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Effects of technique supervision during repeated sprint training in high level junior soccer players

Abstract

Background and purpose: Although sprinting skills are considered important in soccer, several aspects regarding sprint conditioning of players remain unclear in research literature. No studies have so far investigated the effect of direct supervision during repeated sprint training (RST) in soccer players. Moreover, the vast majority of studies recommend that sprinting velocity should be kept on a maximal level during training. The aim of the present study is two-fold: 1) to compare the effects of directly supervised RST versus unsupervised RST on maximal sprint performance and repeated sprint ability (RSA) in high level young soccer players, and 2) to investigate the effects of training at 90% sprint velocity performed off-season on maximal sprint performance and RSA.

Methods: 38 well-trained male soccer players (17±1 years, 71±7 kg, 181±6 cm) were recruited and randomized to either a supervised training group (90SUP, $n = 14$), an unsupervised training group (90UNSUP, $n = 14$) or a control group (CON, $n = 10$). The two training groups performed a weekly RST session in addition to their regular soccer training sessions. The RST consisted of 30x20-m sprints at 90% of maximal sprinting velocity with start each 60 s, and two sprint training experts supervised the 90SUP group during the intervention period. Results from maximal sprint, repeated sprints, countermovement jump (CMJ) and Yo-Yo intermittent recovery test 1 (Yo-Yo IR1) were compared before and after the intervention period.

Results: 90SUP improved CMJ when compared to CON. No other significant changes were observed in physical performance when compared to CON. Effect sizes were either trivial or small for all performance parameters when compared to CON.

Conclusion: Based on the results in the study, it cannot be recommended that young high level soccer players perform the present training regimes under otherwise identical conditions. Greater loads of training are probably required, and it seems essential to diagnose each individual and develop training interventions that target their key physiological and technical weaknesses.

Acknowledgements

Contents

1.   Introduction

Soccer is one of the most popular sports in the world. A wide range of tactical and technical skills are needed to become a successful soccer player (Bradley et al., 2013; Reilly, Bangsbo, & Franks, 2000). However, physical skills must also be well developed (Stølen, Chamari, Castagna, & Wisløff, 2005; Svensson & Drust, 2005), and the importance of sprinting performance is particularly emphasized to perform at international level (Haugen, Tønnessen, Hisdal, & Seiler, 2014). During the last decade, professional soccer players have improved their sprinting performance, while their aerobic capacity has plateaued or decreased slightly (Haugen, Tønnessen, Hem, Leirstein, & Seiler, 2014; Haugen, Tønnessen, & Seiler, 2013; Tønnessen, Hem, Leirstein, Haugen, & Seiler, 2013).

Several aspects concerning the development of sprinting performance in soccer remain unclear, among others intensity (Haugen, Tønnessen, Hisdal, & Seiler, 2014). Most sprint training interventions for soccer players recommend that sprinting velocity should be kept on a maximal level during training (Haugen, Tønnessen, Hisdal, et al., 2014). However, several studies regarding endurance and strength training reveal that larger doses of training at sub-maximal intensity stimulates physiological adaptation more effectively compared to smaller doses with maximal efforts (Kraemer et al., 2002; Seiler, Jøranson, Olesen, & Hetlelid, 2013). Anecdotal evidence shows that international sprinters perform sprint training at intensity as low as 90% (Vittori, 1996; and unpublished training diaries at the Norwegian Olympic Sports Center). Performing greater loads of repeated sprint training (RST) at sub-maximal velocity may enhance repeated sprint ability (RSA) more effectively than training at maximal velocity and perhaps reduce the risk of hamstrings injuries. Sprinting is the main mechanism associated with hamstring injuries (Ekstrand, Hägglund, & Waldén, 2011), and such injuries account for 10-20% of all acute injuries in soccer (Ekstrand et al., 2011; Junge & Dvorak, 2004; Waldén, Hägglund, & Ekstrand, 2005a; Waldén, Hägglund, & Ekstrand, 2005b). Recently, Haugen et al. found that repeated 20-m sprints at 90% intensity did not enhance sprint performance in soccer season (Haugen, Tønnessen, Leirstein, Hem, & Seiler, 2014). The authors suggested that such training should be performed at other times of the season to avoid training-related constraints due to the high volume of overall soccer conditioning.

Repetition is the mother of learning (Schmidt & Wrisberg, 2008), and there is reason to assume that a high number of repetitions at sub-maximal intensity during technical supervised training is required for stimulating motor adaptations. The importance of feedback from expert coaches during practice is well-known in motor skill learning, and performance enhancements may happen immediately in such settings (Schmidt & Wrisberg, 2008). Several studies have concluded that the presence of a training expert was beneficial for maximal strength development over time (Coutts, Murphy, & Dascombe, 2004; Enoksen, Staxrud, Tønnessen, & Shalfawi, 2013; Mazzetti et al., 2000). To the author's knowledge, no studies have so far investigated the effect of direct supervision during RST in soccer players.

1.1   Aims and hypotheses of the study

The aim of the present study is two-fold: 1) to compare the effects of directly supervised sprint training versus unsupervised training on maximal sprint performance and RSA in high level young soccer players, and 2) to investigate the effects of training at 90% sprint velocity performed off-season on maximal sprint performance and RSA.

It was hypothesized that 1) directly supervised training would enhance maximal sprint performance and RSA better than unsupervised training, and 2) a relatively large repetition load of sprints at 90% of maximal sprint velocity performed off-season would improve RSA.

2.   Theory

2.1   The importance of sprinting skills in soccer

Elite players typically cover a total distance of 9-12 km during a game, and the mean distance covered at very high-intensity (>19.8 km·h^{-1}) is approximately 10% of the total distance covered (Burgess, Naughton, & Norton, 2006; Di Salvo et al., 2007; Rampinini, Bishop, Marcora, Ferrari Bravo, Sassi & Impellizzeri, 2007; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007; Rienzi, Drust, Reilly, Carter, & Martin, 2000; Vigne, Gaudino, Rogowski, Alloatti, & Hautier, 2010). The movement is intermittent, and mean recovery time between very high-intensity running bouts are reported to be 72 s during the first 15 min and 83 s during the last 15 min of English FA Premier League soccer games (Bradley et al., 2009).

Mohr, Krustrup, & Bangsbo (2003) reported that international top-class players perform approximately 220 runs at high velocity (18-30 km·h^{-1}) during a game. Bradley et al. (2009) quantified 285 very high-intensity runs on average, including 127 sprints (>25.1 km · h^{-1}. Several studies using time-motion analysis have shown that sprinting accounts for 1-10% of the total distance covered (1-3% of effective playing time) (Bradley et al., 2009; Buchheit, Mendez-Villanueva, Simpson, & Bourdon, 2010; Vigne et al., 2010). The varying estimates reported are probably explained by different definitions used to define what velocity should be considered very high-intensity running and sprinting, respectively. This uncertainty makes it difficult to compare different studies.

Mean duration per sprint in matches is between 2 and 4 s, and the vast majority of sprint displacements are shorter than 20 m (Bangsbo et al., 1991; Burgess et al., 2006; Vigne et al., 2010). Peak sprint velocity values among soccer players are 31-32 km·h^{-1} (Rampinini, Coutts, et al., 2007; Rampinini, Bishop, et al., 2007). Straight sprinting is the most frequent action in goal situations in professional soccer (Faude, Koch, & Meyer, 2012). Haugen et al. (2013) concluded that mean sprinting velocity distinguishes soccer players from different performance levels. Significant reductions in sprinting and high-intensity running actions have been observed towards the end of elite soccer matches in men (Mohr et al., 2003) and women (Krustrup, Mohr, Ellingsgaard, & Bangsbo, 2005). Also for Premier League soccer players, the distance covered by high-intensity running was lower in the last 15 min of each half, compared to the first

15 min of each half (Bradley et al., 2009). This may indicate fatigue. In summary, sprinting skills are important in elite soccer, particularly in crucial moments. Winning a sprint duel or not can be the difference between creating and avoiding goal scoring situations.

2.2 Sprint definitions

In athletics, the 100-m sprint has traditionally been categorized into acceleration, maximum velocity and finally a deceleration phase (Mero, Komi, & Gregor, 1992; Ross, Leveritt, & Riek, 2001). The acceleration phase in a sprint is approximately 30 m (Enoksen & Tønnessen, 2007), and this ability is therefore important for team sport athletes. Well-developed peak velocity is also required in soccer (Haugen et al., 2013; Rampinini et al., 2007). Some authors use the terms "sprint" or "prolonged sprints" to describe maximal sprint running lasting 30 s or more (Ball, Burrows, & Sargeant, 1999; Bogdanis, Nevill, Boobis, & Lakomy, 1996; Bogdanis, Nevill, Boobis, Lakomy, & Nevill, 1995), but this is considered less team sport specific (Girard, Mendez-Villanueva, & Bishop, 2011). In their review, Girard et al. (2011) limited the definition of "sprint" ability to be a short effort lasting ≤ 10 seconds, where maximal running velocity can nearly be maintained until the end of the exercise.

Several physical characteristics are important in soccer, not only the ability to run fast, but also the ability to run fast several times with short brakes. Sprinting skills in soccer has commonly been classified as linear sprint, agility and RSA (Haugen, Tønnessen, Hisdal, et al., 2014), and RSA has particularly been focused in research literature the last two decades. The ability to repeatedly produce maximal or near maximal efforts, interspersed with short recovery intervals (consisting of low- to moderate-intensity activity) over an extended period of time, has been classified as RSA (Dawson, 2012; Girard, Mendez-Villanueva, et al., 2011; Glaister, 2005; Spencer, Bishop, Dawson, & Goodman, 2005). A well-developed RSA has often been associated with a low fatigue index (low decrease in performance from the first sprint to the last). However, well-developed RSA is better explained by having a high average sprint performance during repeated sprints, also termed repeated sprint performance (Bishop, Girard, & Mendez-Villanueva, 2011).

2.3 Decisive factors for repeated sprint ability (RSA)

Numerous test protocols have been used to assess RSA in elite or professional soccer players. The vast majority of tests consists of 15-40 m sprints, 3-15 repetitions and 15-30 s recovery periods between each sprint (Haugen, Tønnessen, Hisdal, et al., 2014). Two measures have been used in order to evaluate RSA: total time and/or deterioration in performance. Total time (or mean sprint time) have been used as performance indices, and results from RSA tests differentiate professionals from amateur players (Aziz, Mukherjee, Chia, & Teh, 2007; Impellizzeri, Rampinini, Castagna, Bishop, et al., 2008; Rampinini, Bishop, et al., 2007; Rampinini et al., 2009). Deterioration in performance, calculated as sprint decrement, has generally been used to quantify the ability to resist fatigue (Glaister, 2008).

According to Bishop et al. (2011), RSA is mainly determined by initial sprint performance and the ability to recover between sprints. Fatigue during repeated sprinting can be caused by a variety of factors; decrease in muscle excitability, limitations in energy supply (phosphocreatine, anaerobic glycolysis and oxidative metabolism), and metabolite accumulation (Girard, Mendez-Villanueva, et al., 2011). Neural factors may also influence RSA, leading to a reduced neural drive and modification of muscle recruitment strategies (Ross et al., 2001). Figure 1 shows the variety of factors influencing RSA, suggested by Bishop et al. (2011). Figure 1 must be assessed critically, as some of the factors interact more with each other than shown in the figure: Power and ATP-supply will not only have an effect on stride length, but also on stride frequency, and neural factors may be critical for both fatigue resistance and initial sprint performance (Matsuura, Arimitsu, Kimura, Yunoki, & Yano, 2007; Mendez-Villanueva, Hamer, & Bishop, 2007, 2008; Racinais et al., 2007).
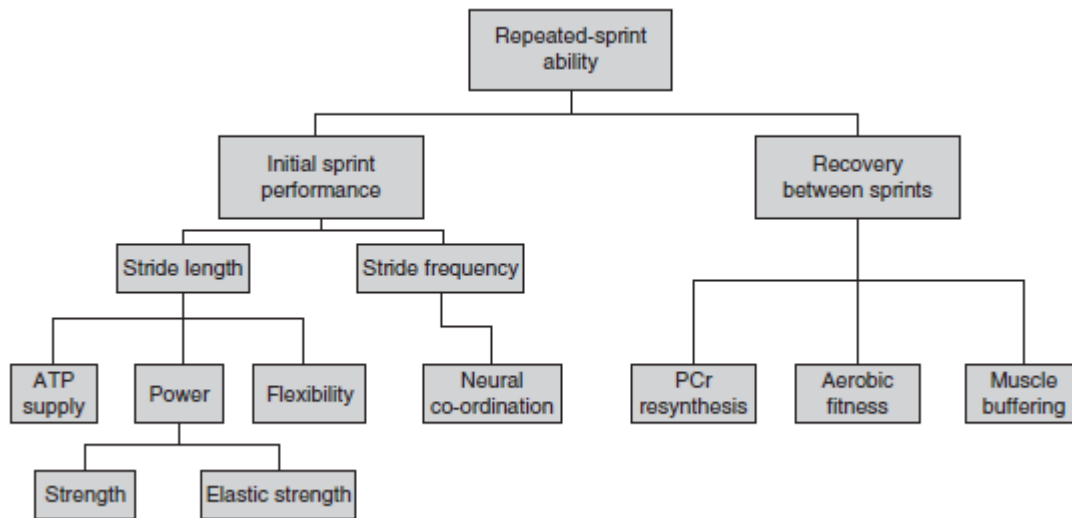
Figure 1: A summary of factors which should be targeted to improve repeated sprint ability. From Bishop et al. (2011) (Figure 4, page 753).

Repeated sprint tests performed after elite soccer games have demonstrated that RSA deteriorates substantially with fatigue development (Krustrup et al., 2006; Mohr, Krustrup, Nybo, Nielsen, & Bangsbo, 2004). The best training methods to improve RSA has not yet been determined (Bishop et al., 2011; Haugen, Tønnessen, Hisdal, et al., 2014), but a reasonable goal will be to improve both the initial sprinting velocity and the underlying factors responsible for fatigue during repeated sprints (Bishop et al., 2011).

2.3.1   Initial sprint performance

Sprint velocity is determined by the laws of motion, and has traditionally been thought to be largely dependent on genetic factors, with only relatively small improvements occurring with training (Haugen, Tønnessen, Hisdal, et al., 2014; Ross et al., 2001). According to the laws of motion, three types of work must be carried out during sprint running; work against gravity, work in order to accelerate upper and lower limbs relative to the body, and work in order to accelerate the body's center of mass horizontally. An increase in running velocity can only be reached by upsetting the balance between propulsive and braking impulses so that the athlete gains a temporary surplus of propulsive impulse, until balance is reestablished at a higher velocity. This can only be achieved by refining the technique and/or develop physiological properties.

Stride length and stride frequency

Running velocity is determined by the product of stride length (SL) and stride frequency (SF) (Mero et al., 1992). An increase in either SL or SF will result in an improvement in running velocity, as long as the other factor does not undergo a proportionately similar or larger decrease (Hunter, Marshall, & McNair, 2004). SF is considered a main limiting performance factor in elite sprinters, while SL is considered to be a more limiting factor in sprint athletes at a lower level (Haugen, Tønnessen, & Seiler, 2014; Mero et al., 1992; Mero & Komi, 1986). The maximal sprint velocity of an athlete corresponds to an optimal SL/SF ratio (Salo, Bezodis, Batterham, & Kerwin, 2011). A different ratio would lead to a lower sprint velocity, referred to as "negative interaction" (Hunter et al., 2004). SL and SF are decided by several factors: range of movement (flexibility), peak power, anthropometric characteristics, running technique (neural coordination) and fatigue (Haugen, Tønnessen, & Seiler, 2014; Ross et al., 2001). Differences in running technique have been observed in elite and non-elite sprinters (Ross et al., 2001), and sprint technique training in soccer players may enhance their sprinting performance. Sprinting is a complex movement task, and a multitude of different muscles must be activated at the appropriate times and with high intensities (Ross et al., 2001).

Sprinting technique

It is important to have optimal upper body angle relative to the ground during the initial steps in order to create high horizontal propulsive forces through effective utilization of hip and knee extensors (di Prampero et al., 2005; Harland & Steele, 1997). With increasing sprint velocity, the horizontal breaking forces during ground contact in each stride increases substantially, and it is important that the breaking forces are minimized (Harland & Steele, 1997). In order to minimize degeneration of horizontal propulsive forces it is important to produce a stiff rebound during ground contact (Chelly & Denis, 2001; Girard, Micallef, & Millet, 2011; Kuitunen, Komi, & Kyröläinen, 2002). An increase in maximum sprint velocity can only be accomplished by making the movement pattern (technique) more efficient and/or increase the power production.

Power

In order to run fast, it is very important that the muscles are able to produce sufficient power. When sprinting in soccer, the player must produce as high peak power as

possible (rate of force development, RFD) and utilize this power to create an efficient and fast movement in the right (preferable) direction. A central factor for power production is muscle strength. Increase in force production in muscles important for sprinting may improve acceleration and running velocity in soccer (Cometti, Maffiuletti, Pousson, Chatard, & Maffulli, 2001). In order to increase the muscle's ability to develop great force, the muscle fibers' cross-sectional area should be increased (Rønnestad & Raastad, 2010; Ross et al., 2001; Ross & Leveritt, 2001).

High power output in sprint requires that the muscles must produce force at a high contraction speed (Rønnestad & Raastad, 2010). High peak power production depends on how fast the muscles are able to produce force, mainly depending on muscle fiber type. There are three types of skeletal muscle fibers in the human body: I (slow twitch oxidative), IIa (fast twitch oxidative-glycolytic) and IIx (fast twitch glycolytic, also described as IIb) (Greising & Gransee, 2012). Animal and human studies indicate that type IIx exhibits the highest power outputs. Type IIa shows superior intermediate power output, while type I exhibits the lowest power outputs (Bottinelli, Pellegrino, Canepari, Rossi, & Reggiani, 1999; Bottinelli, Schiaffino, & Reggiani, 1991). Sprinters have a larger percentage of type II fibers than other athletes (Costill et al., 1976), and sprint performance has been strongly correlated with the percentage of type II fibers (Dawson et al., 1998; Denis et al., 1992; Esbjörnsson, Sylven, Holm, & Janson, 1993). However, for soccer players it is important to resist fatigue during repeated sprints, and sprint training resulting in a transition towards IIa (I→ IIa ← IIx) may be preferred (Ross & Leveritt, 2001).

Neuromuscular factors
A considerable level of neural activation is needed during repeated sprinting (Ross et al., 2001). The ability to voluntarily fully activate the musculature during sprinting, and to maintain rapid firing and recruitment of the muscles may be critical for fatigue resistance (Matsuura et al., 2007; Mendez-Villanueva et al., 2007, 2008; Racinais et al., 2007). Muscle coordination and/or decreased recruitment of fast twitch motor units can also limit sprint performance (Billaut et al., 2006; Billaut, Basset & Falgairette, 2005).

After intense dynamic contractions, marked ionic disturbances have been observed in skeletal muscles (Clausen, Nielsen, Harrison, Flatman, & Overgaard, 1998; Fraser et al.,

2002). This happens because the Na^+/K^+ pump is unable to reaccumulate the K^+ efflux out of the muscle cells, leading to at least a doubling of muscle extracellular K^+ concentration ($[K^+]$) (Juel, Pilegaard, Nielsen, & Bangsbo, 2000). This will impair cell membrane excitability and depress force development. These studies are *in vitro* studies, so it is still unclear if these ionic disturbances contribute to fatigue during sprint conditioning (Girard, Mendez-Villanueva, et al., 2011).

2.3.2 Recovery between sprints

Phosphocreatine stores

Phosphocreatine is the most immediate reserve for the rephosphorylation of adenosine triphosphate (ATP) (Girard, Mendez-Villanueva, et al., 2011). Therefore, phosphocreatine (PCr) is particularly important during repeated sprinting, where a high rate of ATP utilization and resynthesis is needed. After a 6-s sprint, the PCr stores can be reduced to around 35-55% of resting levels (Dawson et al., 1997; Gaitanos, Williams, Boobis, & Brooks, 1993). The complete recovery of PCr stores can take more than 5 min (Bogdanis et al., 1995; Tomlin & Wenger, 2001). There has also been observed a greater PCr reduction in fast-twitch fibers than in slow twitch fibers (Karatzaferi, Haan, Mechelen, & Sargeant, 2001; Söderlund & Hultman, 1991). During RST, fast-twitch fibers produce most of the power (Girard, Mendez-Villanueva, et al., 2011), and PCr deficit may therefore be related to the failure to replicate performance when sprints are repeated (Sahlin & Ren, 1989). The ability to resynthesize PCr stores is probably an important determinant of the ability to reproduce high sprint performance (Bogdanis et al., 1996, 1995).

Muscle glycogen levels

The fatigue observed towards the end of soccer games may be related to a decrease in muscle glycogen levels (Bangsbo, Mohr, & Krustrup, 2006). There has also been observed an increase in blood free-fatty acids during a game, but this probably occurs to compensate for the lower muscle glycogen levels (Bangsbo et al., 2006). A study by Balsom, Wood, Olsson, & Ekblom (1999) showed that a high-carbohydrate diet leads to more high-intensity running during a soccer game and higher muscle glycogen levels when compared to a low-carbohydrate diet. This suggests that muscle glycogen levels are important for RSA.

Anaerobic glycolysis

Anaerobic glycolysis contributes to the energy demand during RST, but mostly in the first sprints. During a 6-s sprint, anaerobic glycolysis supplies for about 40% of the total energy (Gaitanos et al., 1993). But if the sprints are repeated, the glycolysis will probably be inhibited, and ATP resynthesis will mainly be derived from PCr degradation and oxidative metabolism (Gaitanos et al., 1993). It has been discussed if increasing the maximal anaerobic glycolytic and glycogenolytic rate will improve RSA (Girard, Mendez-Villanueva, et al., 2011). Training that enhances the ability to supply ATP from anaerobic glycolysis would be negative for RSA, because individuals with the greatest glycolytic rate during the first sprint have shown the greatest decrements in power output during repeated sprints (Bishop, Edge, & Goodman, 2004). However, Bogdanis et al. (1995) observed that subjects with greater glycogenolytic rate have greater initial sprint performance. There is a strong correlation between initial sprint performance and both total sprint performance and final sprint performance (Bishop, Lawrence, & Spencer, 2003; Bishop et al., 2004; Haugen, Tønnessen, Leirstein, et al., 2014).

Aerobic metabolism

Oxidative phosphorylation contributes little to the total energy expenditure during a single sprint ($< 10\%$) (Parolin et al., 1999), but the contribution increases as sprints are repeated (Balsom, Gaitanos, Ekblom, & Sjödin, 1994; Gaitanos et al., 1993). Aerobic metabolism may contribute up to 40% of the total energy supply during the last repetitions of a repeated sprint session (Girard, Mendez-Villanueva, et al., 2011). During a soccer match, approximately 90% of the total energy expenditure is provided by the aerobic system (Bangsbo & Iaia, 2013). In order to reduce fatigue, top level soccer players should therefore have sufficient aerobic capacity (VO_{2max}). The importance of VO_{2max} has been heavily debated (Girard, Mendez-Villanueva, et al., 2011; Stølen et al., 2005; Tønnessen et al., 2013). Tønnessen et al. (2013) claim that VO_{2max} values of approximately 62-64 mL $\cdot$ kg^{-1} $\cdot$ min^{-1} fulfill the demands for aerobic capacity in men's professional soccer, and that VO_{2max} is not a clearly distinguishing variable separating players of different standards. Beyond this baseline, other physical qualities such as linear sprinting velocity become more important. Shalfawi, Enoksen & Tønnessen (2014) reported a lack of significant relationships between percentage decrement score from the RSA test and measures of aerobic fitness. This supports the

suggestion that a certain level of aerobic capacity fulfill the demands for recovery in soccer and that a further increase of aerobic capacity will not enhance RSA (Shalfawi et al., 2014).

Endurance trained athletes have smaller percentage decrement in power during repeated sprinting when compared to athletes performing repeated sprint-type sports (Hamilton, Nevill, Brooks, & Williams, 1991). However, the athletes from repeated sprint-typed sports tended to produce a higher peak power output and higher peak velocity. RSA seems to be more related to short sprint qualities than endurance fitness (Haugen, Tønnessen, Leirstein, et al., 2014; Pyne, Saunders, Montgomery, Hewitt, & Sheehan, 2008). It is worth emphasizing that fatigue resistance does not ensure successful repeated sprint performance. A long-distance runner will never reach the mean sprinting velocity compared to a fast soccer player during repeated sprints, despite minimal fatigue occurrence. Thus, it appears more important to develop an "optimal" rather than maximal aerobic capacity.

Muscle buffering (H+ accumulation)
A large increase in muscle and blood hydrogen ion (H^+) accumulation has been observed during repeated sprints (Bishop et al., 2003; Bishop & Edge, 2006; Ratel, Williams, Oliver, & Armstrong, 2006; Spencer, Dawson, Goodman, Dascombe, & Bishop, 2008), and this may have a negative effect on sprinting performance via adverse effects on the contractile system and/or through inhibition of ATP derived from glycolysis, possibly via negative effects on phosphofructokinase and glycogen phosphorylase (Girard, Mendez-Villanueva, et al., 2011; Spriet, Lindinger, McKelvie, Heigenhauser, & Jones, 1989). This theory is supported by observed correlations between 1) sprint decrement and muscle buffer capacity, and 2) sprint decrement and changes in blood pH (Bishop et al., 2003; Bishop et al., 2004; Bishop & Edge, 2006). However, the impact of hydrogen H^+ accumulation on fatigue during repeated sprints remain unclear (Girard, Mendez-Villanueva, et al., 2011). H^+ accumulation as a direct cause of fatigue has been challenged by several observations: 1) the recovery time of power/force following maximal/intense work is much faster than the recovery of pH; 2) high power outputs have been obtained under conditions with high H^+ concentrations; and 3) ingestion of sodium bicarbonate (known to increase extra-cellular buffer capacity) has several times shown no effect on RSA (Gaitanos, Nevill, Brooks, &

Williams, 1991; Matsuura et al., 2007). Further research is therefore needed to clarify the effects of H^+ accumulation on RSA.

2.4   Methods to improve repeated sprint ability in soccer

Several different training methods have been used to improve RSA in soccer. The goal of repeated sprint training (RST) is to improve the limiting factors previously mentioned. Training methods which effectively reduce the influence of these limiting factors and improve maximal sprinting performance should also improve RSA (Girard, Mendez-Villanueva, et al., 2011).

Specificity is an important principle of training, and one method to improve RSA is to perform specific RST. RST is characterized by short-duration sprints (≤ 10 s) and ≤ 60 s recovery periods between each sprint (Girard, Mendez-Villanueva, et al., 2011). RST has shown positive training effects in soccer players' RSA, power, and aerobic capacity (Dupont, Akakpo, & Berthoin, 2004; Ferrari Bravo et al., 2008; Tønnessen, Shalfawi, Haugen, & Enoksen, 2011). Players with well-developed aerobic capacity should prioritize initial sprint enhancement, while fast players should strive to maintain their sprint velocity during repeated sprints (Haugen, Tønnessen, Hisdal, et al., 2014).

2.4.1   Training to improve initial sprint performance

It remains unclear what type of training is most effective for development of sprint ability (Haugen, Tønnessen, Hisdal, et al., 2014), but the importance of sufficient recovery between repetitions is probably underestimated (Ross & Leveritt, 2001). One obvious method to improve sprint performance in soccer is specific sprint training (Haugen, Tønnessen, Hisdal, et al., 2014). Sprinting ≤ 30 m improves short sprint (acceleration) performance (Spinks, Murphy, Spinks, & Lockie, 2007), while 40-m sprints enhance peak velocity to a greater extent than acceleration capabilities (Tønnessen et al., 2011). Longer sprints (≈ 30 s) have limited or no effect on neither acceleration nor maximal sprint velocity (Gunnarsson, Christensen, Holse, Christiansen, & Bangsbo, 2012).

Spinks et al. (2007) indicated that resisted sprint training (i.e. towing or weight sleds) was more effective than sprinting under normal conditions to improve acceleration capabilities. Harrison & Bourke (2009) reported that rugby players improved short

sprint capabilities after six weeks of resisted sprint training. However, resisted sprint training may have negative effect on acceleration kinematics (Lockie, Murphy, & Spinks, 2003), and light resistance loading is preferable. Spinks et al. (2007) proposed that a sled load of approximately 10% of body mass is optimal, as no acceleration kinematics are negatively affected, while still stimulating the specific recruitment of the hip and knee extensors, resulting in more power in the horizontal direction.

Plyometric training interventions have showed varying effects on soccer players' sprint performance (Delecluse et al., 1995; Impellizzeri, Rampinini, Castagna, Martino, et al., 2008; Sedano, Matheu, Redondo, & Cuadrado, 2011; Thomas, French, & Hayes, 2009), and is perhaps not an optimal method to improve initial sprint performance.

Some studies have documented that resistance training can be beneficial for initial sprint performance (Buchheit, Mendez-Villanueva, Delhomel, Brughelli, & Ahmaidi, 2010; Delecluse, 1997; Delecluse et al., 1995; Newman, Tarpennig, & Marino, 2004). However, not all studies confirm that strength training improves sprinting abilities (Jullien et al., 2008; López-Segovia, Palao Andrès, & Gonzàlez-Badillo, 2010; Loturco, Ugrinowitsch, Tricoli, Pivetti, & Roschel, 2013). Bogdanis & Papaspyrou (2011) reported improved RSA in professional soccer players after 6 weeks of strength training, consisting of half-squats three times per week with 4 x 5 repetitions at 90% of 1RM. The other training group in this study performed 4 x 12 repetitions at 70% of 1RM, and did not improve as much as the 90% of 1RM group. However, this study did not include a control group. Furthermore, the repeated sprint test was conducted on a cycling ergometer, such that the results should be interpreted with caution. A strong relationship between single sprint performance and maximal strength has been reported in team-sport athletes (Newman et al., 2004). Wisløff, Castagna, Helgerud, Jones, & Hoff (2004) also observed a strong relationship between short sprint performance and 1RM half-squat. However, Marcovic (2007) reported a poor relationship between strength and power qualities and agility performance. Little & Williams (2005) and Vescovi & McGuigan (2008) concluded that straight-sprint, agility, and vertical-jump capabilities are independent locomotor skills. Therefore, an increase in muscle mass is not unconditionally beneficial for overall soccer performance.

2.4.2 Training the ability to recover between sprints

Different methods have been used to improve the ability to recover between repetitions during repeated sprinting. RST is a popular method to improve this ability, but there are many different ways to perform RST. Mitochondrial capacity is of significant importance for the ability to recover between sprints, and RST performed with short recovery periods may improve aerobic capacity (Bishop et al., 2011).

It remains unclear whether RST improve RSA more than interval training (Bishop et al., 2011). A few studies have directly compared these two types of training. RST seems to produce greater improvements in best sprint time (Buchheit, Mendez-Villanueva, Quod, Quesnel, & Ahmaidi, 2010; Mohr et al., 2007) and mean sprint time (Buchheit, Mendez-Villanueva, Quod, et al., 2010; Ferrari Bravo et al., 2008; Mohr et al., 2007), when compared with interval training. Aerobic interval training, however, may be more effective than RST to improve the ability to recover between sprints (Mohr et al., 2007). A study by Nakamura, Suzuki, Yasumatsu, & Akimoto (2012) indicated that aerobic endurance training was not favorable for acceleration ability. It seems difficult to achieve significant changes over short sprint distances, but based on the figures in Table 1 in Nakamura et al. (2012), a negative moderate effect size ($d = 1.0$) can be calculated. This means that aerobic endurance training has had a moderate negative effect on 5-m sprint time (moderate decrease in 5-m sprint performance) based on the effect magnitude scale developed by Hopkins, Marshall, Batterham, & Hanin (2009). For 10 and 20-m sprint times the negative effects were also moderate ($d = 0.7$ and 1.0, respectively). This leads to a difficult topic regarding RST; one type of training can improve some decisive factors for RSA, but at the same time inhibit other decisive factors for RSA.

Ferrari Bravo et al. (2008) observed that RST improved soccer-specific endurance (Yo-Yo Intermittent Recovery Test) to a greater extent than high-intensity aerobic interval training. Many repeated sprint tests use short recovery periods between sprints. In this way they simulate the most intensive game periods, leading to a possible overrating of the aerobic demands (Haugen, Tønnessen, Hisdal, et al., 2014). It has been suggested that it is more difficult to detect detrimental effects with short sprints (15 m) compared to longer sprints (30-40 m) (Balsom, Seger, Sjödin, & Ekblom, 1992). Thus, more soccer specific repeated sprint testing and training with longer recovery periods might be favorable.

3.   Methods

3.1   Experimental approach to the problem

In this randomized controlled trial, participants were randomly assigned to three different treatment conditions. A control group (CON) completed regular soccer training according to their teams` original training plans. Two training groups performed a weekly RST session in addition to their regular soccer training sessions at A) 90% of maximal sprinting velocity with direct supervision (90SUP) or B) 90% of maximal sprinting velocity without direct supervision (90UNSUP). The duration of the intervention period (performed in the off-season) was seven weeks. Results from maximal sprint, repeated sprints, countermovement jump (CMJ) and Yo-Yo intermittent recovery test 1 (Yo-Yo IR1) were compared before and after the intervention period.

3.2   Subjects

38 male soccer players, aged 15-19 years, volunteered to participate in the study. They were playing in the highest or second highest junior level (G19 Interkrets or G19 1st div) for four different clubs in Oslo, Norway. During the intervention period, the participants were requested to refrain from performing any other off-field physical training programs in terms of sprinting, strength and/or endurance. All subjects were free of injuries prior to preliminary testing. The intervention was conducted in accordance with the declaration of Helsinki. All participants provided written, voluntary consent before participation. Written parental consent was obtained for < 18 year old players.

To eliminate the influence of varying overall soccer conditioning, the participants were initially paired for clubs and then randomly assigned to one of three intervention conditions by a fellow student not involved in testing or training intervention. To be included in further analyses, the subjects in the two training groups were required to complete at least six out of seven training sessions during the intervention period, in addition to the sprint and CMJ tests. CON subjects were required to complete all sprint and CMJ tests.

One participant from 90UNSUP and two participants from 90SUP dropped out due to injuries sustained outside of the sprint training intervention. One player from 90SUP dropped out due to Achilles tendon issues, possibly associated with the sprint

intervention. One player from 90SUP was excluded because of insufficient training participation, and one player from CON dropped out due to lack of motivation. Thus, 32 out of 38 subjects completed the study with the following sample sizes: 90UNSUP = 13, 90SUP = 10 and CON = 9. Physical training characteristics of these subjects are presented group-wise in Table 1. Frequency and volume of games and training sessions were similar between the groups.

Table 1. Physical and training characteristics at inclusion.

Group	Age (yr)	BM (kg)	Height (cm)	Weekly training sessions	Games per week	Tot.vol (h/wk)
90UNSUP	17±1	72±6	183±5	4.5±2.4	0.4±1.0	7.0±3.5
90SUP	17±1	70±5	177±6*	4.4±1.6	0.4±0.9	6.8±2.9
CON	17±1	72±11	181±6	4.4±2.3	0.4±0.4	6.8±3.3

Values are mean ± SD. BM = Body mass, Tot.vol = Total training volume. Training values are based on self-reported weekly averages during the intervention period. There were no significant differences across the groups for any of the variables, except for height (* = 90UNSUP > 90SUP, p= 0.04).

3.3 Instruments

3.3.1 Force platform

CMJ tests were performed on an AMTI force platform (OR6-5-1, Watertown, USA). Jump height was determined by center-of-mass displacement calculated from force development and body mass. Force data were sampled at 1000 Hz for 5 seconds with a resolution of 0.1 N. The data were amplified (AMTI Model SGA6-3), digitized (DT 2801) and saved to dedicated computer software (Biojump, Norway). The force platform has been assessed for accuracy and reliability (Enoksen, Tønnessen, & Shalfawi, 2009), and the test-retest reliability did not show any marked systematic bias (0.4 %) for repeated measures. The limits of agreement indicated a negligible random error variation. Measurement error for CMJ with this force platform has been calculated to be ±1.0% (Enoksen et al., 2009).

3.3.2 Timing system

The dual-beam electronic timing system at the Norwegian Olympic Training Centre was used for sprint pre- and post-tests (NOC Timing System, Biomekanikk AS, Norway). The system contained a trigger, with photocells placed at the start (0.5 m after the start

line), and at 20 m. For simplicity, the distance was defined as 0-20 m, even though the distance between the photocells was 19.5 m. The photocells were mounted on separate tripods 1.10/1.30 m above the ground at the start and 1.30/1.50 m above ground level at 20 m, with the trigger criterion being the first occurrence of both beams being broken. The timing system has been recently assessed for accuracy and reliability (Haugen, Tønnessen, Svendsen, & Seiler, 2014), and dual-beamed timing is recommended for scientists and practitioners wishing to derive accurate and reliable sprint time results.

A single-beamed timing system was used to monitor sprint time during the training sessions (TC, Brower Timing Systems, Draper, UT, USA). This system has been shown to generate on average 0.02 s slower 0-20 m sprint times than the dual-beamed timing system, and the absolute time differences compared to dual-beamed timing gates ranged from -0.05 to 0.06 s (Haugen, Tønnessen, Svendsen, et al., 2014). This difference is most likely explained by swinging limbs and typical forward lean of the upper at the start.

3.3.3 Other equipment for the repeated sprint tests

Heart rate was measured continuously during the repeated sprint tests with Polar RS400 heart rate monitors (Kempele, Finland). A blood sample was acquired via finger stick to quantify the blood lactate concentration (BLa$^-$) immediately after the last sprint (Lactate Pro LT-1710, Arkay KDK, Kyoto, Japan). Lactate Pro LT-1710 has been concluded to be a simple and effective measurement device for taking blood lactate in a field or laboratory setting (Mc Naughton, Thompson, Philips, Backx, & Crickmore, 2002). However, they recommended caution against using Lactate Pro to compare data from other machines. A Sony HDR-HC9E video camera was used for video recordings during the repeated sprint tests.

3.3.4 Equipment for the Yo-Yo IR1

The Yo-Yo IR1 test was performed indoors on artificial turf at the Norwegian School of Sport Sciences (PULASTIC SP Combi, Gulv og Takteknikk AS, Norway). The audio file was played from a PC (Intel Core i7) connected to a JVC Powered Woofer CD-system (RV-NB51W). Twenty-six cones were used to mark eight test lanes. Heart rate was measured continuously during the sprint and Yo-Yo IR1 tests with Polar RS400 heart rate monitors (Kempele, Finland).

3.4 Procedures

Both the pre- and post-tests were conducted at the Norwegian Olympic Training Center and the Norwegian School of Sport Sciences on two separate days, with one day in between. Half of the participants tested on Monday and Wednesday, while the other half tested on Tuesday and Thursday. Regarding nutrition, hydration, sleep and physical activity, the participants were instructed to prepare as they would for a regular soccer match, including no high-intensity training the last two days before testing. They were also instructed to use identical footwear and kit for each of the tests. Test day 1 consisted of CMJ test and a 15x20-m repeated sprint test. Prior to testing, participants completed a 25 min standardized treadmill warm-up consisting of 10 min at 60-75% of maximum heart rate (HR_{max}), 3 sets of 4 exercise drills (high knees, back kick, sideway and backwards running) and finally 2-3 repetitions of 40-m runs with a progressive increase in velocity.

CMJ test: Immediately after warm up, each athlete was weighed on the force platform for system calibration before performing three trials of CMJ separated by 1 min recovery. The best result for each player was retained for analysis. To isolate leg extensor muscles and minimize technical elements, all jumps were performed with hands placed on the hips.

Repeated sprint test (RST): A 15x20-m repeated sprint test with start each 60 s was performed after the CMJ test. The test was performed with the athletes' regular running shoes on a dedicated indoor track with 8 mm Mondo FTS surface (Mondo, Conshohocken, USA). Best 20-m time was used to determine maximal sprint ability. Heart rate was measured continuously during the test. BLa⁻ was acquired via finger stick immediately after the last sprint.

All sprint tests were video captured from start to finish to assess the number of steps. The recordings were analyzed in Dartfish ProSuite, version 5.5 (Dartfish, Switzerland) to determine mean SL and stride frequency over the 20 m sprint distance. For precision, the digital ruler in the analyzer window was used to interpolate the last step across the finish line. For example; if the 12th and 13th ground contact occurred 0.8 m in front of and 1.2 m beyond the finish line, respectively, the recorded number of strides was registered as 12.4. Mean SL was calculated by dividing the distance by the number of

steps (in this case 20 m $\cdot$ 12.4^{-1} = 1.61 m). Mean stride frequency (SF) was calculated from mean velocity and mean SL.

Yo-Yo IR1 test: On test day two the athletes completed the Yo-Yo IR1 test indoor on artificial turf at the Norwegian School of Sport Sciences. Prior to the test, participants warmed up with 10 min easy jog at 60-75% of HR_{max}. Then they used the initial 60-90 s of the Yo-Yo IR1 test for specific warm up and as familiarization to the test. The test set-up and procedures were in accordance with the guidelines by Krustrup et al. (2003). The athletes were divided in consecutive groups such that maximum eight athletes were tested simultaneously. The test lanes were marked by cones with 20 m length and 2 m width. Another cone placed 5 m behind the start/finish line marked the area for active recovery. The same test leader was used for all participants. Heart rate monitors were used during the test for measuring heart rate and individual intensity.

All included participants (*n* = 32) conducted the tests on test day 1 (CMJ and repeated sprint test). Only 24 of the 32 participants included in the analyses conducted the pre- and post-test on test day 2 (Yo-Yo IR1). Several participants reported illness as the reason why they could not participate in the Yo-Yo IR1 post-test.

3.5   Intervention program

The training intervention took place from the end of October to the middle of December, corresponding to the off-season in the Norwegian soccer annual cycle. The two training groups performed a weekly sprint training session in addition to their regular soccer training program. All sprint training sessions were performed indoors (air temperature ~ 20$^{°}$C) on an 8 mm Mondo FTS surface (Mondo, Conshohocken, USA). The sessions were performed at the same time and day for each training group throughout the intervention period.

3.5.1   Intensity assessment

Participants in both 90SUP and 90UNSUP performed one weekly training session consisting of 30x20-m sprints at 90% of maximal sprinting velocity with start each 60 s. In a previous intervention accomplished in season, Haugen, Tønnessen, Leirstein et al. (2014) reported that weekly RST sessions consisting of 25x20-m sprints were not sufficient to enhance soccer-related sprinting skills. Since the present intervention was

performed off-season and the overall total soccer conditioning load was reduced, we decided to increase the stimulus to 30 sprints per session. This is about twice the amount of repetitions compared to previous repeated sprint interventions performed at maximal intensity (Mujika, Santisteban, & Castagna, 2009; Spinks et al., 2007). Within endurance training, elite athletes accumulate about twice as much duration when performing intervals at 90% of HR_{max} compared to ≥ 95 % of HR_{max} (Seiler et al., 2013).

In order to control perceived sprint training load used in the present study, session rated perceived exertion (RPE) was recorded for all athletes after the repeated sprints performed in pre-test and first training session. Written and verbal instructions regarding the use of RPE were provided in advance (Foster, 1998). Heart rate, BLa^-, SL and SF were also assessed in the first training session, in the same manner as previously described. These measures were compared to those obtained from the 15x20-m repeated-sprint pre-test. The results from this comparison are shown in Table 2.

Table 2: *Effort related variables in maximal (100%) and sub-maximal (90%) sprinting*

Sprint session	15x20m (100% intensity)	30x20m (90% intensity)
Session RPE	3.8 ±1.2	4.0 ± 1.1
HR_{peak} (beats· min^{-1})	170 ±10	141 ±10*
BLa^- ($mmol·L^{-1}$)	4.4 ±1.8	2.0 ±0.7*
SL (m)	1.55 ±0.08	1.56 ±0.09
SF (strides/s)	4.36 ±0.18	3.87 ±0.22*

*RPE = rated perceived exertion, HR_{peak} = peak heart rate, BLa^- = blood lactate concentration, SL = stride length, SF = stride frequency, * = significantly different from 100% sprinting (p<0.001).*

No meaningful differences in RPE were observed between the sessions. Thus, it is reasonable to claim that sprinting at 90% sprint velocity can be accompanied with a doubling of repetitions compared to maximal sprinting. However, sprinting at 90% velocity was accompanied with 17% lower HR_{peak} ($p<0.001$) and 55% lower BLa^- ($p<0.001$). While heart rate plateaued after ~ 10 repetitions of the 30x20-m (at 90% intensity) sprint training sessions, heart rate increased progressively throughout the 15x20-m sprint sessions performed with maximal intensity. SF was 11% lower at 90% sprint velocity when compared to maximal velocity ($p<0.001$).

3.5.2   Intensity control

Electronic timing (TC, Brower Timing Systems, Draper, UT, USA) was continuously used to control running velocity and adjust intensity according to each player's "target time". Target time for the 90SUP and 90UNSUP subjects were derived from best sprint time achieved during pre-test. This was done by multiplying mean velocity over the 20 m distance by 0.9. No feedback other than sprint time information was provided for 90UNSUP group after each run. Figure 1 shows intensity distribution for the two 90% groups during all training sessions. More than 90% of all sprints were completed with intensity between 87 and 93 % of maximal sprinting velocity (Figure 1).
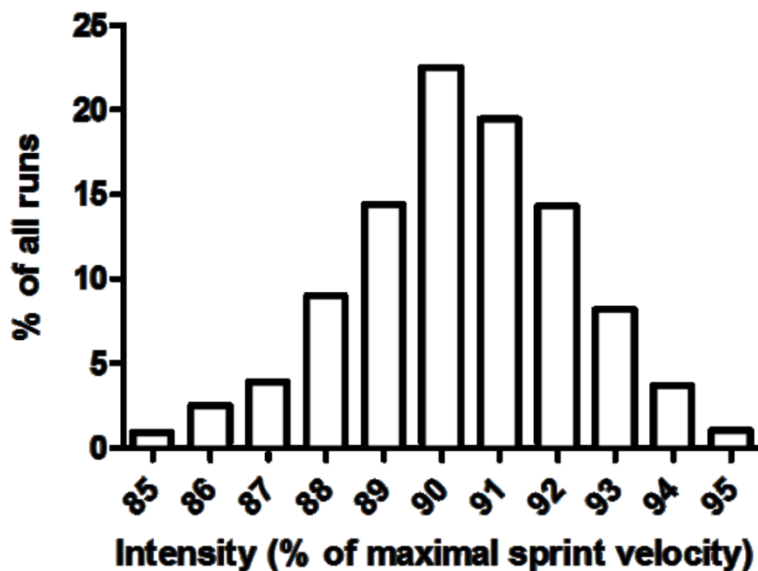
Figure 2. Intensity distribution for 90UNSUP and 90SUP during all training sessions.

3.5.3   Supervision of the 90SUP group

Two sprint training experts with extensive national and international level coaching experience supervised the 90SUP group during the intervention period. The key sprint-technical elements previously mentioned in the theory chapter formed basis for the verbal instructions used during the training sessions. The athletes were instructed to assume a start position with forward leaned upper body and lowered center of gravity, and to gradually become more upright throughout the acceleration. Athletes with apparently too high braking forces were encouraged to assume a more favorable configuration at the point of ground contact with the foot plant closer to the

perpendicular line from the center of mass. This can be achieved by hitting the ground with a bent knee (relevant during acceleration) or with the center of mass at a large vertical distance above the ground (relevant during maximal sprinting). Identified "heal runners" were encouraged to pre-activate dorsiflexion muscles prior to foot plant and stiffen the ankle joint during ground contact, allowing them to utilize the elasticity in the plantar flexors for greater force development.

Most instructions were especially emphasized during warm up drills, but also to some extent during the 30x20-m sprints. The first training session for 90SUP was video recorded and analyzed. After video analysis of the first training session, the two sprint training experts prepared an individual capacity profile for all participants in the 90SUP group. Each athlete was presented one technical task at a time, in accordance with general feedback principles (Schmidt & Wrisberg, 2008). Players with obvious technical limitations were provided more verbal instructions than technically well-performing athletes.

3.6   Validity and reliability

Validity is the degree to which a test or instrument measures what it is supposed to measure (Thomas, Nelson & Silverman, 2011). Vertical jump height in CMJ on force plate assess force development in the lower limb extension muscles and is significantly correlated with the athlete's maximal strength (Wisløff, Castagna, Helgerud, Jones, & Hoff, 2004; Enoksen & Tønnessen, 2007). The Yo-Yo IR1 test has shown a good relationship with the amount of high-intensity activity in game play, and has also been shown to be a valid test to evaluate fitness performance in soccer (Krustrup et al., 2003, 2005). The repeated sprint test used in this study is highly soccer specific; the distance and recovery time is in line with mean frequency and typical distance of sprints reported from match analyses (Di Salvo, Pigozzi, González-Haro, Laughlin, & De Witt, 2013).

An integral part of validity is reliability, which pertains to the consistency, or repeatability, of a measure (Thomas et al., 2011). A test cannot be considered valid if it is not reliable (Thomas et al., 2011). Test-retest reliability is normally calculated by using intraclass correlation (ICC) and coefficient of variance (CV). There was no familiarization test prior to the repeated sprint pre-test in the present intervention.

However, Glaister et al. (2010) did not observe learning effects from repeated sprint tests, therefore we considered familiarization not necessary.

3.7   Statistical analysis

Statistical analyses were carried out using SPSS 20.0 for Windows (SPSS Inc., Chicago, IL, USA) and Microsoft Office Excel 2010. Level of significance was set to $p < 0.05$. The General Linear Model with Repeated Measures followed by Bonferroni adjustment for multiple comparisons was used for 90SUP and 90UNSUP to compare effort related variables in maximal and sub-maximal sprinting. A paired samples t-test (two-tailed) was used to examine within group changes in central location (mean). Analysis of variance (ANOVA) was used to examine between group changes in central location. Bonferroni corrections were used to adjust p-values for multiple testing. The results from pre- and post-tests are expressed as mean ± standard deviation (mean ±SD), and the change from pre- to post is expressed as mean change ±95% confidence interval (change ±CI). Log-transformed effect size was calculated to evaluate the meaningfulness of the difference between category means. Effect size was calculated and log-transformed using Hopkins spreadsheets for analysis (Hopkins et al., 2009). Effect magnitudes were interpreted categorically, and the sizes used are trivial ($d < 0.2$), small ($d = 0.2$–0.6), moderate ($d = 0.6$–1.2), large ($d = 1.2$–2.0) and very large ($d > 2.0$) (Hopkins et al., 2009). Pearson´s r was used to quantify the relationship among anthropometric and physical parameters.

4. Results

Table 3. Physical performance within groups from pre- to post-test, and compared to controls.

Group	Best sprint time (s)	Mean sprint time (s)	CMJ (cm)	Yo-Yo IR1 (m)
Pre 90UNSUP ±SD	2.94±0.12	2.98±0.12	33.5±4.0	1504±376
Post 90UNSUP ±SD	2.93±0.11	2.98±0.11	33.3±4.2	1644±401
Change ±CI	-0.01±0.02	0.00±0.02	-0.2±0.9	140±161
Change vs. CON ±CI	-0.03±0.04	-0.02±0.04	0.6±1.3	-7±279
ES vs. CON	0.23	0.17	0.12	0.03
Pre 90SUP ±SD	2.92±0.11	2.97±0.10	35.9±6.6	1500±512
Post 90SUP ±SD	2.91±0.09	2.97±0.08	37.0±6.3	1745±440
Change ±CI	0.00±0.02	0.00±0.03	1.0±0.9*	245±82*
Change vs. CON ±CI	-0.03±0.04	-0.03±0.04	1.8±1.4*	98±258
ES vs. CON	0.20	0.24	0.35	0.25
Pre CON ±SD	2.93±0.13	2.97±0.14	37.3±3.5	1547±376
Post CON ±SD	2.95±0.14	3.00±0.14	36.6±3.6	1693±356
Change ±CI	0.02±0.02¤	0.02±0.02¤	-0.7±0.9	147±190

Pre = pre-test, Post = post-test, SD = standard deviation, CI = 95 % confidence interval, ES = effect size against control, CMJ = countermovement jump, Yo-Yo IR1 = Yo-Yo intermittent recovery test level 1, CON = controls, * = significantly different (p<0.05), ¤ = tendency (p<0.10)

Table 3 shows changes in analyzed performance parameters within groups and compared to controls from pre- to post-test. 90SUP improved CMJ when compared to CON ($p = 0.046$). 90SUP also had a significant within group change in CMJ from pre- to post-test ($p = 0.0499$). 90SUP improved Yo-Yo IR1 performance ($p = 0.0006$) from pre- to post-test, but not when compared to CON. No other significant changes were observed in physical performance. However, CON showed a tendency towards

performance decline in both best sprint time ($p = 0.09$) and mean sprint time ($p = 0.06$) from pre- to post-test. Effect sizes were either trivial or small for all performance parameters when compared to CON.

Typical variation was 0.025 s (CV 1.0%) for sprint time, 0.028 m (CV 1.8%) for SL, and 0.08 strides·s^{-1} (CV 1.9%) for SF when all groups were pooled together. In CON, we observed ±0.04 s absolute variation in mean sprint time between the pre- and post-tests. Corresponding absolute variation for SL was 0.06 m, and 0.19 strides·s^{-1} for SF.

Table 4: *Underlying performance variables within groups from pre- to post-test, and compared to controls.*

Group	Body mass (kg)	HR$_{peak}$ (beats·min^{-1})	BLa$^-$ (mmol·L^{-1})	SL (m)	SF (strides/s)
Pre 90UNSUP ±SD	72.2±5.6	174±9	4.3±1.7	1.55±0.09	4.34±0.22
Post 90UNSUP ±SD	72.5±5.1	170±14	4.8±2.0	1.55±0.06	4.35±0.17
Change ±CI	0.2±0.6	-3±5	0.57±0.8	-0.006±0.04	0.01±0.10
Change vs. CON ±CI	-0.1±1.0	1±7	1.0±1.3	0.00±0.05	0.02±0.17
ES vs. CON	0.01	0.08	0.63	0.04	0.09
Pre 90SUP ±SD	70.0±5.3	166±10	4.5±2.3	1.54±0.06	4.38±0.12
Post 90SUP ±SD	70.4±5.9	165±10	5.5±2.3	1.55±0.10	4.37±0.22
Change ±CI	0.4±0.9	-1±4	1.0±0.9¤	0.01±0.03	-0.02±0.14
Change vs. CON ±CI	0.0±1.3	4±6	1.5±1.4¤	0.02±0.06	0.00±0.20
ES vs. CON	0.00	0.32	0.81	0.23	0.11
Pre CON ±SD	71.6±11.2	172±12.2	5.2±2.7	1.53±0.08	4.42±0.31
Post CON ±SD	72.0±11.4	167.4±10.4	4.8±3.2	1.52±0.07	4.40±0.29
Change ±CI	0.4±0.8	-4.6±4.3¤	-0.5±0.8	-0.01±0.04	-0.02±0.13

Pre = pre-test, Post = post-test, SD = standard deviation, CI = 95 % confidence interval, ES = effect size, HR = heart rate, BLa$^-$ = blood lactate concentration, SL = stride length, SF = stride frequency, CON = controls, * = significantly different (p<0.05), ¤ = tendency (p<0.10)

Table 4 shows changes in physiological and gait variables within groups and compared to controls from pre- to post-test. No significant within or between group differences were observed. However, there was a tendency for increased BLa⁻ for 90SUP when compared to CON ($p = 0.09$). 90SUP also had a tendency for within group change in BLa⁻ from pre- to post-test ($p = 0.08$). Medium effect sizes were observed in change in BLa⁻ for both 90SUP and 90UNSUP when compared to CON. Small effect sizes were observed in change in HR_{peak} and SL in 90SUP when compared to CON.

Table 5: *Correlations across analyzed variables.*

Variables	Upper *r*	*r*	Lower *r*
Δ BLa⁻ (mmol·l⁻¹) vs. Δ CMJ (cm)	0.68	0.48**	0.23
Δ best sprint time (s) vs. Δ CMJ (cm)	-0.65	-0.41*	-0.16
Δ mean sprint time (s) vs. Δ CMJ (cm)	-0.71	-0.49**	-0.25
Δ best sprint time (s) vs. Δ BLa⁻ (mmol·l⁻¹)	-0.69	-0.43*	-0.06
Δ mean sprint time (s) vs. Δ BLa⁻ (mmol·l⁻¹)	-0.71	-0.42*	-0.02
Δ SL (m) vs. Δ SF (strides·s⁻¹)	-0.97	-0.94**	-0.92
Δ best sprint time (s) vs. Δ mean sprint time (s)	0.92	0.80**	0.63
Δ mean sprint time (s) vs. Δ SF (strides·s⁻¹)	-0.77	-0.48**	-0.06
SL pre vs. SL post	*0.82*	*0.68***	*0.44*
SF pre vs. SF post	*0.79*	*0.61***	*0.37*

n = 32 for all observations. Δ = change, BLa⁻ = blood lactate concentration, CMJ = countermovement jump, SL = stride length, SF = stride frequency. Only significant correlations (p<0.05) are reported. ** = Correlation is significant at the 0.01 level (2-tailed). * = Correlation is significant at the 0.05 level (2-tailed).

Table 5 shows correlation values across analyzed variables. All variables were correlated against each other, and only the significant correlations are reported.

5. Discussion

To the authors' knowledge, this is the first study to compare the effects of supervised vs. unsupervised RST in soccer players. In the 90SUP group a significant training effect was observed in CMJ compared to CON ($p = 0.046$). However, the effect size of this improvement was small (0.35). Overall, one weekly supervised or unsupervised repeated sprint session with sub-maximal intensity was not sufficient to improve performance outcomes for soccer related sprinting performance.

Training at sub-maximal intensity: Based on the current findings, we cannot conclude that training at 90% of maximal sprinting velocity is a sufficient intensity for stimulating physiological adaptation over short sprint distances (Table 3). The concept of training at sub-maximal sprinting intensity is derived from coaching practice in track & field, where the competitive running distances are 60 m and longer (Vittori, 1996). It is possible that sub-maximal sprint training is more appropriate for typical athletic sprinting distances (100 and 200 m) compared to 0-20 m accelerations. Increasing the total work load has been shown to compensate for reduced training intensity in endurance- and strength training sessions (Kraemer et al., 2002; Seiler et al., 2013). During a sprint acceleration, however, the energy demands greatly exceed those at peak velocity (di Prampero et al., 2005). The calculations to estimate the energy demands during a maximal acceleration versus a 90% effort are complex, but a simplification is to calculate the change in kinetic energy ($\frac{1}{2}m \cdot v^2$) (Haugen, Tønnessen, Leirstein, et al., 2014). A reduction in intensity (velocity) from 100% to 90% will therefore lead to a reduction in kinetic energy of nearly 20%. This will probably lead to a similar reduction in the energy demand of the muscles. Because of this, a reduction in velocity of 5% in short sprints during RST would be similar to a 90% work load in endurance and strength training (Haugen, Tønnessen, Leirstein, et al., 2014). This training strategy may give a better balance according to stress management, injury risk reduction and adaptive signal retention, but these possible effects remain to be explored more thoroughly.

Effect of supervised training: The lack of effects on soccer players' maximal and repeated sprint ability may have been affected by the possibility that sprint training with 90% velocity is below the lowest effective running intensity for stimulating

physiological adaptation. This is supported by a recent study by Haugen et al., showing that repeated 20-m sprints at 90% intensity did not enhance sprint performance in soccer season (Haugen, Tønnessen, Leirstein, Hem, & Seiler, 2014). The authors suggested that such training should be performed at other times of the season to avoid training-related constraints due to the high volume of overall soccer conditioning. The present intervention, however, showed that such training in the off-season did not improve sprint performance. One of the reasons that sprint training at 90% intensity were conducted in the present study is that repetitions in training sessions may enhance motor learning (Schmidt & Wrisberg, 2008). There is reason to assume that a high number of repetitions at sub-maximal intensity during technical supervised training is required for stimulating motor adaptations. But since an intensity of 90% seems to be below the lowest effective sprint training intensity for stimulating physiological adaptation, future studies should explore the effect of directly supervised training with a gradual increase in intensity from sub-maximal to maximal sprint velocity. Mazzetti et al. (2000) and Coutts et al. (2004) showed that the presence of a training expert was beneficial for maximal strength and power development over time. In contrast to the present study, the training experts in these studies were allowed to adjust the total training load during the interventions. Based on these observations, one could argue that the effect of expert supervision during training is optimized when combined with greater flexibility in the day-to-day training prescription.

Effect sizes: 90UNSUP had a small effect ($d = 0.23$) in best sprint time when compared to CON. 90SUP had a small effect ($d = 0.20$) in best sprint time when compared to CON, but also in mean sprint time ($d = 0.24$), CMJ ($d = 0.35$) and Yo-Yo IR1 ($d = 0.25$). Database material from the Norwegian Olympic Training Center, including 40-m sprint tests of 628 male elite players between 1995 and 2010 (Haugen et al., 2013), shows that the 75th to 25th percentile difference is 0.13 s over 20-m sprint for male players (Haugen, Tønnessen, Hisdal, et al., 2014). Based on average velocity over the distance, the fastest quartile is at least 1 m ahead of the slowest quartile over 20 m. According to Hopkins et al. (2009), the smallest worthwhile performance enhancement/change in team sport is 0.2 of the between-subject standard deviation. Based on the database material from the Norwegian Olympic Training Center, this corresponds to 0.13s•0.2 = 0.026 s over 20-m sprint, which is quite similar or less than typical variation associated with sprint testing (CV 1-1.5 %) (Haugen, Tønnessen, &

Seiler, 2012). In practical settings, a 30-50 cm difference (~0.04-0.06 s over 20 m) is probably enough to be decisive in one-on-one duels by having body/shoulder in front of the opposing player (Haugen, Tønnessen, Hisdal, et al., 2014). The effect sizes in the range 0.20-0.24 observed for 90SUP in best sprint time and mean sprint time are not sufficient to be considered a worthwhile improvement in sprint performance. Likewise, the effect size of 0.23 observed in best sprint time for 90UNSUP was not "above the threshold" to be considered a worthwhile change. We must therefore conclude that the training methods used in this intervention did not enhance performance in short sprint distances for high level junior soccer players.

Moderate effect sizes were observed in change in BLa^- from pre- to post-test in both 90SUP and 90UNSUP when compared to CON. This may indicate that more fast-twitch glycolytic muscle fibers were used during sprinting. Small effect sizes were observed in increase of HR_{peak} and SL in 90SUP when compared to change in CON. The effect on SL may come from the technique supervision that 90SUP received during the training intervention. However it seems like the athletes in 90SUP were not able to use this small effect to improve sprint performance. The small increase in HR_{peak} in 90SUP may indicate that 90SUP had a larger effort during the post-test than the other groups, but the increase was not significant.

Training volume: Another suggestion for the lack of improvement following the intervention used in this study could be a too low training volume. The training volume in the present study was 30•20m = 600 m "sprint" per week. Tønnessen et al. (2011) performed 40-m sprints with a training volume of 320-800 m per week, and they did not observe improvement in 0-20 m sprint time. However, they did observe improvements in 20-40 m sprint time. Shalfawi et al. (2012) also performed sprints over 40 m, but with a total training volume of 1600 m per week. They reported significant improvement in peak velocity, but not for 0-20 m sprint time. Overall, improving 0-20 m sprint performance seems to be difficult in soccer players. However, the effect size for 0-20 m sprint time in the study by Shalfawi et al. (2012) was moderate to large (1.1), indicating that a larger training volume with repeated sprints is needed to improve 0-20 m sprint time. The greater improvements in 20-40 m versus 0-20 m sprint time suggest that soccer players are more disposed to physiological adaptations over somewhat longer but less soccer-specific sprint distances. Soccer players perform a high number of

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accelerations during training and games. Thus, one could argue that most players have likely taken out much of their 0-20 m sprint potential during regular soccer conditioning.

An increased number of sprint training sessions per week or a longer intervention period could influence the potential of developing faster players. It may, however, be challenging to get team coaches to willingly "sacrifice" soccer training sessions, and it is therefore important that the RST is performed as efficient as possible. The intervention in this study was shaped by several training-related constraints within the overall soccer training program, and these constraints are an important aspect of assessing the practical efficacy of training interventions in team sport. But it could be argued that the "sacrifice" of soccer training sessions has to be larger if RST is to be useful for improving soccer specific sprinting skills.

Correlations across analyzed parameters: There was a significant relationship between changes in BLa⁻ and changes in sprint performance (Table 5). The correlation was moderate (http://www.sportsci.org/resource/stats/effectmag.html), and the athletes seemed to have higher lactate production with improved repeated sprint performance. It could be speculated that an increase in BLa⁻ during sprinting reflects higher neural activation, i.e. increased ability to fully activate fast twitch motor units with maximal firing frequency, and thereby improved sprint performance (Ross et al., 2001).

Table 5 shows a nearly perfect correlation between changes in mean sprint time and changes in best sprint time from pre- to post test, but no significant correlation between mean sprint time and Yo-Yo IR1. This corresponds with the results from Pyne et al. 2008, who found that RSA has a stronger correlation with maximal sprinting velocity than endurance capacity. A small difference between best time and mean time is also shown with a shorter recovery time of 25 s between each 20-m sprint (Dellal & Wong, 2013). An explanation for the nearly perfect correlation between changes in mean sprint time and changes in best sprint time can be the short sprints (20 m) performed in the present study. Balsom et al. (1992) reported that it is more difficult to detect detrimental effects with short sprints compared to slightly longer sprints.

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A moderate correlation was observed between changes in CMJ performance and changes in sprint performance (Table 5). This is a weaker correlation than previously reported by Wisløff et al. (2004), whom reported a strong correlation between maximal strength, sprint performance and vertical jump height. Salaj & Markovic (2011), however, showed that jumping, sprinting and change of direction speed could represent separate and mainly independent motor abilities.

The correlation values for SL ($r = 0.60$) and SF ($r = 0.63$) across the present tests were surprisingly low when all groups were pooled together (Table 5). This indicates that identical sprint performance can be achieved with varying locomotion efficiency among athletes of lower sprint standard, which is in accordance with observations made by Hunter et al. (2004). However, there was a very high negative correlation between Δ SL vs. Δ SF ($r = -0.94$). This indicates that the more the participants increase SF, the more they reduce SL, or opposite, the more they increase SL the more they reduce SF.

No significant correlation was observed between Yo-Yo IR1 and mean sprint time at pre- or post-test. This could be due to the long pauses between the repetitions (start every 60 s) and short sprint distance (20 m) in the repeated sprint test used, since the Yo-Yo IR level 1 test focuses on the capacity to carry out intermittent exercise leading to a maximal activation of the aerobic system (Bangsbo, Iaia, & Krustrup, 2008).

Injuries: After 7 weeks of training, only one of the drop outs developed injury that possibly was related to the training intervention. It is reasonable to believe that more weekly training sessions increases the injury risk, at least when performing sprints with maximal intensity (Ekstrand et al., 2011). Future studies should strive to develop methods on how soccer players can enhance sprint performance without increasing the injury rate.

Sprint distance and recovery duration: Soccer players have been shown to perform eight times as many accelerations as reported sprints per match, and ~85% of these accelerations do not cross the high-intensity running threshold (Varley & Aughey, 2013). Therefore, the amount of high-intensity running and sprinting undertaken by the soccer players may be underestimated (Osgnach, Poser, Bernardini, Rinaldo, & di Prampero, 2010; Varley & Aughey, 2013). Measuring methods that capture

acclerations would markedly strengthen game analyses. This could suggest that the repeated sprints with start each 60 s used in the present do not enhance the required soccer specific actions needed in soccer matches. In a soccer game, players perform many movements in addition to straight sprinting, including stops, turns, jumps, etc. This increases the energy demand. The intervention used in the present study could have been designed differently, but due to injury risk we chose to perform straight sprinting without sudden turns.

Another question is whether the 20-m sprints used in the present study are long enough to be considered as a soccer specific action. The duration of the sprints in soccer is normally between 2 and 4 seconds (Bangsbo et al., 1991; Burgess et al., 2006; Vigne et al., 2010). Studies show that most sprints are initiated while the players are already running at a certain velocity (fast jogging or striding), indicating that the demand for maximum running velocity is larger than what the duration of the sprinting indicates. Therefore, a soccer specific training program may include sprints over distances longer than the 20 m used in the present study.

6.   Conclusion

No significant differences in performance outcomes were observed after supervised or unsupervised sprint training at 90% of maximal sprinting velocity compared to a control group, except for performance in countermovement jump. Based on the effect magnitudes, it cannot be recommended that soccer players perform the present training regimes under otherwise identical conditions. Greater loads of training are probably required, perhaps in combination with other training forms (i.e. resistance training), but this will increase the risk of training-related constraints to the overall soccer conditioning. This needs to be addressed in future studies. Directly supervised RST does not seem to be an effective training method at the group level, and it seems essential to diagnose each individual and develop training interventions that target their key physiological, tactical and technical weaknesses.

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Index of tables and figures

Abbreviations

BLa$^-$ blood lactate concentration

CMJ   countermovement jump

CON   control group

Δ   delta = change

HR   heart rate

HR$_{max}$ maximum heart rate

HR$_{peak}$ peak heart rate

RSA   repeated sprint ability

RST   repeated sprint training

SL   stride length

SF   stride frequency

VO$_{2max}$ maximal oxygen uptake

Yo-Yo IR1   Yo-Yo Intermittent Recovery 1 test

90SUP   training group who performed repeated sprint training at 90%
                          intensity with direct supervision

90UNSUP   training group who performed repeated sprint training at 90%
                          intensity without supervision

Appendices

"Effekten av repetert sprinttrening på elite juniorspillere i fotball"

Bakgrunn og hensikt

Dette er et spørsmål til deg om å delta i en forskningsstudie for å skaffe ny kunnskap om effekten av repetert sprinttrening på elite juniorspillere i fotball. Dette er en gyllen mulighet for å utvikle deg selv som fotballspiller. Vi vil undersøke hvordan repetert sprinttrening påvirker hurtighet, spenst og utholdenhet.

Hurtighet er svært viktig i fotball, og det er også evnen til å løpe hurtig mange ganger etter hverandre med korte pauser (repetert sprint). En hurtig spiller vil ofte nå ballen før andre spillere, og kan dermed skape eller forhindre målsjanser.

Tidligere studier på repetert sprinttrening har vist fremgang både på evnen til å løpe hurtig mange ganger etter hverandre (repetert sprintevne), og på aerob utholdenhet (oksygenopptak) og på agility (evnen til hurtige hastighetsforandringer).

Våre resultater vil kunne få konsekvenser for hvilke treningsmetoder som blir brukt for å få optimal prestasjon på fotballbanen, og det er mulig at dette også kan bli brukt i andre ballidretter.

Hva innebærer studien?

Det skal rekrutteres minst 60 mannlige elite juniorspillere som spiller fotball på høyt nivå. Selve treningsintervensjonen vil vare i 7 uker (uke 44 til uke 50) og det blir gjennomført tester før og etter treningsperioden (i uke 43 og uke 51). Dere blir tilfeldig fordelt ved loddtrekning i 4 grupper der 3 grupper trener ulike varianter av repetert sprint, mens den siste gruppen er kontrollgruppe.

Repetert sprintgruppene skal trene repetert sprint én gang i uken. Treningen vil foregå i idrettshallen på NIH. Prosjektet inkludert testing vil foregå fra uke 43-51, 2013. Testingen før treningsperioden foregår i uke 43. Alle må teste 2 dager hver. Dagene som det er mulig å teste før treningsperioden (Pre-test) er tirsdag 22. oktober, onsdag 23. oktober, torsdag 24. oktober og fredag 25. oktober. Alle må teste på 2 dager hver, vennligst gi beskjed så fort som mulig om hvilke dager som passer for deg. Testingen vil foregå på Olympiatoppen den første dagen og i idrettshallen på NIH den andre dagen. **Det må være en hviledag mellom de to testdagene, så du kan enten teste på tirsdag og torsdag eller på onsdag og fredag, eller på torsdag og lørdag.** Testdagene før og etter treningsperioden (Pre-test og Post-test) vil bestå av følgende tester:

- Vertikalt spensthopp m/svikt
- 15x20m sprint med start hvert minutt, samt puls, EMG målinger og laktatmålinger underveis
- Yo-Yo IR1, som er en aerob og anaerob utholdenhetstest

De som skal delta i prosjektet må møte uthvilte (ingen aktivitet 1-2 dager før testene) til Pre-test og Post-test. Testing til prosjektet vil utføres av fagansatte på den fysiske seksjonen ved Norges idrettshøgskole (NIH), og prosjektet ledes av Professor Eystein Enoksen tilknyttet seksjonen for fysisk prestasjonsevne, og Dr. Espen Tønnesen som er fagsjef for trening i Olympiatoppen.

Treningsøktene som er én gang i uka vil vare ca. 1 time (inkl. oppvarming, løpsdrill og repetert sprinttrening). Deltakerne må ha et <u>minimum oppmøte</u> på 80% (6 av 7 totalt) av treningene for å bli inkludert i studien. Dersom forsøkspersonene trener andre ting enn fotballøkter under treningsperioden, må dette noteres på et eget skjema som deles ut. Dagen etter første treningsøkt (uke 44) vil du gjennomføre en hurtighetstest for å kontrollere at treningsbelastningen er lik mellom gruppene.

Mulige fordeler og ulemper

Som forsøksperson vil du få et profesjonelt treningsopplegg og nøye oppfølgning av kvalifisert personell under treningen. Du får muligheten til å gjennomføre en del tester

du ellers ikke ville fått tilgang til, slik at du vet hva du er god på og hva du kan forbedre for å bli en bedre fotballspiller. Du får også ny kunnskap om ulike typer trening slik at du lettere kan trene slike typer økter på egenhånd.

De ulike testene kan gjøre at du blir sliten og medfører tung fysisk belastning. Forsøksperioden vil til sammen strekke seg over ca. 9 uker, og vil ta endel av din tid og oppmerksomhet. Det vil være én treningsøkt i uka som hver varer ca. 1 time. Vi vil under hele perioden være samarbeidsvillige for å legge treningstidene til rette for deg. Du vil få et profesjonelt treningsopplegg og nøye oppfølging under hele perioden og dessuten tilbud om oppfølging hvis du ønsker å fortsette med slik type trening når intervensjonen er over. Det er alltid en liten skaderisiko når man driver tung fysisk trening, men med nøye oppfølgning av kvalifisert personell under trening, så er denne risikoen minimal.

Hva skjer med prøvene og informasjonen om deg?

Informasjonen du gir blir holdt anonymt. Testresultatene dine vil du og din trener få tilgang på (ved ønske), for alle andre vil resultatene dine holdes anonym. Du vil få en tallkode på spørreskjemaet ditt. Denne tallkoden vil bli brukt om dataene som skal brukes av andre eller om studien blir publisert, noe som betyr at resultatene dine vil da bli holdt helt anonymt. Tester som blir gjennomført av deg og informasjonen som registreres skal kun brukes slik som beskrevet i hensikten med studien. Det er kun autorisert personell knyttet til prosjektet som har adgang til navnelisten og som kan finne tilbake til deg. Det vil ikke være mulig å identifisere deg i resultatene av studien når disse publiseres.

Frivillig deltakelse

Det er frivillig å delta i studien. Du kan når som helst og uten å oppgi grunn trekke ditt samtykke til å delta i studien. Dette vil ikke få konsekvenser for din videre behandling. Dersom du ønsker å delta, undertegner du samtykkeerklæringen på siste side. Om du sier ja til å delta, kan du senere 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 en av oss:

Masterstudent i idrettsfysiologi Øyvind Øksenholt, tlf: 908 68 258, epost: oyvindoo@student.nih.no   eller   o_oksenholt@hotmail.com

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Professor Eystein Enoksen, epost: eystein.enoksen@nih.no

Dr. Espen Tønnesen, epost: espen.tonnessen@olympiatoppen.no

Samtykke til deltakelse i studien

For de som er <u>under 18år</u>, må foreldrene/foresatte godkjenne og signere samtykke.

Jeg er villig til å delta i studien

(Signert av prosjektdeltaker, dato)

Foreldres/foresattes samtykke

 (Signert av foresatt, dato)

Jeg bekrefter å ha gitt informasjon om studien

(Signert, rolle i studien, dato)

Appendix II: Information about the subjects

Info om forsøksperson

Navn (bruk blokkbokstaver):

Klubb:

Fødselsdato:

Høyde:

Telefonnummer:

Mail:

Appendix III: Approval for publishing figures

Til:
david.bishop@vu.edu.au
Sendte elementer

27. august 2014 17:31

Dear Professor Bishop

I'm a student at the Norwegian School of Sports Sciences, and I'm writing my master's thesis on repeated-sprint ability in soccer players.
I really admire your work, and your review article "Repeated-Sprint Ability - Part II" has been a great inspiration for me.

I would like to ask you kindly if I could use your figure on page 753, which shows factors that should be targeted by training to improve repeated-sprint ability.

Best wishes
Øyvind Øksenholt

David Bishop [David.Bishop@vu.edu.au]

Handlinger

Til:
Øyvind Øvrebø Øksenholt

28. august 2014 16:04

Hi Øyvind,

Thank you very much for your nice email. I'm pleased that my research has been of use and of course, absolutely no problems to use the figure from my paper in your thesis. I hope that your research is going well and I look forward to seeing a publication in the near future.

Cheers,

David

Professor David Bishop
Research Leader (Sport)
INSTITUTE OF SPORT, EXERCISE & ACTIVE LIVING (ISEAL)
VICTORIA UNIVERSITY

Appendix IV: Rated perceived exertion (RPE)

Navn:_____

På denne 0-10 skalaen, hvor «hard» var sprinttesten?

Sett ring rundt tallet du synes passer best, ca. 30 min.
etter at testen er avsluttet.

0	Hvile
1	Veldig, veldig lett
2	Lett
3	Moderat
4	Noe hardt
5	Hardt
6	
7	Veldig hardt
8	
9	
10	Maksimalt hardt