position in the domestic league together with one other team (1 draw and 5 victories in 6 matches).

8. References

Aagaard, P., Andersen, J. L., Dyhre-Poulsen, P., Leffers, A. M., Wagner, A., Magnusson, S. P., . . . Simonsen, E. B. (2001). *A mechanism for increased contractile strength of human pennate muscle in response to strength training: changes in muscle architecture*. J Physiol, 534(Pt. 2), 613-623

Aagaard, P., Simonsen, E. B., Andersen, J. L., Magnusson, P., & Dyhre-Poulsen, P. (2002). *Increased rate of force development and neural drive of human skeletal muscle following resistance training*. J Appl Physiol (1985), 93(4), 1318-1326

Abe, T., Fukashiro, S., Harada, Y., & Kawamoto, K. (2001). *Relationship between sprint performance and muscle fascicle length in female sprinters*. J Physiol Anthropol Appl Human Sci, 20(2), 141-147

Abe, T., Kumagai, K., & Brechue, W. F. (2000). *Fascicle length of leg muscles is greater in sprinters than distance runners*. Med Sci Sports Exerc, 32(6), 1125-1129

Abt, G., Siegler, J. C., Akubat, I., & Castagna, C. (2011). *The effects of a constant sprint-to-rest ratio and recovery mode on repeated sprint performance*. J Strength Cond Res, 25(6), 1695-1702

Alegre, L. M., Jimenez, F., Gonzalo-Orden, J. M., Martin-Acero, R., & Aguado, X. (2006). *Effects of dynamic resistance training on fascicle length and isometric strength*. J Sports Sci, 24(5), 501-508

Alexiou, H., & Coutts, A. J. (2008). *A comparison of methods used for quantifying internal training load in women soccer players*. International Journal of Sports Physiology and Performance, 3(1555-0265 (Print)), 320-330

Andersson, H. A., Randers, M. B., Heiner-Moller, A., Krustrup, P., & Mohr, M. (2010). *Elite female soccer players perform more high-intensity running when playing in international games compared with domestic league games*. J Strength Cond Res, 24(4), 912-919

Arampatzis, A., Karamanidis, K., & Albracht, K. (2007). *Adaptational responses of the human Achilles tendon by modulation of the applied cyclic strain magnitude*. J Exp Biol, 210(Pt 15), 2743-2753

Arnason, A., Andersen, T. E., Holme, I., Engebretsen, L., & Bahr, R. (2008). *Prevention of hamstring strains in elite soccer: an intervention study*. Scand J Med Sci Sports, 18(1), 40-48

Arnason, A., Sigurdsson, S. B., Gudmundsson, A., Holme, I., Engebretsen, L., & Bahr, R. (2004). *Risk factors for injuries in football*. Am J Sports Med, 32(1 Suppl), 5S-16S

Balsom, P. D., Seger, J. Y., Sjodin, B., & Ekblom, B. (1992). *Maximal-intensity intermittent exercise: effect of recovery duration*. Int J Sports Med, 13(7), 528-533

Bangsbo, J., Iaia, F. M., & Krustrup, P. (2008). *The Yo-Yo intermittent recovery test : a useful tool for evaluation of physical performance in intermittent sports*. Sports Med, 38(1), 37-51

Bangsbo, J., Mohr, M., & Krustrup, P. (2006). *Physical and metabolic demands of training and match-play in the elite football player*. J Sports Sci, 24(7), 665-674

Behm, D. G., & Sale, D. G. (1993). *Velocity specificity of resistance training*. Sports Med, 15(6), 374-388

Bigland-Ritchie, B., & Woods, J. J. (1984). *Changes in muscle contractile properties and neural control during human muscular fatigue*. Muscle Nerve, 7(9), 691-699

Blazevich, A. J., Cannavan, D., Horne, S., Coleman, D. R., & Aagaard, P. (2009). *Changes in muscle force-length properties affect the early rise of force in vivo*. Muscle Nerve, 39(4), 512-520

Blazevich, A. J., Gill, N. D., Bronks, R., & Newton, R. U. (2003). *Training-specific muscle architecture adaptation after 5-wk training in athletes*. Med Sci Sports Exerc, 35(12), 2013-2022

Bloomfield, J., Polman, R., & O'Donoghue, P. (2007). *Physical Demands of Different Positions in FA Premier League Soccer*. J Sports Sci Med, 6(1), 63-70

Bogdanis, G. C., Papaspyrou, A., Souglis, A. G., Theos, A., Sotiropoulos, A., & Maridaki, M. (2011). *Effects of two different half-squat training programs on fatigue during repeated cycling sprints in soccer players*. J Strength Cond Res, 25(7), 1849-1856

Boyd, L. J., Ball, K., & Aughey, R. J. (2011). *The reliability of MinimaxX accelerometers for measuring physical activity in Australian football*. Int J Sports Physiol Perform, 6(3), 311-321

Bradley, P. S., Bendiksen, M., Dellal, A., Mohr, M., Wilkie, A., Datson, N., . . . Krustrup, P. (2014). *The application of the Yo-Yo intermittent endurance level 2 test to elite female soccer populations*. Scand J Med Sci Sports, 24(1), 43-54

Bradley, P. S., Sheldon, W., Wooster, B., Olsen, P., Boanas, P., & Krustrup, P. (2009). *High-intensity running in English FA Premier League soccer matches*. J Sports Sci, 27(2), 159-168

Brink, M. S., Nederhof, E., Visscher, C., Schmikli, S. L., & Lemmink, K. A. (2010). *Monitoring load, recovery, and performance in young elite soccer players*. J Strength Cond Res, 24(3), 597-603

Buchheit, M., Mendez-Villanueva, A., Delhomel, G., Brughelli, M., & Ahmaidi, S. (2010). *Improving repeated sprint ability in young elite soccer players: repeated shuttle sprints vs. explosive strength training*. J Strength Cond Res, 24(10), 2715-2722

Buchheit, M., Racinais, S., Bilsborough, J. C., Bourdon, P. C., Voss, S. C., Hocking, J., . . . Coutts, A. J. (2013). *Monitoring fitness, fatigue and running performance* *during a pre-season training camp in elite football players*. J Sci Med Sport, 16(6), 550-555

Campos, G. E., Luecke, T. J., Wendeln, H. K., Toma, K., Hagerman, F. C., Murray, T. F., . . . Staron, R. S. (2002). *Muscular adaptations in response to three different resistance-training regimens: specificity of repetition maximum training zones*. Eur J Appl Physiol, 88(1-2), 50-60

Channell, B. T., & Barfield, J. P. (2008). *Effect of Olympic and traditional resistance training on vertical jump improvement in high school boys*. J Strength Cond Res, 22(5), 1522-1527

Chaouachi, A., Hammami, R., Kaabi, S., Chamari, K., Drinkwater, E. J., & Behm, D. G. (2013). *Olympic weightlifting and plyometric training with children provides similar or greater performance improvements than traditional resistance training*. J Strength Cond Res

Chaouachi, A., Manzi, V., Chaalali, A., Wong del, P., Chamari, K., & Castagna, C. (2012). *Determinants analysis of change-of-direction ability in elite soccer players*. J Strength Cond Res, 26(10), 2667-2676

Chelly, M. S., Fathloun, M., Cherif, N., Ben Amar, M., Tabka, Z., & Van Praagh, E. (2009). *Effects of a back squat training program on leg power, jump, and sprint performances in junior soccer players*. J Strength Cond Res, 23(8), 2241-2249

Chilibeck, P. D., Calder, A. W., Sale, D. G., & Webber, C. E. (1998). *A comparison of strength and muscle mass increases during resistance training in young women*. Eur J Appl Physiol Occup Physiol, 77(1-2), 170-175

Cormack, S. J., Mooney, M. G., Morgan, W., & McGuigan, M. R. (2013). *Influence of neuromuscular fatigue on accelerometer load in elite Australian football players*. Int J Sports Physiol Perform, 8(4), 373-378

Cormack, S. J., Newton, R. U., & McGuigan, M. R. (2008a). *Neuromuscular and endocrine responses of elite players to an Australian rules football match*. Int J Sports Physiol Perform, 3(3), 359-374

Cormack, S. J., Newton, R. U., McGuigan, M. R., & Cormie, P. (2008b). *Neuromuscular and endocrine responses of elite players during an Australian rules football season*. Int J Sports Physiol Perform, 3(4), 439-453

Cormack, S. J., Newton, R. U., McGuigan, M. R., & Doyle, T. L. (2008c). *Reliability of measures obtained during single and repeated countermovement jumps*. Int J Sports Physiol Perform, 3(2), 131-144

Cormie, P., McCaulley, G. O., & McBride, J. M. (2007). *Power versus strength-power jump squat training: influence on the load-power relationship*. Med Sci Sports Exerc, 39(6), 996-1003

Cormie, P., McGuigan, M. R., & Newton, R. U. (2010). *Adaptations in athletic performance after ballistic power versus strength training*. Med Sci Sports Exerc, 42(8), 1582-1598

Cormie, P., McGuigan, M. R., & Newton, R. U. (2011). *Developing maximal neuromuscular power: Part 1--biological basis of maximal power production*. Sports Med, 41(1), 17-38

Coutts, A., Reaburn, P., Piva, T. J., & Murphy, A. (2007). *Changes in selected biochemical, muscular strength, power, and endurance measures during deliberate overreaching and tapering in rugby league players*. Int J Sports Med, 28(2), 116-124

Datson, N., Hulton, A., Andersson, H., Lewis, T., Weston, M., Drust, B., & Gregson, W. (2014). *Applied Physiology of Female Soccer: An Update*. Sports Med

Day, M. L., McGuigan, M. R., Brice, G., & Foster, C. (2004). *Monitoring exercise intensity during resistance training using the session RPE scale*. J Strength Cond Res, 18(2), 353-358

Di Salvo, V., Baron, R., Gonzalez-Haro, C., Gormasz, C., Pigozzi, F., & Bachl, N. (2010). *Sprinting analysis of elite soccer players during European Champions League and UEFA Cup matches*. J Sports Sci, 28(14), 1489-1494

Di Salvo, V., Gregson, W., Atkinson, G., Tordoff, P., & Drust, B. (2009). *Analysis of high intensity activity in Premier League soccer*. Int J Sports Med, 30(3), 205-212

Di Salvo, V., Pigozzi, F., Gonzalez-Haro, C., Laughlin, M. S., & De Witt, J. K. (2013). *Match performance comparison in top English soccer leagues*. Int J Sports Med, 34(6), 526-532

Dolezal, B. A., & Potteiger, J. A. (1998). *Concurrent resistance and endurance training influence basal metabolic rate in nondieting individuals*. J Appl Physiol (1985), 85(2), 695-700

Duthie, G. M., Pyne, D. B., Ross, A. A., Livingstone, S. G., & Hooper, S. L. (2006). *The reliability of ten-meter sprint time using different starting techniques*. J Strength Cond Res, 20(2), 246-251

Edge, J., Hill-Haas, S., Goodman, C., & Bishop, D. (2006). *Effects of resistance training on H+ regulation, buffer capacity, and repeated sprints*. Med Sci Sports Exerc, 38(11), 2004-2011

Enoksen, E., Tonnesen, E., & Tjelta, L. I. (2007). *Styrketrening - i individuelle idretter og ballspill*. Kristiansand: Høyskoleforlaget AS.

Faude, O., Roth, R., Di Giovine, D., Zahner, L., & Donath, L. (2013). *Combined strength and power training in high-level amateur football during the competitive season: a randomised-controlled trial*. J Sports Sci, 31(13), 1460-1467

Fédération Internationale de Football Association, F. (2013). *Laws of the game 2013/2014*, Downloaded May 15. 2014 from: http://www.fifa.com/mm/document/footballdevelopment/refereeing/81/42/36/log2013en_neutral.pdf

Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., . . . Dodge, C. (2001). *A new approach to monitoring exercise training*. J Strength Cond Res, 15(1), 109-115

Franks, I. M., & Miller, G. (1986). *Eyewitness testemoney in sport*. Journal of sport behavior (JSB), 9(1), 38-45

Gabbett, T. J. (2010). *The development of a test of repeated-sprint ability for elite women's soccer players*. J Strength Cond Res, 24(5), 1191-1194

Gabbett, T. J., & Jenkins, D. G. (2011). *Relationship between training load and injury in professional rugby league players*. J Sci Med Sport, 14(3), 204-209

Gabbett, T. J., Jenkins, D. G., & Abernethy, B. (2012). *Physical demands of professional rugby league training and competition using microtechnology*. J Sci Med Sport, 15(1), 80-86

Gabbett, T. J., Polley, C., Dwyer, D. B., Kearney, S., & Corvo, A. (2013). *Influence of field position and phase of play on the physical demands of match-play in professional rugby league forwards*. J Sci Med Sport

Gabbett, T. J., Wiig, H., & Spencer, M. (2013). *Repeated high-intensity running and sprinting in elite women's soccer competition*. Int J Sports Physiol Perform, 8(2), 130-138

Garthe, I., Raastad, T., Refsnes, P. E., & Sundgot-Borgen, J. (2013). *Effect of nutritional intervention on body composition and performance in elite athletes*. Eur J Sport Sci, 13(3), 295-303

Gergley, J. C. (2009). *Comparison of two lower-body modes of endurance training on lower-body strength development while concurrently training*. J Strength Cond Res, 23(3), 979-987

Glaister, M., Howatson, G., Pattison, J. R., & McInnes, G. (2008). *The reliability and validity of fatigue measures during multiple-sprint work: an issue revisited*. J Strength Cond Res, 22(5), 1597-1601

Gregson, W., Drust, B., Atkinson, G., & Salvo, V. D. (2010). *Match-to-match variability of high-speed activities in premier league soccer*. Int J Sports Med, 31(4), 237-242

Häkkinen, K., & Komi, P. V. (1985). *Changes in electrical and mechanical behavior of leg extensor muscles during heavy resistance strength training*. Scand J Sports Sci, 7, 55-64

Haugen, T., Tonnessen, E., Hisdal, J., & Seiler, S. (2014). *The role and development of sprinting speed in soccer*. Int J Sports Physiol Perform, 9(3), 432-441

Haugen, T., Tonnessen, E., & Seiler, S. (2012). *Speed and countermovement-jump characteristics of elite female soccer players, 1995-2010*. Int J Sports Physiol Perform, 7(4), 340-349

Hawkins, R. D., Hulse, M. A., Wilkinson, C., Hodson, A., & Gibson, M. (2001). *The association football medical research programme: an audit of injuries in professional football*. Br J Sports Med, 35(1), 43-47

Heasman, J., Dawson, B., Berry, J., & Stewart, G. (2008). *Development and validation of a player impact ranking system in Australian football*. International Journal of Performance Analysis in Sport, 8(3), 156-171

Helgerud, J., Engen, L. C., Wisloff, U., & Hoff, J. (2001). *Aerobic endurance training improves soccer performance*. Med Sci Sports Exerc, 33(11), 1925-1931

Helgerud, J., Rodas, G., Kemi, O. J., & Hoff, J. (2011). *Strength and endurance in elite football players*. Int J Sports Med, 32(9), 677-682

Hoff, J. (2005). *Training and testing physical capacities for elite soccer players*. J Sports Sci, 23(6), 573-582

Hoffman, J. R., Cooper, J., Wendell, M., & Kang, J. (2004). *Comparison of Olympic vs. traditional power lifting training programs in football players*. J Strength Cond Res, 18(1), 129-135

Hopkins, W. G. (2000). *Summarizing data: Precision of measurement*. www.sportsci.org

Hopkins, W. G. (2006). *Spreadsheets for Analysis of Controlled Trials, with Adjustment for a Subject Characteristic*. 46-50(10). http://sportsci.org/

Hopkins, W. G. (2007). *A Spreadsheet to Compare Means of Two Groups*. 11, 22-23. http://sportsci.org/

Hopkins, W. G. (2010). *Assigning Subjects to Groups in a Controlled Trial*. http://sportsci.org/resource/stats/index.html

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). *Progressive statistics for studies in sports medicine and exercise science*. Med Sci Sports Exerc, 41(1), 3-13

Impellizzeri, F. M., Marcora, S. M., Castagna, C., Reilly, T., Sassi, A., Iaia, F. M., & Rampinini, E. (2006). *Physiological and performance effects of generic versus specific aerobic training in soccer players*. Int J Sports Med, 27(6), 483-492

Impellizzeri, F. M., Rampinini, E., Coutts, A. J., Sassi, A., & Marcora, S. M. (2004). *Use of RPE-based training load in soccer*. Med Sci Sports Exerc, 36(6), 1042-1047

Keiner, M., Sander, A., Wirth, K., & Schmidtbleicher, D. (2014). *Long-term strength training effects on change-of-direction sprint performance*. J Strength Cond Res, 28(1), 223-231

Kotzamanidis, C., Chatzopoulos, D., Michailidis, C., Papaiakovou, G., & Patikas, D. (2005). *The effect of a combined high-intensity strength and speed training program on the running and jumping ability of soccer players*. J Strength Cond Res, 19(2), 369-375

Kraemer, W. J., Adams, K., Cafarelli, E., Dudley, G. A., Dooly, C., Feigenbaum, M. S., . . . American College of Sports, M. (2002). *American College of Sports Medicine position stand. Progression models in resistance training for healthy adults*. Med Sci Sports Exerc, 34(2), 364-380

Kraemer, W. J., & Ratamess, N. A. (2004). *Fundamentals of resistance training: progression and exercise prescription*. Med Sci Sports Exerc, 36(4), 674-688

Kreider, R. B., Klesges, R., Harmon, K., Grindstaff, P., Ramsey, L., Bullen, D., . . . Almada, A. (1996). *Effects of ingesting supplements designed to promote lean tissue accretion on body composition during resistance training*. Int J Sport Nutr, 6(3), 234-246

Krustrup, P., Mohr, M., Amstrup, T., Rysgaard, T., Johansen, J., Steensberg, A., . . . Bangsbo, J. (2003). *The yo-yo intermittent recovery test: physiological response, reliability, and validity*. Med Sci Sports Exerc, 35(4), 697-705

Krustrup, P., Mohr, M., Ellingsgaard, H., & Bangsbo, J. (2005). *Physical demands during an elite female soccer game: importance of training status*. Med Sci Sports Exerc, 37(7), 1242-1248

Kumagai, K., Abe, T., Brechue, W. F., Ryushi, T., Takano, S., & Mizuno, M. (2000). *Sprint performance is related to muscle fascicle length in male 100-m sprinters*. J Appl Physiol (1985), 88(3), 811-816

Kwah, L. K., Pinto, R. Z., Diong, J., & Herbert, R. D. (2013). *Reliability and validity of ultrasound measurements of muscle fascicle length and pennation in humans: a systematic review*. J Appl Physiol (1985), 114(6), 761-769

Lemon, P. W. (1998). *Effects of exercise on dietary protein requirements*. Int J Sport Nutr, 8(4), 426-447

Little, T., & Williams, A. G. (2007). *Effects of sprint duration and exercise: rest ratio on repeated sprint performance and physiological responses in professional soccer players*. J Strength Cond Res, 21(2), 646-648

Losnegard, T., Mikkelsen, K., Ronnestad, B. R., Hallen, J., Rud, B., & Raastad, T. (2011). *The effect of heavy strength training on muscle mass and physical performance in elite cross country skiers*. Scand J Med Sci Sports, 21(3), 389-401

Maio Alves, J. M., Rebelo, A. N., Abrantes, C., & Sampaio, J. (2010). *Short-term effects of complex and contrast training in soccer players' vertical jump, sprint, and agility abilities*. J Strength Cond Res, 24(4), 936-941

Mandelbaum, B. R., Silvers, H. J., Watanabe, D. S., Knarr, J. F., Thomas, S. D., Griffin, L. Y., . . . Garrett, W., Jr. (2005). *Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow-up*. Am J Sports Med, 33(7), 1003-1010

Manson, S. A., Brughelli, M., & Harris, N. K. (2014). *Physiological characteristics of international female soccer players*. J Strength Cond Res, 28(2), 308-318

McBride, J. M., Triplett-McBride, T., Davie, A., & Newton, R. (1999). *A Comparison of Strength and Power Characteristics Between Power Lifters, Olympic Lifters, and Sprinters*. Journal of Strength and Conditioning Research, 13(1), 58-66

McBride, J. M., Triplett-McBride, T., Davie, A., & Newton, R. U. (2002). *The effect of heavy- vs. light-load jump squats on the development of strength, power, and speed*. J Strength Cond Res, 16(1), 75-82

McLean, B. D., Coutts, A. J., Kelly, V., McGuigan, M. R., & Cormack, S. J. (2010). *Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players*. Int J Sports Physiol Perform, 5(3), 367-383

McLellan, C. P., Lovell, D. I., & Gass, G. C. (2011). *Markers of postmatch fatigue in professional Rugby League players*. J Strength Cond Res, 25(4), 1030-1039

McMaster, D. T., Gill, N., Cronin, J., & McGuigan, M. (2014). *A brief review of strength and ballistic assessment methodologies in sport*. Sports Med, 44(5), 603-623

Millet, G. P., Jaouen, B., Borrani, F., & Candau, R. (2002). *Effects of concurrent endurance and strength training on running economy and .VO(2) kinetics*. Med Sci Sports Exerc, 34(8), 1351-1359

Mjolsnes, R., Arnason, A., Osthagen, T., Raastad, T., & Bahr, R. (2004). *A 10-week randomized trial comparing eccentric vs. concentric hamstring strength training in well-trained soccer players*. Scand J Med Sci Sports, 14(5), 311-317

Mohr, M., Krustrup, P., Andersson, H., Kirkendal, D., & Bangsbo, J. (2008). *Match activities of elite women soccer players at different performance levels*. J Strength Cond Res, 22(2), 341-349

Mohr, M., Krustrup, P., & Bangsbo, J. (2003). *Match performance of high-standard soccer players with special reference to development of fatigue*. J Sports Sci, 21(7), 519-528

Mooney, M. G., Cormack, S., O'Brien B, J., Morgan, W. M., & McGuigan, M. (2013). *Impact of neuromuscular fatigue on match exercise intensity and performance in elite Australian football*. J Strength Cond Res, 27(1), 166-173

Myklebust, G., Engebretsen, L., Braekken, I. H., Skjolberg, A., Olsen, O. E., & Bahr, R. (2003). *Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons*. Clin J Sport Med, 13(2), 71-78

Nilstad, A., Andersen, T. E., Bahr, R., Holme, I., & Steffen, K. (2014). *Risk factors for lower extremity injuries in elite female soccer players*. Am J Sports Med, 42(4), 940-948

Norwegian Football Association, N. (2014). *Lov og regelement 2014*, Downloaded May 15. 2014 from: https://www.fotball.no/Documents/PDF/2014/NFF/Lov_og_reglement_2014.pdf

Raastad, T., Paulsen, G., Refsnes, P. E., Rønnestad, B. R., & Wisnes, A. R. (2010). *Styrketrening - i teori og praksis* (1. st. edition ed.). Oslo, Norway: Gyldendal Norsk Forlag AS.

Rampinini, E., Coutts, A. J., Castagna, C., Sassi, R., & Impellizzeri, F. M. (2007). *Variation in top level soccer match performance*. Int J Sports Med, 28(12), 1018-1024

Rhea, M. R., Alvar, B. A., Burkett, L. N., & Ball, S. D. (2003). *A meta-analysis to determine the dose response for strength development*. Med Sci Sports Exerc, 35(3), 456-464

Rhea, M. R., Ball, S. D., Phillips, W. T., & Burkett, L. N. (2002). *A comparison of linear and daily undulating periodized programs with equated volume and intensity for strength*. J Strength Cond Res, 16(2), 250-255

Rhea, M. R., Lavinge, D. M., Robbins, P., Esteve-Lanao, J., & Hultgren, T. L. (2009). *Metabolic conditioning among soccer players*. J Strength Cond Res, 23(3), 800-806

Rodriguez, N. R., Di Marco, N. M., & Langley, S. (2009). *American College of Sports Medicine, American Dietetic Association Dietitians of Canada Position Statement. Nutrition and athletic performance.* Med Sci Sports Exerc, 41(3), 709-731

Ronnestad, B. R., Hansen, E. A., & Raastad, T. (2012a). *High volume of endurance training impairs adaptations to 12 weeks of strength training in well-trained endurance athletes*. Eur J Appl Physiol, 112(4), 1457-1466

Ronnestad, B. R., Kojedal, O., Losnegard, T., Kvamme, B., & Raastad, T. (2012b). *Effect of heavy strength training on muscle thickness, strength, jump performance, and endurance performance in well-trained Nordic Combined athletes*. Eur J Appl Physiol, 112(6), 2341-2352

Ronnestad, B. R., Kvamme, N. H., Sunde, A., & Raastad, T. (2008). *Short-term effects of strength and plyometric training on sprint and jump performance in professional soccer players*. J Strength Cond Res, 22(3), 773-780

Ronnestad, B. R., Nymark, B. S., & Raastad, T. (2011). *Effects of in-season strength maintenance training frequency in professional soccer players*. J Strength Cond Res, 25(10), 2653-2660

Rozenek, R., Ward, P., Long, S., & Garhammer, J. (2002). *Effects of high-calorie supplements on body composition and muscular strength following resistance training*. J Sports Med Phys Fitness, 42(3), 340-347

Scott, T. J., Black, C. R., Quinn, J., & Coutts, A. J. (2013). *Validity and reliability of the session-RPE method for quantifying training in Australian football: a comparison of the CR10 and CR100 scales*. J Strength Cond Res, 27(1), 270-276

Sedano, S., Marin, P. J., Cuadrado, G., & Redondo, J. C. (2013). *Concurrent training in elite male runners: the influence of strength versus muscular endurance training on performance outcomes*. J Strength Cond Res, 27(9), 2433-2443

Sedano, S., Matheu, A., Redondo, J. C., & Cuadrado, G. (2011). *Effects of plyometric training on explosive strength, acceleration capacity and kicking speed in young elite soccer players*. J Sports Med Phys Fitness, 51(1), 50-58

Seynnes, O. R., de Boer, M., & Narici, M. V. (2007). *Early skeletal muscle hypertrophy and architectural changes in response to high-intensity resistance training*. J Appl Physiol (1985), 102(1), 368-373

Shalfawi, S. A., Haugen, T., Jakobsen, T. A., Enoksen, E., & Tonnessen, E. (2013). *The effect of combined resisted agility and repeated sprint training vs. strength training on female elite soccer players*. J Strength Cond Res, 27(11), 2966-2972

Singh, F., Foster, C., Tod, D., & McGuigan, M. R. (2007). *Monitoring different types of resistance training using session rating of perceived exertion*. Int J Sports Physiol Perform, 2(1), 34-45

Spencer, M., Fitzsimons, M., Dawson, B., Bishop, D., & Goodman, C. (2006). *Reliability of a repeated-sprint test for field-hockey*. J Sci Med Sport, 9(1-2), 181-184

Stark, M., Lukaszuk, J., Prawitz, A., & Salacinski, A. (2012). *Protein timing and its effects on muscular hypertrophy and strength in individuals engaged in weight-training*. J Int Soc Sports Nutr, 9(1), 54

Stolen, T., Chamari, K., Castagna, C., & Wisloff, U. (2005). *Physiology of soccer: an update*. Sports Med, 35(6), 501-536

Storen, O., Helgerud, J., Stoa, E. M., & Hoff, J. (2008). *Maximal strength training improves running economy in distance runners*. Med Sci Sports Exerc, 40(6), 1087-1092

Thomas, A., Dawson, B., & Goodman, C. (2006). *The yo-yo test: reliability and association with a 20-m shuttle run and VO(2max)*. Int J Sports Physiol Perform, 1(2), 137-149

Thomas, J., Nelson, J., & Silverman, S. (2011). *Research methods in physical activity* (6th. ed. ed.). USA: Human Kinetics.

Tipton, K. D., & Wolfe, R. R. (2004). *Protein and amino acids for athletes*. J Sports Sci, 22(1), 65-79

Tonnesen, E., Alnes, L. O., & Aasen, S. B. (2009). *Hurtighetstrening i fotball*. Downloaded March 12. 2014 from: http://www.olympiatoppen.no/fagomraader/trening/spenst_og_hurtighet/hurtighet/fagartikler/Fotballhurtighet/page2748.html

Tonnessen, E., Shalfawi, S. A., Haugen, T., & Enoksen, E. (2011). *The effect of 40-m repeated sprint training on maximum sprinting speed, repeated sprint speed* *endurance, vertical jump, and aerobic capacity in young elite male soccer players*. J Strength Cond Res, 25(9), 2364-2370

Tsuzuku, S., Shimokata, H., Ikegami, Y., Yabe, K., & Wasnich, R. D. (2001). *Effects of high versus low-intensity resistance training on bone mineral density in young males*. Calcif Tissue Int, 68(6), 342-347

Vescovi, J. D. (2012). *Sprint profile of professional female soccer players during competitive matches: Female Athletes in Motion (FAiM) study*. J Sports Sci, 30(12), 1259-1265

Vittorri, C. (1996). *The European school in sprint training: The experiences in Italy*. New Studies in Athletics, 2-3

Walden, M., Hagglund, M., & Ekstrand, J. (2005). *UEFA Champions League study: a prospective study of injuries in professional football during the 2001-2002 season*. Br J Sports Med, 39(8), 542-546

Wallace, L. K., Slattery, K. M., Impellizzeri, F. M., & Coutts, A. J. (2014). *Establishing the criterion validity and reliability of common methods for quantifying training load*. J Strength Cond Res

Wernbom, M., Augustsson, J., & Thomee, R. (2007). *The influence of frequency, intensity, volume and mode of strength training on whole muscle cross-sectional area in humans*. Sports Med, 37(3), 225-264

Wilson, G. J., Newton, R. U., Murphy, A. J., & Humphries, B. J. (1993). *The optimal training load for the development of dynamic athletic performance*. Med Sci Sports Exerc, 25(11), 1279-1286

Wisloff, U., Castagna, C., Helgerud, J., Jones, R., & Hoff, J. (2004). *Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players*. Br J Sports Med, 38(3), 285-288

Woolford, S., Polglaze, T., Rowsell, G., & Spencer, M. (2013). Field testing principles and protocols *Physiological test for elite athletes* (2nd ed. ed., pp. 231-248): Human Kinetics.

Overview of tables

Overview of figures

Abbreviations

1RM	One Repetition Maximum
CL	Confidence limits
CMJ	Countermovement jump
CT	Contraction time
CV	Coaches votes
ES	Effect size
FT	Flight-time
MAX	Maximal strength training group
NMF	Neuromuscular fatigue
PLY	Plyometric strength training group
PTW	Pre Training Wellness questionnaire
SD	Standard deviation
sRPE	Session rate of perceived exertion
TL	Training load

Appendix

Appendix I – Strength training program MAX group

MAX

	Week 1 - 5					Week 6 - 10			
	Exercises	Series	Rep	Pause length (min)		Exercises	Series	Rep	Pause length (min)
Day 1	Front squat	3	4 RM	3	Day 1	Front squat	4	3 RM	3
	Stiff leg deadlift	3	4 RM	3		Stiff leg deadlift	4	3 RM	3
	Bulgarian split squat	3	4 RM	3		Bulgarian split squat	4	3 RM	3
	Hip flexor (cable)	3	4 RM	3		Hip flexor (cable)	4	3 RM	3
	Bench press	3	5 RM	2		Bench press	3	5 RM	2
	Bent rows	3	5 RM	2		Bent rows	3	5 RM	2
	Abdominal (elastic)	3	12 - 15	2		Abdominal (elastic)	3	12 - 15	2
Day 2	Front squat	3	6 RM	3	Day 2	Front squat	4	5 RM	3
	Deadlift	3	6 RM	3		Deadlift	4	5 RM	3
	Nordic hamstring	3	6 RM	3		Nordic hamstring	4	5 RM	3
	Lunge (sideways)	3	6 RM	3		Lunge (sideways)	4	5 RM	3
	Flies	3	6 RM	2		Flies	3	6 RM	2
	Chins	3	6 RM	2		Chins	3	6 RM	2
	Abdominal (dumbell)	3	8x3	2		Abdominal (dumbell)	3	8x3	2

Appendix II – Strength training program PLY group

PLY	**Week 1 - 5**					**Week 6 - 10**			
	Exercises	Series	Rep	Pause length (min)		Exercises	Series	Rep	Pause length (min)
Day 1	Front squat	3	4 RM	3	Day 1	Front squat	4	3 RM	3
	Stiff leg deadlift	3	4 RM	3		Stiff leg deadlift	4	3 RM	3
	Bulgarian split squat	3	4 RM	3		Bulgarian split squat	4	3 RM	3
	Hip flexor (cable)	3	4 RM	3		Hip flexor (cable)	4	3 RM	3
	Bench press	3	5 RM	2		Bench press	3	5 RM	2
	Bent rows	3	5 RM	2		Bent rows	3	5 RM	2
	Abdominal (elastic)	3	12 - 15	2		Abdominal (elastic)	3	12 - 15	2
Day 2	Sub max squat jump	3	6	2	Day 2	Sub max squat jump	2	6	2
	Single leg box jump	3	6	3		Single leg box jump	4	6	3
	SL horisontal jump (4)	3	6	3		SL horisontal jump (4)	4	6	3
	Squat jump (0-40kg)	3	6	3		Squat jump (0-40kg)	4	6	3
	Flies	3	6 RM	2		Flies	3	6 RM	2
	Chins	3	6 RM	2		Chins	3	6 RM	2
	Abdominal (dumbell)	3	8x3	2		Abdominal (dumbell)	3	8x3	2

Appendix III – sRPE log

NAVN:…………………………………………………………

Dato	Hva	Hvor	Varighet (min)	sRPE

0	**Rest**
1	Very easy
2	Easy
3	Moderate
4	Somewhat hard
5	Hard
6	Harder
7	Very hard
8	Very, very hard
9	Nearly maximal
10	Maximal effort

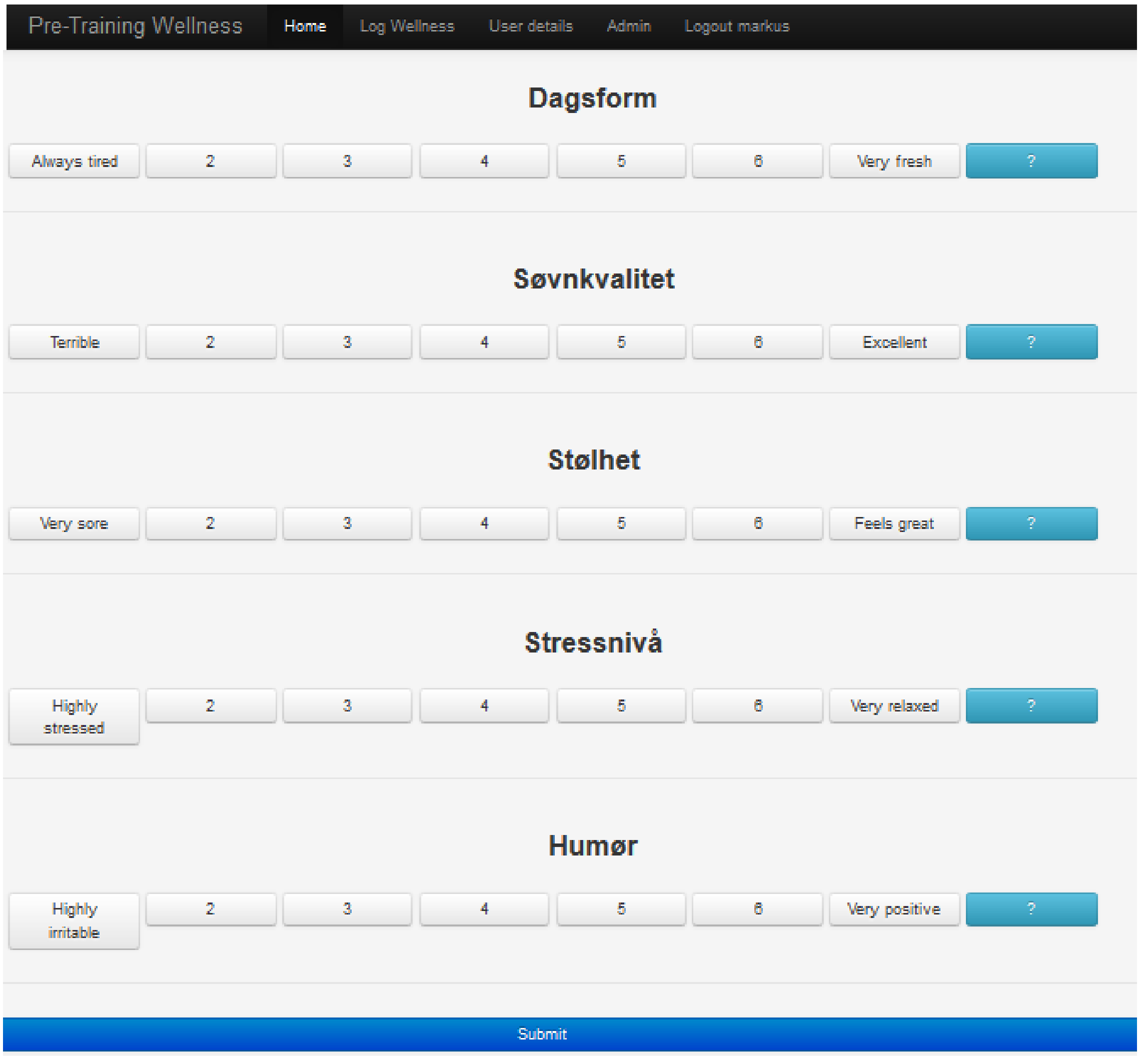
Hva = football, styrke, ren utholdenhetstrening, o.l.

Hvor = Røa, fitness express, elixia, tredemølle, skogen o.l.

HUSK AT RATING SKAL VÆRE ET GJENNOMSNITT FOR HELE ØKTA UNDER ETT!

Appendix IV – FIFA 11+ warm-up routine

Appendix V – Pre Wellness rating questionnaire



Forespørsel om deltakelse i forskningsprosjektet: Fysisk trening og belastningsovervåkning i fotball

Bakgrunn og hensikt
Dette er et spørsmål til deg om å delta i en forskningsstudie ved Norges idrettshøgskole (NIH). Du blir spurt om deltagelse fordi du aktivt spiller fotball for et lag i toppserien. Studien ønsker å finne ut om det kan være en sammenheng mellom ulike metoder for å registrere belastning i løpet sesong i fotball. Samt å sammenligne to ulike treningstilnærminger for å utvikle fysiske ressurser. Hensikten med studien er å samle data som kan sammenlignes og derav bidra til å si noe om den enkelte deltagers restitusjonsprosess og prestasjon. I tillegg til å sammenligne effekten av og eventuelt forskjellen på to ulike treningsopplegg på utvikling av de fysiske egenskapene.

Hva innebærer studien?
Studien vil være delt i 2 deler, hvor **del en** består av en treningsintervensjon og **del to** består av en belastningsovervåkning. Følgende metoder vil bli brukt for å overvåke belastning og prestasjon:

- Session rate of percived exertion (sRPE): Deltagerne skal rate intensiteten på hver treningsøkt og kamp på en skala fra 0 – 10, hvor 0 = hvile og 10 = maksimal.
- En «counter movement jump test» (CMJ) (motbevegelseshopptest) vil bli brukt for å kartlegge neruromuscular fatigue. Testen består av å gjennomføre et par enkle CMJ hopp på en kraftplattform til oppsatte tidspunkter i løpet av en treningsuke.
- «PreWellness» Et spørreskjema for fysisk og psykisk påkjenning/opplevelse skal fylles ut en til to ganger i uka, her vil deltagerne rate dagsform, søvn, stølhet, stress og sykdom fra 1 – 7, hvor 7 tilsvarer meget bra, 4 normal, og 1 veldig dårlig.
- «Coaches votes», den går ut på at enkelte personer i trenerapparatet vil rate deltagerens prestasjon i kamp på en skala fra 1 – 10 der 1 er dårligst og 10 er best.
- Ultralyd, for å overvåke eventuelle endringer i muskelarkitektur og volum. Med volum menes muskelenesstørrelse. Arkitektur vil si vinkel og retning på muskelfibrene. Størrelse og vinkel kan si noe om bl.a. konsentrasjonen av fibre per cm^2, muskelstyrke, og evne til rask kraftutvikling.
- Felttester som 30m sprint, repetert sprint, spenst, styrke og Yo-yo som mål på prestasjon og utvikling.

I **del en** vil det gjennomføres en ca. 10 ukers intervensjon i ressursperioden. Belastningsstyringen vil fortsette, men deltagerne vil i tillegg følge to spesifikke treningsprogrammer for utvikling av de fysiske ressursene. Dere vil deles tilfeldig i to grupper med noen regler for inndelingen slik at gjennomsnittet på enkelte av de fysiske ressursene blir så likt som mulig på tvers av gruppene. De to gruppene vil gjennomføre to ulike treningsregimer for å bedre de fysiske ressursene. Begge er tilnærmingene er brukt av andre utøvere tidligere og er <u>forventet å føre til fremgang</u>, men vi ønsker å se om det kan være noen forskjell mellom dem. All trening vil bli nøye planlagt og fulgt opp. Alt av felttester og ultralydmålinger vil gjennomføres i denne delen av prosjektet også.

I **del to** av prosjektet vil all denne informasjonen samlet brukes til å danne et bilde av en deltagers totale belastning igjennom en treningsuke, og hvordan dette kan virke inn på prestasjon.

Fordeler og ulemper
Deltakelse i prosjektet vil kreve noe tid og oppmerksomhet av deg som deltaker da du må følge opp sRPE hver dag i forbindelse med trening, samt «pre wellness» en til to ganger i uken. I tillegg krever det at du gjennomfører CMJ testen til oppsatt tid. Denne vil alltid gjennomføres i forbindelse med annen trening så det vil ikke kreve noe ekstra oppmøte og/eller tid utover vanlig trening. Ultralyd målingene vil bli gjennomført før og etter den/de aktuelle perioden(e), og krever at du møter opp på NIHs laboratorium til avtalt tid. Denne typen målinger er unnagjort på ca. 10 min. og er ikke kjent å føre til noen form for ubehag eller fysisk påkjenning.

Del to av studien vil innebære en større fysisk påkjenning som følge av treningsintervensjonen. Intervensjonen vil i utgangspunktet inngå i den mengden trening du allerede gjennomfører og vil kun fremstå som en variasjon ifra tidligere treningsarbeid. Treningen kan føre til større og sterkere muskler og kan bidra til å endre kroppssammensetningen noe. Dette er ansett som en fordel da større og sterkere muskler også vil bidra til å nå studiens mål. Treningen skal gjennomføres med stor belastning og vil medføre en viss risiko for skade og følelse av sårhet/stølhet i muskulaturen. Gjennomføring av de fysiske testene kan kjennes ubehagelig da disse krever maks innsats og tidvis utmattelse. All trening og testing vil bli nøye planlagt og vurdert. Testing vil alltid foregå under oppsyn av kvalifisert personell og medfører i utgangspunktet minimalt med risiko. Som under **del en** vil muskelarkitekturmålingene finne sted før og etter den aktuelle perioden og disse utgjør ingen ubehag eller risiko.

Hva skjer med informasjonen om deg?
Det er frivillig å delta i studien. Om du nå sier ja til å delta, kan du senere når som helst og uten å oppgi noen grunn, trekke tilbake ditt samtykke. Informasjonen som registreres om deg skal kun brukes slik som beskrevet i hensikten med studien. Alle opplysningene vil bli behandlet uten navn og fødselsnummer eller andre direkte gjenkjennende opplysninger. En kode knytter deg til dine opplysninger og prøver gjennom en navneliste. Denne kodelisten som inneholder ditt navn og personnummer vil være fysisk innelåst. Det er kun autorisert personell knyttet til prosjektet som har adgang til navnelisten og som kan finne tilbake til deg. Alle som får innsyn i informasjonen om deg har taushetsplikt.

Av hensyn til etterprøvbarhet og kontroll vil informasjonen lagres i 10 år etter at prosjektet er avsluttet. Informasjonen vil lagres hos Norsk Samfunnsvitenskapelig Datatjeneste. Det er kun direktøren ved Norges idrettshøgskole som kan be om tilgang til informasjonen når prosjektet er avsluttet. Det vil ikke være mulig å identifisere deg i resultatene av studien når disse publiseres.

Ytterligere informasjon om studien finnes i kapittel A, og dine rettigheter finnes i Kapittel B. Ved ytterligere spørsmål, kontakt:

Matthew Spencer
Seksjon for Fysisk Prestasjonsevne (SFP)
matthew.spencer@nih.no

Markus Vagle
Seksjon for Fysisk Prestasjonsevne (SFP)
markusv@student.nih.no

Kapittel A: Utdypende forklaring om hva studien innebærer

Kriterier for deltagelse

- Kvinne
- Fotballspiller i toppserien
- Ikke inneha noen langvarig skade ved studiets oppstart

Fysisk testing

Studien innebærer noe fysisk testing. Med dette menes tester som skal måle den enkeltes prestasjonsnivå. Testene som gjennomføres er tester du som fotballspiller allerede er kjent med. Enkelte av testene som skal gjennomføres kan føles ubehagelig fordi de krever maksimal innsats og tidvis utmattelse. Siden testene er maksimale medfører de en viss risiko for skade.

Bakgrunnsinformasjon for studien

I fotball kreves det er «formtopp» gjennom hele sesongen. For å klare dette er vi avhengig av at utøverne er «riktig trent» og restituert til enhver kamp. Det stilles store krav til kartlegging, planlegging og overvåkning for å oppnå dette. Sammen kan belastningsovervåkning og utvikling av fysiske ressurser bidra til færre skader blant utøverne og heve deres prestasjonsnivå. Vi ser helt klart at det er nødvendig med mer kunnskap på disse områdene, særlig i kvinnefotballen. Mye av studiene som finnes er gjennomført på menn og det er helt klart ulike forutsetninger og tilpasninger for kvinner enn menn. Studien vil tilføre området verdifull informasjon om belastningsovervåkning og sammenhengen mellom ulike verktøy som brukes for å måle dette. Den kan bidra til å danne et grunnlag for retningslinjer i forbindelse med planlegging og tilrettelegging av trening. Samt tilføre verdifull informasjon om utvikling av fysiske ressurser i kvinnefotball og sammenligningen av de to ulike tilnærmingene til treningen.

Tidsskjema

Hva	Når	Kommentar
Tilvenning	Høst 2013	NMF baseline
Pre-test; H, S, RS, Yo-yo	Uke 48-49	
Start prosjekt I og II	Uke 50	Trening og bel.overvåkning
Post-test	Uke 8-9	
Innlevering av studie	30. Mai	

Kompensasjon for utgifter

Det kan gis kompensasjon for reiseutgifter i forbindelse med reiser til og fra Norges Idrettshøgskoles laboratorium mot kvittering.

Kapittel B: Informasjon om dine rettigheter

Personvern
Opplysninger som registreres om deg er:
Personsummer, alder, høyde, vekt, resultater fra samtlige tester og ultralydmålinger, loggføring av styrketrening, belastning gjennom sRPE, dagsform osv. gjennom Pre Wellness, og prestasjonsrating.

Opplysningene vil kun være tilgjengelige for de involverte i studien. Deler av opplysningene som resultater fra felt- styrke- og hopptestene vil også være tilgjengelig for samtlige i trenerapparatet i ditt lag. Det vil ikke være mulig å identifisere deg som person gjennom materialet som blir frigjort for andre enn de nevnte.

Norges idrettshøgskole ved administrerende direktør er databehandlingsansvarlig.

Utlevering av resultater og opplysninger til andre
Hvis du sier ja til å delta i studien, gir du også ditt samtykke til at prøver og avidentifiserte opplysninger utleveres til samarbeidende forskere, Matthew Spencer, Torstein Dalen, Truls Raastad, Håvard Wiig, samt andre i trenerapparatet rundt ditt lag.

Rett til innsyn og sletting av opplysninger om deg og sletting av prøver
Hvis du sier ja til å delta i studien, har du rett til å få innsyn i hvilke opplysninger som er registrert om deg. Du har videre rett til å få korrigert eventuelle feil i de opplysningene vi har registrert. Dersom du trekker deg fra studien, kan du kreve å få slettet innsamlede prøver og opplysninger, med mindre opplysningene allerede er inngått i analyser, er brukt i vitenskapelige publikasjoner, eller er innsamlet i forbindelse med legemiddelutprøving.

Økonomi
Studien er en masterstudie ved NIH uten noen form for økonomisk sponsing av tredjepart. Forskeren er ansatt og mottar kompensasjon fra klubben for arbeidet med laget, men kan forsikre deg om at dette ikke på noen måte skal påvirke resultatene fra studien og publiseringsprosessen.

Forsikring
Deltaker i prosjektet er forsikret dersom det skulle oppstå skade eller komplikasjoner som følge av deltakelse i forskningsprosjektet. NIH er en statlig institusjon og er således selvassurandør. Dette innebærer at det er NIH som dekker en eventuell erstatning og ikke et forsikringsselskap.

Informasjon om utfallet av studien
Studien vil bli publisert som en masteroppgave ved Norges Idrettshøgskole (NIH). Den vil være tilgjengelig via NIHs bibliotek og på nett gjennom NIHs open access-arkiv «Brage».

Resultatene fra studien kan også offentliggjøres i internasjonale, fagfellevurderte, tidsskrift. Du vil få tilsendt artiklene om du ønsker det.

Skjema for samtykke til deltakelse i forskningsprosjekt - Voksne over 16 år			
Prosjekttittel Fysisk trening og belastningsovervåkning i fotball			Prosjektnummer
Prosjektleders navn Matthew Spencer (veileder) Markus Vagle (student)		Seksjon Seksjon for Fysisk Prestasjonsevne (SFP)	
Det er frivillig å delta i studien. Dersom du ønsker å delta, undertegner du denne samtykkeerklæringen. Om du nå sier ja til å delta, kan du senere når som helst og uten å oppgi noen grunn, trekke tilbake ditt samtykke uten at det påvirker din øvrige behandling. Dersom du senere ønsker å trekke deg eller har spørsmål til studien, kan du kontakte prosjektleder.			
Jeg er villig til å delta i forskningsprosjektet:			
Navn med blokkbokstaver		Fødselsnummer (11 siffer)	
Dato	Underskrift		
Fylles ut av representant for forskningsprosjektet			
Jeg bekrefter å ha gitt informasjon om forskningsprosjektet:			
Dato	Underskrift		Brukerkode (4-tegnskode)
Eventuelle kommentarer:			

Appendix VII – Overview of completed test by each subject

Overview of each test completed both pre and post by which subjects. “X” = test completed; “-“ = test not performed.

Group	Subject no.	Tests										Sum of tests each subject
		Sprint			Jump	Strength			Endurance	Muscle architecture	Training load	
		10-m	30-m	RS	CMJ	Squat	Bench	Pulld.	Yoyo IR1	UL	sRPE	
MAX (n=5)	112	x	x	x	x	x	x	x	-	x	x	9
	116	x	x	x	x	x	x	x	x	x	x	10
	121	x	x	x	x	-	-	-	-	x	x	6
	126	x	x	x	x	x	x	x	x	x	x	10
	127	x	x	x	x	x	x	x	-	-	x	8
PLY (n=6)	104	x	x	x	x	x	x	x	x	x	x	10
	108	x	x	x	x	x	x	x	x	x	x	10
	110	x	x	x	x	x	x	x	x	x	x	10
	113	x	x	x	x	x	x	x	x	x	-	9
	122	x	x	x	x	x	x	x	x	-	x	9
	124	x	x	x	x	x	x	x	x	x	x	10
n in test		11	11	11	11	10	10	10	8	9	10	

MAX = maximum strength training group; PLY = plyometric strength training group; CMJ = countermovement jump; Bench = bench press; Pulld. = pull down; Yoyo IR1 = yoyo intermittent recovery level 1; UL = ultrasound measurements; sRPE = session rate of perceived exertion