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Anaerobic conditioning of soccer players

The evaluation of different anaerobic training methods on soccer players' physical performance

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Abstract

Background:
High performance in soccer depends on various physical qualities and skills, including tactical and technical skills as the two most import factors that contribute to success. These skills could be more important than small differences in physical performance abilities. Nevertheless, to be able to utilize the tactical and technical skills during a top soccer match, a soccer player has to cope with the physical demands of the game. Besides the high aerobic demands in soccer, game analyses indicate that soccer players sprint between 1–11% of the total game with durations of 2 to 4 s for each sprint every 60–90 s, which equals about 60–90 sprints during a soccer match. Those sprints suggest a high-energy demand from the anaerobic energy system and the need to repeat high velocity sprints throughout the match. Therefore, the improvement of soccer players' anaerobic conditioning could be regarded as essential.

Aims:
The overall objective of this thesis was to develop, evaluate and compare hypothetically deducted anaerobic training methods for the purpose of improving the anaerobic physical components in soccer players. To achieve this overall objective, three sub objectives were developed. First: assuring the reproducibility of the measuring systems used in data collection. Second: implementing, evaluating and comparing the effects of anaerobic training programs designed. Third: to better understand the effect of the implemented anaerobic training programs; a follow-up study that investigates the relationship between measures of aerobic and anaerobic variables was conducted.

Methods:
Five studies were conducted to achieve the aims of this thesis. **Study I** was a methodological study where well-trained male soccer players were tested and re-tested. The tests used were countermovement vertical jump, squat vertical jump and 0–40 m linear sprint with the aim of examining the reliability (reproducibility) of the testing equipment's.

Study II aimed to evaluate and examine the effect of 8-weeks 40 m repeated sprint training on young elite male soccer players' physical performance. The participants were divided into two groups, a training group and a control group. Both groups were instructed to continue the teams' original training plan, with the training group conducting two weekly extra training sessions consisting of repeated sprint training. The pre- and post-tests conducted were 3-6-9 m agility with a 180° turn, 0–40 m linear sprint, 10 × 40 m repeated linear sprint, countermovement vertical jump, squat vertical jump, and Yo-Yo Intermittent Recovery level 1 test. The study took place during the pre-season period.

Study III aimed to evaluate and compare the effects of 10-weeks combined agility with repeated sprint training versus strength training, twice a week, on well-trained female soccer players. The participants were randomly assigned to one of two groups, either a combined agility with repeated sprint training group or strength training group. Both groups were instructed to continue the teams' original training plan, with the strength training group conducting two extra strength training sessions per week, and the agility with repeated sprint training group conducting two extra training sessions per week, one with resisting band, and one with repeated sprint training. The study took place at the beginning of the competition season. The pre- and post-tests conducted were squat vertical jump, countermovement

vertical jump, 7 × 30 m repeated linear sprint, 0–40 m linear sprint, S180º agility test, and multi stage fitness test (Beep test).

Study IV aimed to evaluate and compare the effect of 8-weeks repeated agility training versus repeated sprint training on elite female soccer players` physical performances. Participants were randomly assigned to either a repeated agility training group or a repeated sprint training group. Both groups were instructed to continue the teams' original training plan, with the repeated agility training group completing one extra training session per week consisting of repeated agility training, and the repeated sprint training group completed one extra training session per week consisting of repeated sprint training. The participants were pre- and post-tested for 0–40 m linear sprint, 40 m agility test, countermovement vertical jump, 10 × 40 m repeated linear sprint, and Yo-Yo Intermittent Recovery level 1 test. The study took place during the pre-season period.

Study V aimed to investigate the relationship between measures of sprinting abilities, lower body strength and power, and aerobic fitness. Well-trained female soccer players were tested on 0–40 m linear sprint, 7 × 30 m repeated linear sprint, S180º agility test, countermovement vertical jump, squat vertical jump, and Beep test.

Results:
The results from **study I** indicate that the total error (systematic bias and random variation) would not exceed 1.54% for the Newtest Powertimer photocells, 1.6% for the Norwegian Olympic Centre (NOC) photocells, and 1.4% for the NOC force platform. Furthermore, the test–retest reliability in study I did not show any marked systematic bias for the Newtest Powertimer testing system and the NOC testing systems. However, the results indicate that the total error associated with the Newtest Powertimer contact mat was higher than our analytical goals, and therefore the contact mat was omitted from being used further in testing.

The results from **study II** indicate a significant improvement within the repeated sprint training group from pre- to post-test in 0–40 m linear sprint time (-0.33 ±0.13 s), 10 × 40 m repeated linear sprint mean time (-0.29 ±0.13 s), 0–20 m linear sprint time (-0.19 ±0.10 s), 20–40 m linear sprint time (-0.15 ±0.08 s) and countermovement vertical jump (1.3 ±1.2 cm). The within control group results showed a significant improvement in 0–40 m linear sprint time (-0.11 ±0.06 s), 10 × 40 m repeated linear sprint time (-0.09 ±0.03 s) and 0–20 m linear sprint time (-0.10 ±0.06 s). A comparison between the two groups showed statistically significant differences in 0–40 m linear sprint time, 10 × 40 m repeated linear sprint time and 20–40 m linear sprint time.

The results from **study III** indicate that the combined resisted agility with repeated sprint training implemented did not have any significant effect on the combined training group results with the exception of Beep test performance (1.2 ±0.7 level). The strength-training group had a significant improvement in Beep test performance (1.2 ±0.7 level) and squat vertical jump performance (1.7 ±2.1 cm). Analysis of between groups' differences revealed no significant differences between the groups.

The within group results from **study IV** showed that the repeated agility training group had a significant improvement in 10 × 40 m repeated linear sprint mean time, agility time and Yo-Yo Intermittent Recovery level 1 distance covered. The repeated sprint training group showed significant improvements in 10 × 40 m repeated linear sprint mean time, 20–40 m linear sprint time, 0–40 m linear sprint time, countermovement vertical jump, and Yo-

Yo Intermittent Recovery level 1 distance covered. No significant differences between the groups were observed.

Analyzing **study V** reveals that squat vertical jump in absolute terms had the highest correlation with linear sprint times over 0–40 m and 0–20 m. Countermovement vertical jump had the highest correlation with 20–40 m linear sprint time. Peak power relative to body weight from countermovement vertical jump had the highest correlation with 0–40 m and 20–40 m linear sprint times. Linear sprint time over 0–40 m was correlated with linear repeated sprint fastest time, mean time, and total time. Sprint with change of direction had the highest correlation with linear sprint time over 0–20 m. Beep test distance covered had a significant correlation with repeated linear sprint fastest time, mean time, total time, sprint with change of direction time, 0–40 m linear sprint time and 20–40 m linear sprint time.

Conclusion:
The present thesis confirms that the use of the same testing system from pre- to post-test is advisable because different systems give different results. The results from the present thesis demonstrate that improvements in soccer players' physical performance and the rate of adaptation to anaerobic training depend on specificity, progression, intensity, volume and frequency in order to be able to stimulate improvement in already well-trained individuals. The present thesis demonstrates that greater training volume with high intensity close to the observed intensity during match play in the form of total distance covered during repeated sprint training appears to impact positively on players' physical performance. Analyses of the results indicate that a higher training frequency of two sessions per week gives better results compared to one session per week. The results from study II and IV demonstrate that repeated sprint training is a useful form of anaerobic conditioning to improve soccer players' repeated sprint ability, indicating that this skill appears to be trainable using only repeated sprint training. The present thesis confirms that the specificity of the exercise choice can highly effect the improvement of the players. Similar to other studies, the present thesis demonstrates that agility training induces specific agility enhancement and linear sprint training improves linear sprint abilities. Comparing the outcome across the part studies of the present thesis demonstrates that the improvement of the players conditioning is highly connected to the total stress level. Therefore, the time of implementing the training program is crucial and consequently the correct use of periodization, progression and the total training load is highly important. Finally, sprinting abilities seem to depend greatly on technical elements and continuous presence of a physical conditioning expert likely increases the odds of a more successful outcome.

Abbreviations

$^{-}$ $m \cdot s^{-2}$ = Decelerations measured as meter per second squared

% = Percent

%Dec = Deterioration in performance expressed as percentage of speed decrement

° = Degrees

× = Multiplied

$>$ = Greater than

~ = Approximately

≤ = Less than or equal to

2nd S = Second strikers

ATT = Attackers

CB = Central backs

cm = Centimeter

CMJ = Countermovement vertical jump

DF = Defenders

e.g. = For example

F = Forwarders

FB = Full backs

GK = Goalkeepers

Hz = Hertz

kg = Kilograms

kj = Kilojoule

km = Kilometers

$km\ h^{-1}$ = Velocity kilometer per hour

m = Meter

$m \cdot s^{-2}$ = Acceleration measured as meter per second squared

MD = Middle defenders

MF = Midfielders

min = Minute

$mL \cdot kg^{-1} \cdot min^{-1}$ = Milliliters of oxygen per kilogram of body mass per minute

$mmol\ l^{-1}$ = Mill moles per liter

ms = Milliseconds

N = Force in newton

n = Sample number (participants number)

NOC = Norwegian Olympic Sport Centre timing system

R = Recovery between Repetitions

Rep = Repetitions

RM = Repetition maximum

RSA = Repeated sprint ability

s = Seconds

S = Strikers

SJ = Squat vertical jump

SR = Recovery between sets

VO_2 = Aerobic power

VO_{2max} = Maximal aerobic power

VO_{2peak} = Peak rate of oxygen consumption

wk = Week

WM = Wide midfielders,

Yo-Yo IR1 = Yo-Yo Intermittent Recovery level 1 test

Yrs = Years

List of Publications

I. Enoksen, E., Tønnessen, E., & **Shalfawi, S.**
Validity and reliability of the Newtest Powertimer 300- series (R) testing system.
Journal of Sports Sciences, 27, 77-84 (2009).
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Hereafter Study I.

II. **Shalfawi, S.,** Ingebrigtsen, J., Dillern, T., Tønnessen, E**.**, Delp, T. K. & Enoksen, E.
The effect of 40 m repeated sprint training on physical performance in young elite male soccer players.
Serbian Journal of Sports Sciences, 6(3), 111-116 (2012).
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Hereafter Study II.

III. **Shalfawi, S.**, Haugen, T., Jakobsen, T. A., Enoksen, E., & Tønnessen, E.
The Effect of Combined Resisted Agility and Repeated Sprint Training Vs. Strength Training on Female Elite Soccer Players.
The Journal of Strength & Conditioning Research, 27(11), 2966-2972 (2013).
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Hereafter Study III.

IV. **Shalfawi, S.**, Young, M., Tønnessen, E., Haugen, T., & Enoksen, E.
The effect of repeated agility training vs. repeated sprint training on elite female soccer players' physical performance.
Kinesiologia Slovenica, 19(3), 29-42 (2013).
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Hereafter Study IV.

V. **Shalfawi, S.**, Enoksen, E., & Tønnessen, E.
The relationship between measures of sprinting, aerobic fitness, and lower body strength and power in well-trained female soccer players.
International Journal of Applied Sport Sciences, 26(1), 18-25 (2014).
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Hereafter Study V.

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Contents

1 Introduction

1.1 Rationale for the thesis

Over the past years, the research within soccer has been very successful in investigating the fundamental processes that contribute towards improving the game and players. Scientific research shows that soccer players' performance depends on a number of characteristics and skills, of which the player's technical and tactical skills are the two major performance determining factors for success (17, 24, 143). These skills could be more important than small differences in physical performance measures among players. Other studies support this assumption, but suggest that the physical characteristics of aerobic endurance, strength and speed must also be well developed in order to be able to reach a high performance level (83, 87, 108, 138). These physical characteristics do not need to be exceptionally developed, but must be at a high level (143, 178). How high, depends, among other factors, on the competition level and the role and position of the player. Research shows that soccer players who have the ability to cope with the physical demands of the game can utilize their tactical and technical skills more effectively during match play (20, 83, 87, 108, 138).

Analyses of soccer match indicate that the length of the match and the high-intensity actions observed outline the importance of both the aerobic and the anaerobic energy systems throughout the game (108, 143, 169, 179). Both energy systems should be able to provide the players with the energy demanded to perform and conduct all types of movements required during a high level soccer match. Consequently, physical demands in soccer have been investigated in several studies (21, 24, 38, 121, 141, 144) with aerobic demands been significantly explored and established, while information about the anaerobic demands is still in progress. The latest analyses of soccer however, shows that, among the anaerobic actions performed, linear sprint with and without the ball in position were the most frequent action prior to scoring situation (64). Considering that the majority of scored goals occurring between the 75th and 90th min of the match (2) emphasizes the importance of being able to conduct high intensity anaerobic actions throughout the entire match, both in attacking situations and in returning back to position after losing the ball to prevent a goal.

Soccer is unpredictable sport in nature, and the anaerobic actions within soccer constitute only a minor percentage of the total distance covered in a match. However, the possibility of such actions to occur at anytime during the 90 min match highlights the importance of integrating anaerobic conditioning into the training of soccer players. Furthermore, a brief examination of the literature reveals that soccer-specific anaerobic training is not very well established, and therefore, the main idea prior to the start of this Ph.D. project back in 2006 was to develop soccer players anaerobic conditioning by developing and testing different approaches and training methodology and evaluate its effect on soccer players physical performances. In this sense, the present Ph.D. thesis (extended abstract) summaries the outcome of those part studies implemented for that purpose.

1.2 Literature search

The purpose of the theoretical framework is to present and summaries the scientific research that helps in understanding the fundamental processes involved in improving soccer players' physical performance, as well as outline the challenges ahead for further improvements. To be able to obtain an overview of the recent literature, a systematic and manual literature search approach was used using different databases. The keywords were used solely and combined with other words to capture the most relevant literature.

The systematic search was mainly carried out using Norwegian School of Sport Sciences library system (bibsys) and bibliographic databases available through the Norwegian School of Sport Sciences (e.g. PubMed, ProQuest, SPORTDiscus, Google Scholar). The searches were not limited and were conducted on all fields. The results then were limited based on "soccer", "review articles" or "all". The search was further refined based on "publish date" where the newest research comes first. Furthermore, if limited literature was available, then a general search of the topic was conducted.

The following keywords were used during the systematic literature search: Time motion analyses in soccer, physiology of male soccer players, physiology of female soccer players, aerobic capacity in soccer, aerobic capacity demands in soccer, aerobic capacity requirements in soccer, aerobic capacity and soccer game analyses, aerobic capacity and time motion analysis, soccer game analyses, distance covered in soccer, Vo_2 and soccer, Vo_{2max} and soccer, heart rate in soccer match, heart rate in top soccer players, heart rate and soccer, maximal oxygen uptake and soccer, high intensity action in soccer, speed and soccer, speed in top soccer match, speed and time motion analyses, soccer match and speed analyses, sprint in soccer, sprint and soccer, soccer match performance and speed, acceleration and soccer, repeated sprint ability in soccer, RSA, soccer RSA, soccer and RSA, repeated sprint exercise, RSE and soccer, soccer repeated sprint exercise, elite soccer players and repeated sprint ability, and speed elite soccer. The references for the manual literature search were obtained from the articles found through the systematic literature search using the full text of the article from the systematic article reference list. All articles were obtained using the same databases used in the systematic search.

2 Theoretical framework

2.1 Match analyses

Soccer is the largest sport in the world, which is played by both males and females from different age groups. Alongside the tactical and technical skills required to be able to play the game, the physical demands differ according to sex, level of competition, playing position, and age of the player (23, 78). Therefore, soccer intensity has been intensively analyzed using different methods, and one of the most used approaches is to analyze intensity as a function of distance covered during match play (24, 121, 144). This type of analysis has given researchers the ability to break down the actions during the match for both the team and the individual player. Researchers have been able to classify those actions as a function of internal intensities measured as a percentage of maximal aerobic power, heart rate and blood lactate, and external intensities measured as distance covered as a function of locomotion type (standing, walking, jogging, running, high speed running, sprinting, changing direction, with or without ball, heading, tackling, and scoring situations) throughout the game. A brief review of the available intensity analyses of soccer games would, therefore, clarify the importance and the need of this thesis.

2.1.1 Total distance covered

The results from different elite male and female soccer players' match analyses indicate that a field player covers an average distance of ~10 km during the 90 min match, with top elite male soccer players covering 5% more in total distance compared to players from lower competition levels (24, 30, 35, 38, 54, 120, 121, 134, 136). Elite male and female soccer players have been reported to cover ~5% more total distance in the first half compared to the second half of the game, with greater decrease in total distance covered in the second half for those players who cover the greatest distance in the first half (26, 35, 38, 120, 121, 136). Midfielders from both elite male and female soccer have been reported to cover ~5% more in total distance compared to other playing positions (35, 58, 86, 170, 173). The total distance covered with ball in possession was reported to be around 1–2% for both male and female elite soccer players (58, 72). The total distance covered by elite senior male and female players was found to be ~13% higher compared to young elite male and female players (25, 42, 46, 117, 153, 170).

While the distance covered with the ball in possession is as low as 1–2% of the total distance covered during match play, the quality of conducting soccer tactical and technical skills with the ball in possession have a great impact on the final result of the game. Therefore, to be able to utilize tactical and technical skills during match play, soccer players have to be able to cope with the physical demands of the game. One way to investigate those demands is by investigating the intensity during match play.

2.1.2 Match intensity

During a soccer match play, the total distance covered is performed at different intensities and these intensities are affected by playing tactic, opponent team playing style, player position, and level of competition (144). Scientifically, the best method to measure energy expenditure during a match is by directly measuring the oxygen consumption (VO_2), however, measurements of VO_2 during match play or training has been found to be a very difficult task because of the restrictions placed on players using measurement systems (141). Due to the small error associated with heart rate, heart rate has been proposed as a viable alternative for measuring energy expenditure (19). Generally, the average intensity measured as a percentage of maximal heart rate for both elite male and female soccer players in a full match has been reported to be between 80–90%, with ~4% higher heart rate in the first half compared to the second half of the game (68, 83, 104, 135). This indicates that the intensity during a match is close to the anaerobic threshold of a top soccer player (142, 159). Research further shows that elite male midfielders and forwarders have ~9% higher heart rate compared to center back and fullback players (141). In contrast, no marked heart rate differences were observed between elite female soccer players as a function of playing position (104).

Since it would be physiological difficult to work at 90% of maximal heart rate for the entire soccer match, several authors agreed that expressing the intensity as an average over 90 min is not fully representative as it underestimate the periods of high-intensity activities (3, 159). Therefore, measuring blood lactate concentration was suggested as another alternative. The results indicate that elite soccer players spend 13.9% of the total game time below 2.0 mmol l^{-1}, 35.5% between 2.0–4.0 mmol l^{-1}, and 49.6% above 4.0 mmol l^{-1} (60). However, in order to be able to draw a better picture of the intensity required during match play, approaches that also take into account the frequent change in activities have been employed. The reported results for both elite male and female soccer players indicate that 60–70% and 20–30% of the total distance covered were at low intensity and high intensity, respectively (5, 24, 35, 85, 134, 144, 173). Further analyses of high intensity moments in match play, would further help in determining the anaerobic demands of the game and aid in the process of planning and designing anaerobic conditioning programs.

2.1.3 High-intensity running

High-intensity running velocities in elite male soccer players were divided into high intensity running (> 14.3 km h^{-1}), very high intensity running (> 19.8 km h^{-1}), and sprinting (> 25.1 km h^{-1}) (36, 38, 69, 136, 176). For elite female soccer players, high intensity running velocities were divided into high intensity running (> 12 km h^{-1}), very high intensity running (> 18 km h^{-1}), and sprinting (> 25 km h^{-1}) (24, 85, 120, 121). Research shows that the total high intensity running comprises between 20–30% of the total distance covered, with ~11% reported to be at very high intensity running and ~2.5% sprinting, with an average of 2–4 s per run occurring every 60–90 s (5, 35, 57, 85, 120, 136, 154, 159, 176). Elite male and female soccer players typically perform ~10% more high intensity running in the first half compared to the second half of the game, with midfielders covering a greater distance (> 5%) at high intensity running compared to fullbacks, defenders, and attackers (35, 38, 58, 85, 120, 121).

Research shows that 45% of scored goals in the first German national league (out of a total of 360 goals analyzed) were preceded by a straight sprint mostly without the ball in possession and with no opponent, and it was noted that the most frequent action for the assisting player was straight sprint with the ball in possession (64). Such sprints have been reported to typically be within the range of ~20 m or 2–4 s (24, 45, 57, 58, 121, 154, 168). In this context, sprinting is undoubtedly an important skill in soccer, contributing to both creating and stopping goal scoring opportunities. Furthermore, analyzing the world cup in 2006 revealed that 35% of the scored goals occurred between the 75th and 90th min of the match, with 80% scored by foot and 20% scored by head (2). This highlights the importance of being able to conduct high intensity running towards the end of the game, both in attacking situations and in returning back to position after losing the ball to prevent a goal.

The importance of speed with change of direction (agility) in soccer can be outlined from the analysis conducted by Bloomfield et al. (29) of 55 FA Premier League soccer players. Using only 5 min of playing time for each player, they reported a total of 26613 movements during the time analyzed, of these, 5115 movements were change of direction movements which consisted of turning events divided into ≤ 90° or > 90°, and a total of 514 deceleration events. Furthermore, analyses of Australian national league soccer players using global positioning system technology revealed that soccer players typically perform 304 medium speed accelerations (2.4–4.0 $m \cdot s^{-2}$), 360 medium speed decelerations (¯2.4–¯4.0 $m \cdot s^{-2}$), 20 high-speed accelerations (> 4.0 $m \cdot s^{-2}$) and 72 high-speed decelerations (> ¯4.0 $m \cdot s^{-2}$) in the course of the match (176). The results from the presented studies indicate that, although high intensity running and sprinting constitute only a minor percentage of the total distance covered, the possibility of such actions occurring at anytime during the 90 min match highlights the importance of integrating anaerobic conditioning into the training of soccer players.

2.2 Physical demands in soccer

Match analyses points out clearly that soccer is an intermittent sport with high intensity efforts throughout the entire match, indicating that the physiological stress on both the aerobic and anaerobic energy systems is high. Therefore, it is an advantage for soccer players that both energy systems are well developed so that they are able to cope with the physical demands of the game. A well developed aerobic energy system not only allows the player to play an entire match, but also to recover more quickly after high intensity bouts during the match. However, the difficulties associated with direct measures of energy expenditure during a match, and the variability in performance between matches, make the task of standardizing the actual demands challenging. Therefore, testing soccer players and evaluating the results obtained make it possible to further explore the demands of the game, and properly organize and prescribe conditioning training programs for soccer players.

2.2.1 Aerobic demands

Reilly et al. (143) has reported that energy expenditure during a match is ~5700 kj for a male weighing 75 kg with a maximum aerobic power (VO_{2max}) of 60 $mL \cdot kg^{-1} \cdot min^{-1}$, with an average intensity during a 90 min match close to 70% of VO_{2max}. However, the reported test results from several studies indicate that VO_{2max} typically falls within the range of 58–64 $mL \cdot kg^{-1} \cdot min^{-1}$ for elite male soccer player (32, 143, 157, 163) and 45–57 $mL \cdot kg^{-1} \cdot min^{-1}$for elite female soccer players (54, 77, 94). Analyzing the results of 1545 elite male Norwegian soccer players, revealed no significant differences between playing positions, although midfielders tended to score highest on the VO_{2max} test, followed by defenders, forwarders and goalkeepers (163). In contrast, Haugen et al. (77) reported a significant difference between elite female midfielders and goalkeepers. Reports from elite soccer players have also shown that fullbacks and midfield players' possess the highest VO_{2max} values compared to defenders and goalkeepers (17).

Field test results from the Yo-Yo Intermittent Recovery level 1 have been reported to be between 2179–2600 m for elite male soccer players (22, 33, 47, 95) and 826–1479 for elite female soccer players (104, 124). Research has further showed that both male and female top elite soccer players cover more distance in the Yo-Yo Intermittent Recovery test compared to elite players from lower playing levels and young elite players (22, 34, 104, 121, 124). Furthermore, the reported results indicate that both elite male and female wide midfielders cover more distance during the Yo-Yo Intermittent Recovery test compared to central midfielders, fullbacks, central defenders and attackers (34, 37). However, since the shared variance between Yo-Yo Intermittent Recovery test and VO_{2max} is only 50.4%, the test cannot be used to precisely determine the demands for aerobic capacity expressed as VO_{2max} (103). Therefore, soccer-specific field-testing of VO_{2max} involving dribbling, jumping, acceleration, deceleration, and change of directions have been suggested, but not widely used at the current time (88, 99).

2.2.2 Anaerobic demands

The reported high-intensity running from match analyses (24, 45, 58, 64, 121, 154, 159, 168) demonstrates the importance of anaerobic capacity for soccer players. Alongside the reported importance and frequency of sprinting actions, other anaerobic actions such as acceleration, deceleration, rapid change of direction, and skills such as tackling, jumping, and holding off opponents occur frequently during the course of a match. This emphasizes the importance of agility, ability to repeat sprints, and strength and power.

2.2.2.1 Linear sprint

Linear sprint can be divided into acceleration and maximum speed. Acceleration has been defined as the "rate of change in velocity that allows a player to reach maximum velocity in a minimum amount of time" and maximum speed is the "maximal velocity at which a player can sprint" (108). In the examination of linear sprint demands in soccer, it should be noted that testing of sprint performances is influenced by the testing system activation method and the start position of the player being tested (79). Hence, mean results from linear sprint performance are not fully representative in establishing a reference number in soccer. However, data from a large study consisting of 939 Norwegian elite soccer players who were tested on the same testing system for a period of 15 years with identical test procedures, indicate that a male top elite soccer player (n=49) typically scored 1.51 s for 10 m, 2.75 s for 20 m, and 5.02 s for 40 m linear sprints (Table 1). These data further indicate that players of higher playing level scored highest, and the fastest playing position was forwarders followed by defenders, midfielders and goalkeepers, respectively (81). Data for elite female soccer players was limited. However, the reported score results for top Norwegian elite female soccer players (n=85) tested between the year 1995 and 2010 on the same testing system with identical test procedures, were 1.67 s for 10 m, 3.05 s for 20 m, and 5.64 s for 40 m linear sprints (Table 1). The results further indicate that there were differences between playing levels with the higher level scoring highest, and forwarders were reported to sprint fastest followed by defenders, midfielders and goalkeepers, respectively (80).

2.2.2.2 Agility

Agility has been defined as the "speed in changing body positions or in changing direction" (51). The wide range of agility testing protocols used in the literature (Table 2) make it difficult to compare results across studies or calculate a generalizable reference number that can be set as a standard demand for soccer players. However, from the reported results it is noteworthy that different playing positions perform differently with different test protocols (156). The results from all agility tests in Sporis et al. (156) indicate that midfielders performed highest on all agility tests with the exception of the T-test where defenders performed highest compared to the other playing positions (Table 2).

Agility as defined by Clarke (51) involves the player directing the force applied to the ground in the opposite direction of the desired direction of movement. This action requires the player to adjust their position while traveling at a high linear speed in order to be able to perform the desired change of direction. This adjustment has been found to be a physical skill that can be improved by training (182) and therefore, it was advised to include agility in testing and training of soccer players.

2.2.2.3 Repeated sprint ability

The repeated production of high-intensity sprints, with short recovery time has been defined as repeated sprint ability (73, 78, 154). Repeated sprint ability has received increasing interest by researchers in the past years, resulting in several testing protocols emerging (Table 3). The majority of these tests were developed based on match analysis data from time motion studies available at the time (55). However, the widely used scoring methods in such repeated sprint tests were time and deterioration in performance expressed as percentage speed decrement (78). The results of the available studies within soccer indicate that top elite male and female soccer players score highest on repeated sprint ability tests compared to players from lower playing levels (70, 93). Fullbacks from elite senior male soccer were reported to score highest on repeated sprint ability tests compared to midfielders, forwarders, and defenders, respectively (93).

The repeated sprint test has been found to be a useful test for soccer players as it simulates the most intensive game periods and gives an indication of the ability to sustain speed over time and resist fatigue (78). Since soccer game is not predictable in nature, and repeated sprint efforts could occur in any time during the match play, it was strongly advised to test and train repeated sprint ability (55). However, the variation in test protocols used and the variability in test results complicate the task of comparing the results across studies in order to establish a reference number (Table 3).

2.2.2.4 Strength and power

Speed strength (power) has been reported to be an important factor during soccer match play (20, 64, 146). Faude et al. (64) reported that powerful actions in soccer in the form of power and speed were 61% straight sprinting, 22% vertical jumping, 8% speed with change of direction and 8% rotation. Vertical jump performance as a measure of strength and power has been evaluated in several investigations within soccer (Table 1). The reported results from those studies indicate that the score for elite male soccer players' were 38–46 cm and 39–48 cm for squat vertical jumping and countermovement vertical jump, respectively. For elite female soccer players the reported results were 28–36 cm for countermovement vertical jump. Furthermore, the results form studies that were conducted with a large number of players using the same testing system and identical procedures, indicate that top elite male and female soccer players have better vertical jump scores compared to players from lower playing levels (80, 81). Goalkeepers and forwarders were further reported to have the highest vertical jump performance compared to midfielders and defenders (80, 81, 157).

Power is the product of force × velocity (20, 127), indicating that an increase in force and velocity will in turn cause an increase in power output which would reflect on powerful moments during match-play (64). Thus, several authors agree that there is a benefit for soccer players to have higher levels of strength, achieved via strength training (20, 84, 113, 159). Therefore, vertical jump performance (as a measure of power) should be included in the test battery of soccer players to facilitate proper design of a training program based on the demands and capacity of players.

Table 1: Test results for linear sprint and vertical jump performances from different studies within elite male and female soccer players.

Study	Description	Sex	Country	n	Level / position	5 m (s)	10 m (s)	20 m (s)	40 m (s)	SJ (cm)	CMJ (cm)
Tomas et al. (162)	Elite junior	Male	Czech	22	All	1.09	1.85	2.48	-	-	-
Haugen et al. (81)	Top class	Male	Norway	49	National team	-	1.51	2.75	5.02	-	39.4
				315	1st div.	-	1.52	2.76	5.05	-	39.0
				106	Junior national	-	1.54	2.80	5.11	-	39.0
				136	Elite junior	-	1.55	2.83	5.19	-	35.4
				150	Forwarders	-	1.5	2.73	4.98	-	40
				210	Defenders	-	1.53	2.78	5.06	-	39.5
				210	Midfielders	-	1.54	2.8	5.11	-	37.5
				58	Goalkeepers	-	1.55	2.82	5.17	-	39.8
Enoksen et al. (61)	Elite junior	Male	Norway	26	All	1.52	-	5.09	-	40.1	-
Ingebrigtsen et al. (95)	Elite junior	Male	Norway	16	All	-	1.82	-	-	32.5	37.1
Boone et al. (32)	1st div.	Male	Belgium	289	All	1.46	2.20	-	-	40.8	43.6
				17	Goalkeepers	1.46	2.22	-	-	42.2	45.6
				60	Central backs	1.48	2.25	-	-	42.4	46.0
				82	Full backs	1.45	2.19	-	-	38.6	41.0
				68	Midfielders	1.46	2.21	-	-	39.4	41.4
				62	Attackers	1.43	2.15	-	-	41.2	44.2
Buchheit et al. (42)	Elite junior	Male	Qatar	90	All	-	1.71	-	-	-	44.5
Sporis et al. (157)	1st div.	Male	Croatia	270	All	1.44	2.27	3.38	-	44.1	45.1
				80	Defenders	1.43	2.14	3.36	-	42.3	44.2
				80	Midfielders	1.47	2.23	3.43	-	41.5	44.3
				80	Attackers	1.39	2.03	3.28	-	44.2	45.3
				30	Goalkeepers	1.45	2.35	3.51	-	46.8	48.5
Mujika et al. (124)	1st div.	Male	Spain	17	Senior	1.40	-	-	-	-	43.7
				17	Junior	1.40	-	-	-	-	43.9
Haugen et al. (80)	Top class	Female	Norway	85	National	-	1.67	3.05	5.64	-	30.7
				47	1st div.	-	1.70	3.11	5.75	-	28.1
				33	Elite junior	-	1.70	3.12	5.77	-	28.5
				44	Forward	-	1.68	3.05	5.62	-	30.5
				55	Defenders	-	1.69	3.09	5.71	-	29.6
				50	Midfielders	-	1.7	3.12	5.76	-	28.4
				16	Goalkeepers	-	1.71	3.14	5.83	-	30
Gabbett (70)	Highly trained	Female	Australia	11	National	-	-	3.3	-	-	-
				8	State	-	-	3.6	-	-	-
Krustrup et al. (105)	Top elite	Female	Denmark	23	All	-	-	-	-	-	36
Mujika et al. (124)	1st div.	Female	Spain	17	Senior	-	1.59	-	-	-	32.6
				17	Junior	-	1.62	-	-	-	28.4
Gabbett et al. (71)	Top elite	Female	Australia	16	All	1.15	1.90	3.2	-	-	-

Table 2: Test results from different agility test protocols used in soccer players testing for both male and female.

Study	Description	Sex	Country	n	Level/position	Protocol	All (s)	DF (s)	MF (s)	ATT (s)	CB (s)	FB (s)	GK (s)
Tomas et al. (162)	Elite	Male	Czech	22	Junior	Agility 505	2.42	-	-	-	-	-	-
						Agility k-test	10.65	-	-	-	-	-	-
Gunnarsson et al. (74)	Elite	Male	Denmark	18	Senior	4 high speed turns (30 m)	7.15	-	-	-	-	-	-
Boone et al. (32)	Elite 1st div.	Male	Belgium	289	Senior	Shuttle run 5 × 10 m	12.23	-	(n=68) 12.09	(n=62) 12.01	(n=60 12.53	(n=82) 12.22	(n=17) 12.32
Sporis et al. (156)	Elite	Male	Croatia	152	Junior	T-test	8.09	(n=36) 8.06	(n=84) 8.35	(n=32) 8.38	-	-	-
						Slalom test	7.79	7.97	7.82	7.85	-	-	-
						Sprint 4 x 5 m test	5.94	6.00	5.93	5.96	-	-	-
						Sprint with 90° turn (S90)	7.71	7.85	7.71	7.75	-	-	-
						9-3-6-3-9 m test (S180°)	7.44	7.42	7.30	7.66	-	-	-
						SBF test	7.78	7.80	7.78	7.94	-	-	-
Mujika et al. (124)	Elite 1st div.	Male	Spain	17	Senior	Agility 15 m	2.20	-	-	-	-	-	-
				17	Junior		2.37	-	-	-	-	-	-
	Elite 1st div.			17	Senior	Agility 15 m with ball	2.93	-	-	-	-	-	-
				17	Junior		3.29	-	-	-	-	-	-
Kaplan et al. (97)	Elite national	Male	Turkey	108	Senior	10 x 5 m shuttle run test	17.96	(n=32) 18.05	(n=38) 18.00	(n=28) 17.89	-	-	(n=10) 17.9
Brooks et al. (39)	Elite	Female	USA	22	NCAA div. I	Illinois Agility	16.1	-	-	-	-	-	-
Vescovi et al. (172)	Dedicated	Female	USA	113	College players	Illinois Agility	10.20	-	-	-	-	-	-
						Pro-agility	4.87	-	-	-	-	-	-
Mujika et al. (124)	Elite	Female	Spain	17	Senior	Agility 15 m	2.92	-	-	-	-	-	-
				17	Junior		3.07	-	-	-	-	-	-
				17	Senior	Agility 15 m with ball	3.93	-	-	-	-	-	-
				17	Junior		3.96	-	-	-	-	-	-

DF = Defenders, **MF** = Midfielders, **ATT** = Attackers, **CB** = Central backs, **FB** = Full backs, **GK** = Goalkeepers

Table 3: Test results from different repeated sprint ability (RSA) test protocols used in soccer players testing for both male and female.

Study	Description	Sex	Country	n	Level/position	RSA test Protocol	Recovery	Mean (s)	Mean %Dec
Buchheit and Mendez-Villanueva (40)	Elite	Male	Qatar	278	Junior	10 × 30 m	30 s	4.71	2.90
Ingebrigtsen et al. (95)	Elite	Male	Norway	16	Junior	7 × 35 m	30 s	5.44	-
Dellal and Wong del (56)	Elite	Male	France	8	Senior	10 × 20 m	25 s	2.96	0.94
Tonnessen et al. (164)	Elite	Male	Norway	20	Junior	10 × 40 m	60 s	5.32	-
Buchheit et al. (42)	Elite	Male	Qatar	90	Junior	10 × 30 m	30 s	4.31	-
				15	Full backs			4.73	-
				16	Central backs			4.59	-
				13	Middle defenders			4.65	-
				13	Wide midfielders			4.51	-
				9	Second strikers			4.60	-
				11	Strikers			4.51	-
Chaouachi et al. (48)	Elite	Male	Tunisia	23	Senior	7 × 30 m	25 s	4.46	5.87
Mujika et al. (125)	Elite	Male	-	11	U18	6 × 30 m	30 s	4.39	4.6
Impellizzeri et al. (93)		Male	Switzerland	30	Top-pro	6 × 40 m (20 + 20)	20 s	7.12	3.3
				45	Mid-pro			7.20	5.1
				33	Amateur			7.55	6.1
				34	Defenders			7.40	5.2
				20	Full backs			7.18	4.8
				33	Midfielders			7.25	4.8
				21	Forwarders			7.26	4.8
Rampinini et al. (134)	Elite	Male	Europe	18	Top-pro	6 × 40 m (20 + 20)	20 s	7.18	4.8
Gabbett (70)	Elite	Female	Australia	11	National	6 × 20 m	10 m	3.48	6.2
				8	State			3.88	6.8
Krustrup et al. (105)	Elite	Female	Denmark	23	Top-pro	3 × 30 m	25 s	-	-
					Pre-game			4.86	-
					Post-game			5.06	-
Gabbett et al. (71)	Elite	Female	Australia		Top-pro	6 × 20 m	10 m active	3.45	-

2.3 Aerobic and anaerobic relationship in soccer

Findings from match analyses suggest that aerobic energy allows the players to play the entire match, as well as aiding in the recovery process after anaerobic actions occurring during the game. However, to be able to understand the shared variance between the two energy systems and how they interact during the game, several researchers investigated the relationship between aerobic and anaerobic measures. Investigation of 42 professional soccer players showed a significant relationship between VO_{2max} scores and both total and average time from repeated sprint ability test (96). This is supported by Aziz et al. (11), who reported a significant relationship between VO_{2max} and total time from repeated sprint ability test for 40 male national hockey (n=17) and national soccer players (n=23), however, no significant relationship between VO_{2max} and single linear sprint time was reported. A significant relationship between VO_{2max} with repeated sprint test mean time and percentage of speed decrement was also reported for 29 well-trained Brazilian soccer players (53). The results reported by Pyne et al. (133) for 60 well trained male Australian football players revealed a significant relationship between repeated sprint measures and single sprint time over a distance of 20 m. Meckel et al. (116) reported a significant relationship between peak VO_2 and percentage speed decrement, but they did not find any significant relationship between measures of two repeated sprint ability tests and the calculated peak VO_2. However, the results from the presented studies, confirm the contribution of aerobic capacity to the recovery between high-intensity sprints during a repeated sprint test, and further highlights that repeated sprint ability is a function of single sprint speed and the ability to recover between sprints. Therefore, developing players' aerobic capacity and single sprint speed could improve the overall performance of soccer players. The relationship between aerobic and anaerobic tests in soccer is not well investigated and variation within results can be observed. Therefore, investigating the relationship between measures of aerobic and anaerobic performances in well-trained soccer players could add value and understanding to the underlying mechanism of how these two energy systems contribute during matches and training.

2.4 Sprint training for soccer players

Developing elite players' physical capacity requires implementation of a training program that should be based on optimal intensity, volume and frequency. Sprinting speed was originally believed to be a genetic quality that could not be improved through training. The positive results from different types of training methods tested with soccer players suggest that sprint abilities can be enhanced through well-designed training programs. A review of the literature showed that static stretching (150), constant sprint-to-rest ratio and recovery mode (1), plyometric training (151), repeated shuttle sprints with explosive strength (41) and different whole-body vibration frequencies (145) resulted in improved sprint performance. The results from these studies suggest that soccer players, irrespective of playing level, can be considered untrained in terms of sprint training compared to classical sprinters.

The challenge that faces soccer coaches is the time available for training, and most soccer coaches prefer to use the time available to train soccer specific tactical and technical skills rather than investing time in sprint training. It has therefore been suggested that other forms of anaerobic conditioning should be implemented in order to reduce the negative effect on available soccer training time (20, 142, 159). In order to be able to improve the anaerobic conditioning within the limited training time available, efficient training programs are needed. In order to design the optimal training program, training principles and load variables should be carefully considered by physical conditioning coaches.

2.4.1 Training principles

Research suggests that following the well-known training principles helps conditioning coaches to optimize and design training programs that could give the best effect in terms of enhancing the players performance, while also resulting in the lowest chance of injury. Among these principles are training specificity, variation, progression, individualization, periodization and trainings load. Therefore, a brief review of those principles could inform the design of anaerobic conditioning programs that match the physical demands required to play soccer at high level.

2.4.1.1 Specificity

After a physical training program being conducted, the physiological adaptation that reflects on performance transpires in the tissues and movement pattern that were exposed to training (142). In soccer, strength and speed training could be seen as specific supplementary training, which is believed to provide training advantages and reduce the risk of injury (76). Based on the presented match analyses data, the principle of specificity suggests that the development of the anaerobic conditioning in soccer could be achieved by selecting exercises similar to the activities observed in terms of the specific skeleton region, muscle and joint movement, direction of movement, energy source used, and other external factors such as playing ground, shoes etc. (14, 76, 137).

Research shows, for example, that agility and linear sprint are specific and independent qualities (108, 156, 171, 183), and suggests that improving agility should be related to adaptations in the specific coordination of the neuromuscular system (148, 149). Wojtys et al. (180) reported a neuromuscular adaptation to agility training in the form of improved spinal reflex and cortical response times in typical lower limb muscles. Other studies have reported that repeated sprint training improves repeated sprint ability (59, 66, 164). This highlights that, to be able to transfer the physical qualities gained through other forms of training (e.g. strength, power, plyometric), players should perform and train the specific task of sprinting or agility (151). However, performing the specific tasks for the purpose of causing adaptations is directly connected to the mode, duration and frequency of the training program implemented (82).

2.4.1.2 Variation

While the principle of specificity helps to advance the desired adaptations, training in general places high physiological stress on the player. Variation of training could alternate the physiological load on the player's body and thereby prevent undesired outcomes (15). In this sense, variation refers to the "change in program characteristics to match the changes in program goals as well as providing changes to the body to adapt forward" (101). Choosing different selections of exercises, or varying the intensity and the volume of the training could achieve this goal. Several studies have used combined exercises to improve the physical performance of soccer players as a form of variation in training. For example, Marques et al. (111) used a combined sprint and jump training program with a group of young soccer players and reported improvements in sprinting time and kicking velocity performances. Ferrete et al. (67) used a combined strength and high intensity training program and reported improvements in sprinting time, vertical jump, sit and reach flexibility test, and Yo-Yo Intermittent Recovery test performances in soccer players. Similarly, Faude et al. (65) used a combined strength and power training program and found improvements in sprinting, agility, vertical jumping and Yo-Yo Intermittent Recovery test performances in soccer players. The results of these studies, combined with specificity of training, indicate that variation can be a useful tool in developing new anaerobic conditioning programs to facilitate the physical development of soccer players.

2.4.1.3 Progression

Improving physical performance depends on an increase in the training load applied over time. However, it is well known that well-trained athletes will not respond to a training stimulus at the same rate as a beginner or a less trained athlete (90). Therefore, with improvements in the players' physical performance, the response and rate of adaptation to training becomes slower over time. Hence, the principle of progression refers to the "systematic increase in training frequency, volume, and intensity in various combinations" (131), and underlines the importance of increasing the load of exercise appropriately over time in order to cause continuing adaptation. However, the training load should not be increased at too fast a rate, nor should it be increased too slowly. Rather, the increase should be proportional to each individual player's increase in performance. Research shows that a dramatic increase in training load can result in injury, with the most frequent injuries in soccer occurring in the lower extremities (8). However, the limited time available for strength and conditioning training in soccer will impact on the approach to designing the conditioning training program, as it needs to fit around the soccer training program or, alternatively, be integrated into soccer training sessions.

2.4.1.4 Individualization

It has already been mentioned that the progression of training should be based on the individual player's progression. The individualization principle, therefore, is highly recommended for all athletes, including those who play in team sports. This is because research has shown that it promotes the highest training adaptation to the pre-identified variables that need to be improved (101). It is well known that setting the same training program for all players in a soccer team does not account for individual differences (6). The ideal idea of individualization is to organize the training program for each and every individual in the team based on their physical capacity profile and the physical demand of the game based on the individual playing position, level of play, and role in the team (31). This could be one of the reasons that individualization of training is notably established in the field of resistance training and other individual sports (15). Within soccer, individualization of the training program in an intervention study is a very difficult task due to the time available for soccer training and the balance and distribution of the intensity and training loads between soccer sessions. Therefore, most researchers within the field of applied sport sciences in team sports typically ask a one dimensional question, such as "does the training program implemented, whatever the mechanisms of its action, make a difference to the players' performance" (10). However, the literature show that studies targeting the individual capacity within team sports is lacking.

2.4.1.5 Periodization

Periodization has been defined as "a systematic variation in training specificity, intensity, and volume organized in periods or cycles within an overall program" (175). Matveyev (112) first introduced periodization in 1960's as a result of the different periods involved in the season. Matveyev divided the training plan into phases over a competition year and gave each phase specific characteristics. One of the key aims of periodization is to prevent overtraining, facilitate planning of the supercompensation of the players prior to matches and maintain the physical performance of the players (160, 166), and ultimately lead to successful results in important competitions (165). To achieve these goals, the choice of exercises, alongside the volume, intensity, and frequency of training should be considered carefully in the training plan. Therefore, considering the goal of the training program and the timing of implementation during the year is essential (175).

Some discrepancies can be observed in the results from intervention studies, and one of the possible explanations for this variation is that the development of players' performance as a result of training interventions is limited by the amount of stress they are exposed to during regular training and competition (102). It has been reported that the basal concentration of the two performance markers (testosterone and cortisol) were low during the completion of the season and significantly increased one week after the season, reflecting a dramatic reduction in total stress, which would cause better adaptation to training stimuli (102). This suggests that better effect of conditioning training programs could be observed in periods prior to competition. However, research conducted with soccer players have found a positive effect in both the pre- and in-season periods. This suggests that the adaptation of the players is also dependent on the players training status (30, 59, 109, 115, 128, 174). These results indicate that a well-balanced conditioning which is integrated with the soccer training program and in which the fundamental training load variables (volume, intensity and frequency) are manipulated appropriately, both in the short and long term, should lead to a positive results (165).

2.4.1.6 Training load

Beside tactical and technical skills that soccer players need to possess to play soccer, match analyses allow coaches and trainers to identify the physical demands players have to meet in order to perform at a high level. Therefore, in order to design effective training programs, testing of soccer players to identify their physical profiles and capacities is essential. Based on the information from the physical demands of the game and the physical profile of the players, a set of training goals can be determined. These training goals, in turn, facilitate the development of the players' physical performances. Conditioning coaches should design training programs to meet these pre-determined goals. Thus, developing soccer players' physical performance requires that the design of the conditioning program be based on the appropriate volume, intensity, and frequency.

2.4.1.6.1 Training volume

Training volume has been defined as "the sum of work performed during a training session or training phase" (31). Data from match analyses of both elite male and female soccer players have revealed that the total distance covered at high intensity during a game is between 20–30% of the total match distance covered, with ~11% at very high intensity, ~2.5% sprinting and with an average duration of 2 to 4 s per run, every 60–90 s. Considering the specificity principle, these findings indicate that in order to develop sprinting abilities, players are required to perform at maximal intensity (20, 62). However, to be able to perform the high intensity distance covered at maximal intensity, it was advised that players should conduct short bouts combined with recovery periods (intervals) (20, 142, 159). Therefore, several studies within soccer have chosen to use repeated sprinting intervals, taking into consideration total distance covered, time spent per single run, and the recovery periods observed between runs to properly plan the total training session volume (16).

Several protocols have been used in training, for example, Tønnessen et el. (164) used a 10 week periodized, once weekly, training program consisting of 2–5 sets × 4–5 repetitions over a 40 m distance (total volume 320–1000 m per week) with 90 s recovery between repetitions and 10 min recovery between sets. This study found significant improvements in 20–40 m linear sprint time and repeated linear sprint mean time. Buchheit et al. (41) implemented a 10 week periodized, once weekly, repeated sprint training program consisting of sprinting 2–3 sets of 5–6 repetitions over a distance of 15–20 m (total volume 200–360 m per week) with 14 s of passive recovery or 23 s of active recovery at a velocity of ~2 $m \cdot s^{-1}$ between repetitions and 3 min recovery between sets and found a significant improvement in linear sprint time over 30 m, repeated linear sprint mean time and vertical jump performance. Ferrari Bravo et al. (66) used a program of 3–4 training sessions per week consisting of 3 sets of 6 × 40 m repeated sprint (total volume 2160–2880 m per week) with 20 s recovery between repetitions and 4 min recovery between sets. They found an improvement of 2.5% in repeated sprint time performance. The results from these studies confirm that different training volumes (total work) give different results, and that the optimal volume, intensity, and frequency of training should be carefully considered when designing a conditioning program as these factors play a major role in determining the outcome.

2.4.1.6.2 Training intensity

Intensity has been defined as the "quality component of work an athlete performs in a given time" (31), or "the tension or stress put on the muscle" (129). Since intensity is relative to the individual player's capacity, it has been suggested that the best method of expressing intensity is by the percentage of the player's maximum capacity for that specific exercise (63). Research shows that soccer players, in certain periods of the match, perform high intensity runs without sufficient recovery time in between. This causes phosphocreatine levels to drop very low, triggering energy production from glycogen that lasts up to 30–40 s. This process, in turn, causes lactic acid to accumulate, affecting the player's performance. Hence, anaerobic conditioning has been suggested to be of great importance and value for soccer players (20, 21, 28, 140, 154, 161).

Anaerobic conditioning has been reported to impact positively on a player's ability to produce power rapidly, continuously, as well as improving their ability to recover after high intensity exercise. It has consequently been found that high intensity interval training can be an effective training method to improve the anaerobic conditioning of soccer players (20, 21, 28, 62, 142). Based on available data from match analyses and the principle of specificity, the recommended training dose for soccer players has been found to be in the region of 2–10 s in duration, performed with maximal intensity, with 2–10 repetitions, and a recovery of >10 times the exercise duration (20, 21, 164). Research conducted following these guidelines has been reported to have a positive effect on anaerobic performance measures such as linear sprint, vertical jump, and repeated sprint ability (41, 66, 114, 164).

2.4.1.6.3 Training frequency

One of the challenges facing soccer coaches is the time available for training. Therefore a sprinter's training program is not feasible for soccer players, because the sum of soccer training and sprint training would increase the physical stress level and could lead to overtraining. As a result, soccer coaches are often skeptical about implementing such training programs, especially considering the fact that to optimize the anaerobic training outcome, it is strongly advised to have appropriate recovery time (62). Therefore, one of the characteristics that should shape the sprint training program for soccer players is efficiency. Burgomaster et al. (43) has had a major impact on sport science concluding that low volume sprint interval training for ~1.5 hour per week gave similar results to traditional endurance training ~4.5 hour per week.

Since soccer players are not sprinters and can therefore be considered untrained in terms of sprint training, sprint training has been reported to have a positive effect on anaerobic measures even after just one session per week. Buchheit et al. (41) reported an improvement in sprint time following a repeated sprint training program of one session per week. Spinks et al. (155) reported an improvement in acceleration speed, power output, and reactive strength with a protocol consisting of training 1 session per week. Ferrari Bravo et al. (66) found an improvement in Yo-Yo Intermittent Recovery test distance covered, repeated sprint mean time, and an increase in $VO2_{max}$ respiratory compensation point following repeated sprint training sessions 3–4 sessions per week. Furthermore, comparing the effect of short vs. long high intensity runs on anaerobic performance revealed significant improvements in 30 m sprint time, 4 × 10 m shuttle running time, and 250 m running time after implementing a training program three sessions per week (114). Tønnessen et el. (164) used a weekly anaerobic training program and reported significant improvements in 20–40 m linear sprint time and repeated linear sprint ability mean time. In fact, comparing the results from the studies that have conducted training sessions once a week versus 3–4 sessions a week indicate almost similar improvements. Thus, it could be hypothesized that training just 1–2 times per week would give positive results in future studies. No study has so far examined the effect of anaerobic training frequency on soccer players' performance. However, it was advised that speed training should be incorporated at least twice a week in the soccer training program (75, 142).

2.4.1.6.4 Other load factors

Different load factors have been used to improve anaerobic performance. Among these are resisted sprint training, assisted sprint training, sled resisted training, weighted vests, parachutes and weight belts (4, 13, 50, 167, 177). The main purpose of these extra loads is to maximize force output through stimulating greater neural activation, which is believed to activate more fast-twitch muscle fibers, and thereby improve anaerobic performance (167).

Whether using such extra loads provide any added benefit is not yet clear. Clark et al. (50) did not find any significant improvement using weighted sled and weighted vests with 25 male national lacrosse players. Another study conducted with 19 male sport science students reported that sled load at 20% of body mass would benefit sprint speed over 30 m, and that a load of 12.5% would benefit acceleration speed (13). Whelan et al. (177) analyzed the effect of resisted sprint training on 12 physically active males and reported that, although there was a statistically significant improvement, the typical error did not provide strong evidence of an improvement. A further study that was conducted with 27 Division IA female soccer players (167), reported an increase in velocity over 36.6 m for both the assisted sprint group and resisted sprint group. Acceleration speed between 13.7–22.9 m was reported to improve significantly for the resisted sprint group, while decreasing for the assisted sprint group, and 22.9–36.6 m sprint time was improved significantly for the resisted sprint group while remaining unchanged for the assisted sprint group (167). The results from Upton (167) suggest that resisted sprint training could be beneficial to soccer players. Therefore, further studies using external loading factors could advance our knowledge about optimal anaerobic conditioning training for soccer players. It is worth noting that none of the studies mentioned above have combined the resisted and assisted phases in the same run. Therefore, it is possible that a combination and variation of the exercise could result in a superior effect.

In summary, the presented theoretical framework indicates that, while the aerobic system is the dominant energy source in soccer, anaerobic activities such as sprinting, changing direction and jumping have been shown to play a major role in the final match result. Therefore, anaerobic conditioning should be an essential part of the training program for soccer players. The challenge of time available for training can be overcome by considering the principles of training and the load factors affecting the design of the training program. Since soccer is not an entirely anaerobic sport in comparison to, for example, sprinting, it is expected that an appropriate anaerobic conditioning program would have positive results since soccer players can be considered untrained in terms of anaerobic training such as sprinting. However, in order to achieve these goals, strength and conditioning coaches should consider the physical demands of the game, the players' capacity profile, and the training principles. This will facilitate the design of an effective conditioning program appropriate for soccer players. Hence, the correct manipulation of load variables (volume, intensity and frequency) is crucial.

3 Aims and hypotheses of the thesis

The overall objective of this thesis was to develop and evaluate hypothetically deducted anaerobic training approaches for the purpose of training the anaerobic physical components of soccer players. To achieve this overall objective, five original research studies were carried out. In the first study (**Study I)**, a methodological study to verify the reproducibility of the measuring systems (equipment) used to collect data was conducted. A secondary objective of study I was to test the validity of the system. We hypothesized that since the construct validity of the systems are present and provided by the manufacturer, we expect that the errors associated with the systems are acceptable for us and would not degrades the ability to track changes in measurements in the experimental studies conducted in the present thesis.

In all the sub-studies presented in this thesis, the authors attempted as much as possible to design the intervention training programs taking into consideration the majority of the training principles. Therefore, the reported data from match analyses shaped the design of the training programs to target specifically the tissues and movement patterns reported to be involved. In the second study (**Study II),** the program implemented consisted of high intensity sprinting, with a working volume of 800 m per session and a frequency of two sessions per week. However, at the time of study II, there was only one study that we conducted that had examined the effect of specialized repeated sprint training without strength, plyometric or agility training on soccer player (164). Based on the outcome of this study, we developed the training program in study II in this thesis. Therefore, study II aimed to evaluate the effect of eight weeks specialized repeated sprint training program on elite male soccer players' anaerobic physical conditioning. Since soccer players are not sprinters, we hypothesized that this training approach, which is similar to the training models used for sprinters, would primarily benefit soccer players' repeated sprint ability and could also influence other anaerobic physical performance components such as linear single sprint and vertical jump.

Despite the high number of females participating in soccer, few studies have been conducted to improve their performance. No studies to date have evaluated the effect of combined resisted/assisted agility with repeated sprint training on soccer players' performance. Therefore, in the third study (**Study III)**, the participants followed a periodized training program consisting of high intensity sprinting with a total working volume of 320–800 m for repeated sprint training and 206–412 m for the resisted/assisted agility training, twice a week making a total volume for the combined group of 526–1212 m per week. For the strength training group, the total volume was individualized with a frequency of twice a week. The length of the intervention was 10-weeks. We hypothesized that resisted/assisted agility in combination with repeated sprint training would induce more positive changes in agility and sprinting abilities, whereas strength training would result in more positive effects on vertical jump and linear sprint performance.

In the fourth study (S**tudy IV),** the aim was to evaluate and compare the effects of an 8-weeks periodized repeated agility training program versus periodized repeated sprint training program on the anaerobic conditioning of elite female soccer players. Participants were required to perform a periodized high intensity effort with a training volume of 400–720 m for the repeated linear sprint training group and 320–640 m for the repeated agility training group with a frequency of once a week. We hypothesized that repeated agility training would induce more positive effects on agility performance, while repeated sprint training would enhance linear sprinting abilities. We further anticipated that study III and IV could provide valuable information for the planning of physical training in female soccer, as well as other sports involving repeated explosive actions. A secondary purpose of study II, III, and IV were to determine whether there were any changes in aerobic capacity as a result of the anaerobic training programs implemented in these studies.

In order to better understand the results from study II–IV, a follow-up fifth study (**Study V**) was conducted, with the aim of investigating the relationship between measures of sprinting abilities, fatigue index, measures of lower body strength and power outputs, and aerobic fitness in well trained elite female soccer players. We hypothesized that there would be a relationship between measures of sprinting but not between linear sprinting and agility. We also hypothesized that there would be a relationship between aerobic capacity and repeated sprint ability performances, and that there would be a relationship between fatigue indexes from repeated sprint ability test and the results of repeated sprinting ability test. Finally, we hypothesized that there would be a relationship between measures of vertical jump and sprint performances.

4 Methods

4.1 Participants

After the volunteered to participate in the present project, results for one hundred and five well-trained elite male (n=38) and female (n=67) soccer players were collected throughout the project. The participants were all highly committed to training and competing under the Norwegian football association championships in different divisions. Participant characteristics are presented in Table 4.

Table 4: Participant characteristics across studies (mean ±SD).

	n	Sex	Age (yrs.)	Body mass (kg)	Height (cm)	Division
Study I	20	Male	19.1 ±3.5	72.6 ±7.8	179.0 ±0.8	3rd div.
Study II	18	Male	16.4 ±0.9	67.2 ±9.1	176.3 ±7.4	Junior elite (top division)
Study III	20	Female	19.4 ±4.4	59.1 ±5.6	167.6 ±5.0	2nd div.
Study IV	17	Female	21.2 ±2.6	64.0 ±5.9	168.8 ±4.6	Top div.
Study V	30	Female	19.0 ±4.0	57.5 ±6.9	167.0 ±4.0	2nd div.

4.2 Ethical considerations

The data in study I was collected as a part of my work as a strength and conditioning coach for the soccer team tested at the time (2004). All participants that took part in study I had signed a contract with the club to commit to training and conduct the regular testings required. All participants were verbally informed and verbal consent was obtained to use the data in my master degree study at the time. My masters study head supervisor, professor Eystein Enoksen, approved the study and the procedure after carefully reviewing the approach. Further approval was granted by the Norwegian Olympic Sport Centre to set up extra timing systems and testing equipment's.

Studies II, III and IV were a part of this Ph.D. project description that was submitted for approval and approved by the external and internal scientific committee assigned by the Norwegian School of Sport Sciences, Study V was based on data collected from pre-testing in study III. Due to the nature of the studies in this Ph.D. thesis and after a careful review of the Helsinki Declaration and the roles and regulations of the Regional Committees for Medical and Health Research Ethics of Southern Norway (REC), the approval of REC was not required as none of the studies conducted involves individual patients, health and diseases, using central health registers, human biological materials, and/or using traceable personal information and evaluations of health conditions (139). Therefore, my main supervisor professor Eystein Enoksen at both the Norwegian School of Sport Sciences and the University of Nordland approved all part studies in this thesis after carefully reviewing the procedures and approaches.

Thereafter, the project was submitted to and approved by the Norwegian Social Science Data Services (NSD) with the reference number: 37679/3/LT (Appendix B). All participants older than 18 years old gave their oral and/or written voluntary informed consent, and the parents of all participants younger than 18 years old gave their oral and/or written voluntary informed consent on behalf of their children. Appendix B also shows the informed consent that was provided to the players and their parents at the time of the studies. After the publishing of each study, as requested by NSD, all raw data was anonymized to encrypt and remove personal identifiable information from the data sets.

4.3 Experimental approach

Study I was conducted to measure the reliability and reproducibility of the testing systems used throughout study II to V. However, to be able to evaluate and compare the effects of the training protocols used in study II, III and IV, a pre-test – post-test randomized groups research design was applied. In each of the three studies, two independent groups of participants were tested before and after the experimental period. Furthermore, to understand the relationship between aerobic and anaerobic measures, a follow up descriptive research design study (study V) was assessed based on the pre-test data collected in study III.

4.3.1 Reproducibility of measures (Study I)

The aim of this study was to assess the reliability and reproducibility of the Newtest Powertimer 300-series measuring system and the Norwegian Olympic Center (NOC) measuring systems. Twenty Norwegian well-trained male soccer players were tested for countermovement vertical jump, squat vertical jump and 0–40 m linear sprint with a split time from 0–20 m and 20–40 m. To measure the validity of the Newtest Powertimer contact mat, we placed the Newtest Powertimer contact mat over the NOC force platform. The purpose was to calibrate the force platform to Zero with the contact mat placed on top to be able to register the vertical jumping height on both systems simultaneously. Thus, measurement of the NOC force platform was not influenced by the weight of the Newtest Powertimer contact mat. The NOC force platform had a time resolution of 1000 Hz and a force resolution of 0.1 N.

For sprinting, the Newtest Powertimer photocells were placed exactly at the same angle as the NOC photocells that were mounted on an indoor sprint track. All testing instruments were checked and approved by the testing experts at the Norwegian Olympic Sport Centre before the testing took place. All measures were carried out at the Norwegian

Olympic Sport Centre, Oslo, Norway. Each athlete was permitted three trials, with the best result retained for analysis. To be able to test reliability of the systems, all measurements of variables were performed on two consecutive days at the same place and time of day, and with the same settings and configurations.

4.3.2 Evaluation of repeated sprint training (Study II)

The aim of the study was to evaluate and examine the effect of 8 weeks 40 m repeated sprint training program on young elite male soccer players' physical performance. The pre- and post-tests conducted were 3-6-9 m agility with a 180° turn, 0–40 m linear sprint, 10 × 40 m repeated linear sprint, countermovement vertical jump, squat vertical jump and Yo-Yo Intermittent Recovery level 1 test. Measures were carried out at the Department of Sport (University of Nordland), and Nordland indoor soccer stadium, Bodø/Norway. Participants in this study were matched according to their pre-test results from the 0–40 m linear sprint test, before being randomly assigned to one of two groups, a repeated sprint training group (n=9) and a control group (n=9). Three participants were dropped out and the study continued with 15 subjects divided into repeated sprint training group (n=8) and a control group (n=7). Both groups were instructed to continue the teams' original training plan, with the repeated sprint training group conducting two extra training sessions per week consisting of repeated sprint training. The training program completed by the repeated sprint training group included sprinting four sets of 5 × 40 m with 90 s recovery between repetitions, and 10 min recovery between sets. The study took place in the pre-season period.

4.3.3 Evaluation of agility, repeated sprint, and strength training (Study III & IV)

The aim of study III was to evaluate and compare the effect of 10 weeks combined agility with repeated sprint training versus strength training on elite female soccer players. The pre- and post-tests conducted were squat vertical jump, countermovement vertical jump, 7 × 30 m repeated linear sprint with 30 s recovery in between, 0–40 m linear sprint, S180º agility test (156), and multi stage fitness test (Beep test). Measures were carried out at the Nordland indoor soccer stadium, Bodø/Norway. The participants were matched according to their pre-test results from the 0–40 m linear sprint test, before being randomly assigned to one of two groups, either combined agility with repeated sprint training group (n=10) or strength training group (n=10). Both groups were instructed to continue the teams' original training plan, with the combined agility with repeated sprint training group conducting two extra training sessions per week, one with resisting band (Table 5, Figure 1), and one with repeated sprint training (Table 6). The strength training group completed two weekly strength-training sessions in addition to their regular soccer training (Table 7). The study took place at the beginning of the competition season.

Table 5: Periodization of sprint training with resistance running band in study III (session one of every week).

Week 1	2 Sets	R=1 min	SR=10 min	I=100%
Week 2	3 Sets	R=1 min	SR=10 min	I=100%
Week 3	4 Sets	R=1 min	SR=10 min	I=100%
Week 4	3 Sets	R=1 min	SR=10 min	I=100%
Week 5	3 Sets	R=1 min	SR=10 min	I=100%
Week 6	4 Sets	R=1 min	SR=10 min	I=100%
Week 7	2 Sets	R=1 min	SR=10 min	I=100%
Week 8	3 Sets	R=1 min	SR=10 min	I=100%
Week 9	3 Sets	R=1 min	SR=10 min	I=100%
Week 10	2 Sets	R=1 min	SR=10 min	I=100%

R = Recovery between exercises, **SR** = Recovery between sets, **I** = Intensity.

Table 6: Periodization of repeated sprint training in study III (session two of every week).

Week 1	3 Sets of 4 × 40 m	R=1:30 min	SR=10 min	I=95%
Week 2	4 Sets of 4 × 40 m	R=1:30 min	SR=10 min	I=95%
Week 3	5 Sets of 4 × 40 m	R=1:30 min	SR=10 min	I=95%
Week 4	2 Sets of 5 × 40 m	R=1:30 min	SR=10 min	I=95%
Week 5	3 Sets of 5 × 40 m	R=1:30 min	SR=10 min	I=95%
Week 6	4 Sets of 5 × 40 m	R=1:30 min	SR=10 min	I=100%
Week 7	2 Sets of 5 × 40 m	R=1:30 min	SR=10 min	I=100%
Week 8	3 Sets of 5 × 40 m	R=1:30 min	SR=10 min	I=100%
Week 9	4 Sets of 5 × 40 m	R=1:30 min	SR=10 min	I=100%
Week 10	2 Sets of 4 × 40 m	R=1:30 min	SR=10 min	I=100%

R = Recovery between exercises, **SR** = Recovery between sets, **I** = Intensity.

Table 7: Strength training program followed by the strength training group in study III.

Exercise	**wk 1**	**wk 2**	**wk 3**	**wk 4**	**wk 5**	**wk 6**	**wk 7**	**wk 8**	**wk 9**	**wk 10**
Leg press	2x10 RM	3x10 RM	3x8 RM	3x8 RM	3x8 RM	3x6 RM	3x6 RM	3x6 RM	3x4 RM	3x4 RM
Squat jump	2x6	3x6	3x5	3x5	3x5	3x5	3x5	3x5	3x4	3x4
Nordic-Hamstring	2x10 Rep	3x10 Rep	3x8 Rep	3x8 Rep	3x8 Rep	3x6 Rep	3x6 Rep	3x6 Rep	3x4 Rep	3x4 Rep
Leg-extension	2x10 RM	3x10 RM	3x8 RM	3x8 RM	3x8 RM	3x6 RM	3x6 RM	3x6 RM	3x4 RM	3x4 RM
Cable Hip flexion	2x10 RM	3x10 RM	3x8 RM	3x8 RM	3x8 RM	3x6 RM	3x6 RM	3x6 RM	3x4 RM	3x4 RM
Cable Hip Extension	2x10 RM	3x10 RM	3x8 RM	3x8 RM	3x8 RM	3x6 RM	3x6 RM	3x6 RM	3x4 RM	3x4 RM

Recovery between sets = 2 min; **RM** = Repetition maximum.
In the squat jump the players used a weight between 20-50 kg depending on the player strength level and technical abilities.
Rep = Repetitions; **wk** = Week.

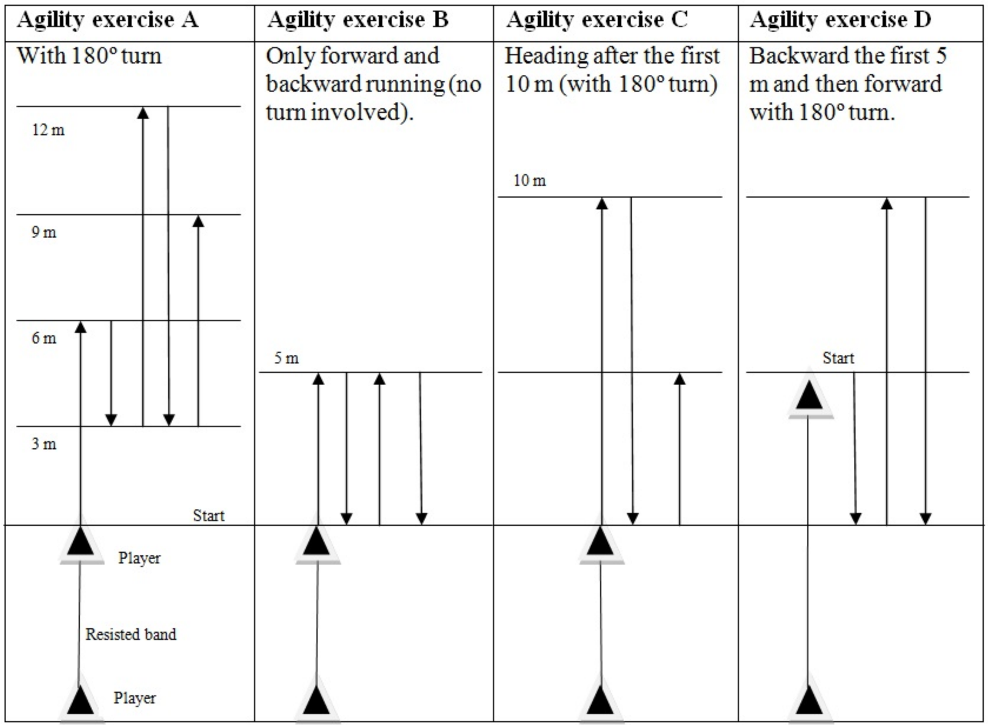

Figure 1: The 4 agility exercises performed during the resisted running sessions in study III.

The aim of study IV was to evaluate the effect of 8 weeks repeated agility training compared to repeated sprint training on elite female soccer players. The pre- and post-tests conducted were 0–40 m linear sprint, 40 m agility test, countermovement vertical jump, 10 × 40 m repeated linear sprint test with 60 s recovery between each sprint, and the Yo-Yo Intermittent Recovery level 1 test. All measures were carried out at the Norwegian Olympic Sport Centre, Oslo, Norway. The participants were randomly assigned to either a repeated agility training group (n=8) or a repeated sprint training group (n=9). Both groups were instructed to continue the teams' original training plan, with the repeated agility group completing one extra training session per week consisting of repeated agility training (Table 8, Figure 2), while the repeated sprint training group completed one extra training session per week consisting of repeated sprint training (Table 9). The study took place during the pre-season period. Since the repeated agility training lasted approximately 4 s longer than the repeated sprint training group, the repeated agility program was designed to allow between 15–20% fewer repetitions and an extended 30 s longer recovery period between each run to better match for total training load.

Table 8: Periodization of the repeated agility training in study IV.

Week 1	2 Sets of 4 × agility run	R=2 min	SR=10 min	I=95–100%
Week 2	2 Sets of 5 × agility run	R=2 min	SR=10 min	I=95–100%
Week 3	2 Sets of 6 × agility run	R=2 min	SR=10 min	I=95–100%
Week 4	2 Sets of 4 × agility run	R=2 min	SR=10 min	I=95–100%
Week 5	2 Sets of 6 × agility run	R=2 min	SR=10 min	I=95–100%
Week 6	2 Sets of 7 × agility run	R=2 min	SR=10 min	I=100%
Week 7	2 Sets of 8 × agility run	R=2 min	SR=10 min	I=100%
Week 8	2 Sets of 6 × agility run	R=2 min	SR=10 min	I=100%

R = Recovery between exercises, **SR** = Recovery between sets, **I** = Intensity.

Table 9: Periodization of the linear repeated sprint training in study IV.

Week 1	2 Sets of 5 × 40 m	R=1:30 min	SR=10 min	I=95–100%
Week 2	2 Sets of 6 × 40 m	R=1:30 min	SR=10 min	I=95–100%
Week 3	2 Sets of 7 × 40 m	R=1:30 min	SR=10 min	I=95–100%
Week 4	2 Sets of 5 × 40 m	R=1:30 min	SR=10 min	I=95–100%
Week 5	2 Sets of 7 × 40 m	R=1:30 min	SR=10 min	I=95–100%
Week 6	2 Sets of 8 × 40 m	R=1:30 min	SR=10 min	I=100%
Week 7	2 Sets of 9 × 40 m	R=1:30 min	SR=10 min	I=100%
Week 8	2 Sets of 7 × 40 m	R=1:30 min	SR=10 min	I=100%

R = Recovery between exercises, **SR** = Recovery between sets, **I** = Intensity.

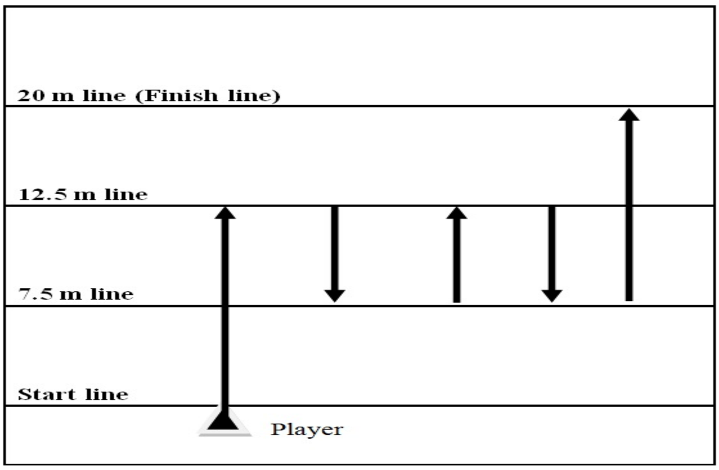

Figure 2: The repeated agility exercise performed by the repeated agility training group during the intervention period in study IV.

4.3.4 The relationship between aerobic and anaerobic measures (Study V)

The main purpose of the study was to investigate the relationship between measures of sprinting abilities (0–40 m linear sprint time, 0–20 m linear sprint, 20–40 m linear sprint, repeated linear sprint, and sprint with change of direction), fatigue index, measures of lower body strength and power output (force, peak power), and aerobic performance. A secondary purpose of the study was to conduct stepwise analyses to determine the physical parameters that most affect performance of repeated sprint ability and sprint with change of direction. Thirty well-trained female soccer players were tested at an indoor track and field and soccer arena. All tests were supervised by testing experts from the Norwegian Olympic Sport Centre. The players were tested for 0–40 m linear sprint, 7 × 30 m repeated linear sprint, S180º agility test (156), countermovement vertical jump, squat vertical jump, and Beep test.

4.4 Apparatus

4.4.1 Timing systems

In study I and IV, the NOC timing system was used. The system is a fixed mounted laboratory timing system at the Norwegian Olympic Sport Center, with a dedicated indoor 40 m track with 8 mm Mondo track FTS surface (Mondo, Conshohocken, USA) and electronic timing equipment. A 60 × 60 cm start pad was placed under the track at the start line. The timer was initiated when the front foot left the start pad. Infrared photocells with transmitters and reflectors were placed in pairs on each side of the running track with 1.6 m in between and approximately 140 cm above the floor. The beams had to be broken to trigger each photocell. Electronic times were transferred to computer software (Biorun, made in MatLab by Biomekanikk AS, Oslo, Norway).

In study I, II, III and V, the Newtest Powertimer testing system photocells (Oy, Finland) was used. The testing system is portable consisting of photocells with a narrow infrared beam and no reflectors, and a portable briefcase with built in connections and rechargeable batteries. The photocells were connected via cables to the system briefcase and the briefcase was connected via cables to a laptop. All measures were recorded using Powertimer PC that measures time to the nearest 0.001 s (132). Reproducibility of both timing systems was assessed in study I.

4.4.2 Force platform

In study I, II, III, IV and V, vertical jump height was estimated both in the laboratory and in the field using the AMTI force platform-based determinations of impulse and thus velocity at takeoff. The force platform used was AMTI model AccuPower (Watertown, MA, USA). The force platform had a built-in amplifier model SGA6-3, and a digitizer model DT 2801, and the data were saved to a computer with the aid of the AccuPower software (Biopack MP 100). According to the manufacture, the lowest natural frequency of the force platform is >100 Hz. Reproducibility of the AMTI force platform was assessed in study I.

4.4.3 CD player system

A JVC powered woofer CD-system (RV-NB51WEN) was used to play the Beep test (Study III and V) and Yo-Yo Intermittent Recovery level 1 test (study IV) CDs that came with the test packages. The Beep time intervals were monitored with a stopwatch before each test in order to control for the playing speed of the CD-player. In study II, A Denon CD-player (DC 1015, Denon Brand Company, Japan) with amplifier (F590ES), and loudspeakers (SS-E420, Sony Corporation, Japan) were used to play the Yo-Yo Intermittent Recovery level 1 test CD track.

4.5 Testing procedures

Study I, II, III, IV and V followed identical standard warm-up procedures prior to testing. The warm up consisted of 15 minutes of general warm-up, comprised of running at 60–70% of maximum heart rate, followed by 3–5 accelerations over 40–50 m, stretching, and cool down during the last 5–6 min prior to testing.

4.5.1 Linear sprint test

The distance of 0–40 m was chosen for the sprint tests in order to evaluate both acceleration and maximum sprint capabilities. The 0–20 m split time was defined as acceleration, while the 20–40 m split time was defined as maximal sprint velocity. The participants started from a standing position by placing the front foot on the starting line, and when the test leader gave the signal, the subject started the sprint to the finish photocell (40 m). The timer started automatically when the subject broke the beam from the first photocell, placed at the starting line (Study I, II, III & V) or when the athlete left the starting mat (Study I & IV), which was defined as time Zero, and stopped when the player passed the photocells at both 20 m and 40 m.

4.5.2 Repeated linear sprint ability

In study II and IV, participants were asked to complete a 40 m repeated linear sprint test by completing 10 maximum sprints separated by 60 s recoveries. Participants were asked to run as fast as possible for every sprint. Participants started from a standing position with the front foot placed on the starting mat (study IV) or by placing the tip of the toe of the front foot on the starting line (study II). The timer started automatically when the athletes left the starting mat or broke the beam of the first photocell (time Zero) and stopped when they passed the photocell at the 40 m mark. The distance of 40 m and the recovery time of 60 s between each sprint were selected based on the duration and frequency of high intensity running reported from time motion match analyses. In study III and V, the players were asked to complete a 7 × 30 m repeated linear sprint ability test. The test started from an upright position with participants placing the tip of the toe of the front foot on the starting line. When the test leader gave the signal, the participant sprinted to the finish line, using the shortest possible time to cover the 30 m. After 30 seconds recovery, the participant started the next 30 m sprint. This procedure was repeated until the participant had completed all 7 sprints. The timer started when participants crossed the photocell placed on the start line (time Zero) and stopped when the participants crossed the 30 m photocell. The test was modified from the soccer specific repeated sprint ability test known as the Bangsbo repeated sprint test (18).

4.5.3 Countermovement vertical jump

The countermovement vertical jump test was performed by standing with the plantar section of the foot in contact with a force platform. The jumps were performed from an erect standing position with a knee angle of 180º and hands placed on hips. When instructed, participants lowered themselves until the knee angle reached approximately 90º, before immediately rebounding in a vertical jump.

4.5.4 Squat vertical jump

The squat vertical jump test was performed from a semi-squat position with no countermovement. Participants were instructed to start in a stationary squat position with a knee angle of approximately 90° and the plantar section of the foot in contact with the force platform. The hands were placed on hips and the trunk was erect. On the test leader's signal, participants were instructed to jump immediately, straight vertically.

4.5.5 Multi stage fitness test (Beep test)

To measure aerobic performance, participants in study III and V completed a shuttle running test. Participants ran back and forth between two lines 20 m apart. Running speed was dictated by a recorded soundtrack and increased progressively by 0.5 $km \cdot h^{-1}$ every minute, with an initial starting speed of 8.5 $km \cdot h^{-1}$ (107). Participants were required to reach the opposite 20 m line in time with the beep signal from the CD soundtrack or before. When the participant could no longer maintain the required pace, indicated by failing twice to reach the opposite line in time with the beep, the final stage number was recorded.

4.5.6 Yo-Yo Intermittent Recovery level 1 test

This test has been proposed to be a soccer specific test to assess aerobic performance (103) and it was used in study II and IV. Prior to the start, the test leader measured and marked out a 20 m running lane, and a recovery area of 2 × 5 m behind the finishing line. The test was conducted according to the test criteria and procedures described by Krustrup et al. (103). Briefly, participants were required to run 2 x 20 m before a 10 s active recovery consisting of jogging 2 x 5 m. When participants could no longer maintain the required pace, indicated by failing twice to reach the opposite line in time with the beep, the final stage number was recorded.

4.5.7 Agility tests

In study II, the 3-6-9 m agility with a 180° turn test was used (total distance of 40 yards). This involved positioning three lines on the playing field: one at 3 m, one at 6 m, and one at 9 m. A photocell was placed at the start/finish line. Participants were instructed to sprint to the first line (3 m) and touch it with one foot, make a 180° turn and sprint back to the starting line, touching it with the foot. Immediately, the participant sprinted to the second line (6 m) and repeated the procedure described above. Finally, participants ran to the third line (9 m) before sprinting back to complete the test by crossing the start/finish line. The timer started when the participant passed the photocell at the start/finish line (time zero) and stopped when the participant passed the photocell after finishing the last run.

In study III and V, the S180º Agility test proposed by Sporis et al. (156) was performed with a total distance of 30 m. For this test, participants were required to start on a signal from the test leader and run 9 m from the starting line. Having touched the 9 m line with one foot, the participant made either a left or right 180º turn. All the following turns had to be made in the same direction. The players then ran 3 m, made another 180º turn, before running another 6 m. After another 180º turn, the participant had to run another 3 m, before making the final turn and running the final 9 m to cross the finish line.

In study IV, the agility test had a total running distance of 40 m and included four 180º turns. Lines were marked with tape at 7.5 m, 12.5 m and at the finish line at 20 m.

Participants sprinted from 0–12.5 m, back to the 7.5 m line, forward to the 12.5 m line, back to the 7.5 m line, and finally forward to the finish line at 20 m (Figure 2).

4.6 Statistical Analyses

Raw data were transferred to SPSS (SPSS Inc., Chicago) for Windows and Analyse-it for Microsoft Excel. In study I, Bland and Altman's 95% limits of agreement as described by Atkinson and Nevill (9), were used to assess the reliability of both testing systems. A paired t-test was used to assess the hypothesis of zero bias in both reliability and validity. To determine whether the systems is of practical use, the analytical goals regarding reliability were set to a total error (systematic bias and random error) that did not exceed ± 0.2 s for sprint measures and ± 1.5 cm for vertical jump measures.

To detect differences in measures between the pre-test and the post-test in study II and III, a paired sample t-test was performed to test for a difference in central location (mean) between the paired samples (within group). To test for a difference in central location (mean) between groups, an independent sample t-test was applied. In order to determine the effectiveness of the applied training interventions, the effect size (Cohen's d) was calculated according to Rosnow and Rosenthal (147). Furthermore, to determine whether the effect size was trivial (d>0.2), small (d=0.2–0.6), moderate (d=0.6–1.2), large (d=1.2–2.0), or very large (d>2.0), the scale developed by Batterham and Hopkins (27) was used.

In study IV, a 2 × 2 mixed-model analysis of variance (also known as a split-plot ANOVA) was used to test for differences between the groups' results from pre- to post-test. Furthermore, a one-way repeated measures ANOVA was used to determine within group differences from pre- to post-test. To determine whether the effect size between groups was small (0.10), medium (0.25) or large (0.40), the scale developed by Cohen (52) was used.

In study V, correlation matrices between all variables were determined using Pearson's r. A stepwise linear regression analysis was used to determine the physical abilities that, to the greatest extent, explained performance of repeated sprint ability and sprint with change of direction. The $P < 0.05$ level of significance was adopted for all statistical tests used in all the studies.

5 Results

5.1 Reproducibility of measuring systems (Study I)

The results from study I indicate that the total error (systematic bias and random error) would not exceed 1.54% for the Newtest Powertimer timing system, 4.0% for the Newtest Powertimer contact mat, 1.6% for the NOC timing system, and 1.4% for the force platform (Table 10). Furthermore, the test–retest reliability in study I did not show any marked systematic bias for all testing systems.

Table 10: Reliability measures for the Newtest Powertimer, NOC and the force platform (Study I).

System	Test	Re-test	Bias	Limits of agreement	Paired t-test *P* value
NP 0–20 m (s)	3.00 ± 0.11	3.01 ± 0.12	–0.04%	± 1.1%	0.081
NP 0–40 m (s)	5.35 ± 0.20	5.39 ± 0.18	–0.04%	± 1.5%	0.156
NP CMJ (cm)	39.3 ± 3.8	39.1 ± 3.4	0.2%	± 3.2%	0.776
NP SJ (cm)	37.0 ± 3.3	36.2 ± 3.4	0.7%	± 3.3%	0.303
NOC 0–20 m (s)	2.84 ± 0.08	2.84 ± 0.09	0.01%	± 1.1%	0.699
NOC 0–40 m (s)	5.22 ± 0.15	5.23 ± 0.17	0.00%	± 1.6%	0.852
NOC CMJ (cm)	39.5 ± 2.1	39.2 ± 2.2	0.4%	±1.0%	0.069
NOC SJ (cm)	35.7 ± 1.0	35.6 ± 0.9	0.1%	± 0.9%	0.616

NP =Newtest Powertimer; **NOC** = the Norwegian Olympic center; **CMJ** = Countermovement vertical jump; **SJ** = Squat vertical jump.

5.2 Evaluation of repeated sprint training (Study II)

The results from study II indicate a significant improvement within the repeated sprint training group from pre- to post-test in 0–40 m linear sprint time (-0.33 ±0.13 s), 10 × 40 m repeated linear sprint time (-0.29 ±0.13 s), 0–20 m linear sprint time (-0.19 ±0.10 s), 20–40 m linear sprint time (-0.15 ±0.08 s) and countermovement vertical jump (1.3 ±1.2 cm). The within control group results showed a significant improvement in 0–40 m linear sprint time (-0.11 ±0.06 s), 10 × 40 m repeated linear sprint time (-0.09 ±0.03 s) and 0–20 m linear sprint time (-0.10 ±0.06 s). A comparison between the two groups (Table 11) showed statistically significant differences in 0–40 m linear sprint time, 10 × 40 m repeated linear sprint time and 20–40 m linear sprint time (Figure 3).

Table 11: Mean differences between groups from pre to post-test (Study II).

Variable	Training group	Control group	Difference	95% confidence interval
0–40 m (s)	-0.33 ±0.13	-0.11 ±0.06	-0.22 ±0.05	-0.34 to -0.10**
10x40 m mean (s)	-0.29 ±0.13	-0.09 ±0.03	-0.20 ±0.05	-0.30 to -0.09**
0–20 m (s)	-0.19 ±0.10	-0.10 ±0.06	-0.08 ±0.04	-0.18 to 0.01
20–40 m (s)	-0.15 ±0.08	-0.00 ±0.05	-0.15 ±0.03	-0.22 to -0.07**
CMJ (cm)	1.3 ±1.2	-0.9 ±2.6	2.2 ±1.0	-0.03 to 4.32
SJ (cm)	0.9 ±2.0	-0.5 ±2.5	1.4 ±1.2	-1.12 to 3.96
Yo-Yo IR1 (Level)	-0.2 ±0.6	-0.5 ±0.8	0.3 ±0.4	-0.45 to 1.08
Agility (s)	-0.10 ±0.15	-0.08 ±0.23	-0.02 ±0.10	-0.23 to 0.19
Body mass (kg)	0.8 ±1.4	0.7 ±0.9	0.0 ±0.6	-1.29 to 1.31

CMJ = Countermovement vertical jump; **SJ** = Squat vertical jump, * = $P < 0.05$, ** = $P < 0.01$.

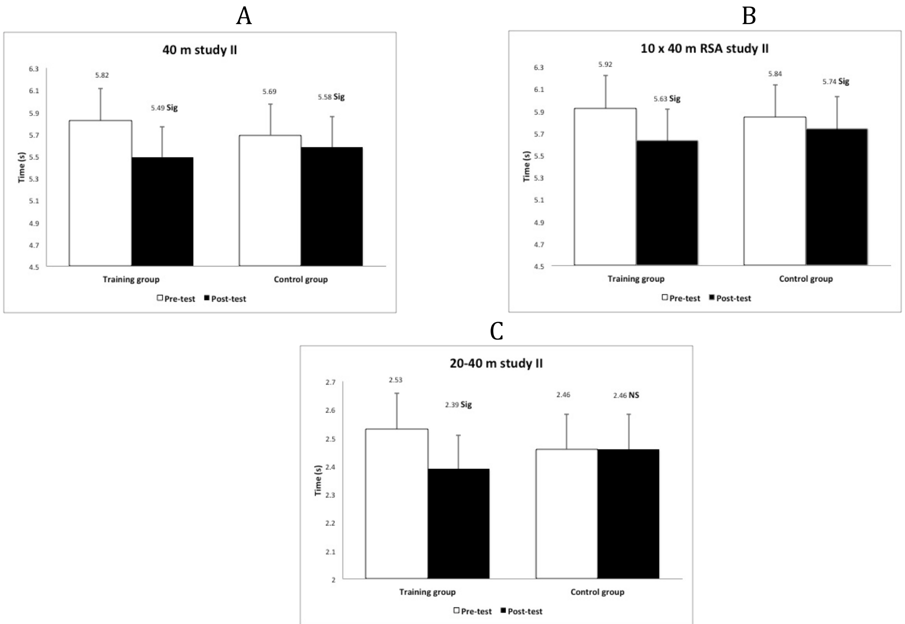

Figure 3: (A) mean time of 0–40 m linear sprint, (B) 10 × 40 m repeated linear sprint ability, and (C) 20–40 m linear sprint for both groups (Study II).

5.3 Evaluation of agility, repeated sprint, and strength training (Study III & IV)

The results from study III indicate that the combined resisted agility with repeated sprint training implemented did not have any significant effect on the resisted sprint training group performance tests results (Table 12) with the exception of Beep test performance (1.2 ±0.7 level). However, the strength training group (Table 13) had a significant improvement in Beep test performance (1.2 ±0.7 level) and squat vertical jump performance (1.7 ±2.1 cm). Analysis of between group differences revealed no significant differences between the groups. However, the Cohen's *d* from between groups analysis indicate that the agility and repeated sprint training program had a larger effect on agility performance compared with that of strength training (d = 0.8).

Table 12: Mean (SD) results of combined agility with repeated sprint training group on the various performance variables (Study III).

Variable	Pre-test	Post-test	Change	95% CI	E.S.
Agility (s)	8.23 ±0.32	8.06 ±0.21	-0.17 ±0.33	-0.07 to 0.41	0.8
7x30 m mean (s)	5.07 ±0.20	5.16 ±0.16	0.09 ±0.14	-0.19 to 0.01	-0.5
0–40 m (s)	6.45 ±0.19	6.44 ±0.26	-0.01 ±0.22	-0.15 to 0.17	0.1
0–20 m (s)	3.57 ±0.12	3.59 ±0.09	0.02 ±0.12	-0.10 to 0.07	-0.2
20–40 m (s)	2.87 ±0.16	2.87 ±0.15	-0.00 ±0.13	-0.09 to 0.10	0.0
CMJ (cm)	26.8 ±3.3	27.7 ±2.2	0.9 ±2.9	-3.0 to 1.2	0.3
SJ (cm)	25.1 ±2.8	26.3 ±2.1	1.2 ±2.9	-3.3 to 0.9	0.5
Beep-test (Level)	9.6 ±1.4	10.8 ±1.0	1.2 ±0.7	-1.7 to -0.7**	1.0
Body mass (kg)	60.7 ±5.6	61.3 ±5.7	0.7 ±1.8	-2.0 to 0.7	-0.1

* = $P < 0.05$, ** = $P < 0.01$, **E.S.** = Cohen's d (effect size), **CMJ** = Countermovement vertical jump; **SJ** = Squat vertical jump.

Table 13: Mean (SD) results of strength training group on the various performance variables (Study III).

Variable	Pre-test	Post-test	Change	95% CI	E.S.
Agility (s)	8.14 ±0.38	8.17 ±0.30	0.04 ±0.28	-0.24 to 0.17	-0.1
7x30 m mean (s)	5.01 ±0.26	5.05 ±0.21	0.04 ±0.10	-0.11 to 0.03	-0.2
0–40 m (s)	6.30 ±0.23	6.32 ±0.22	0.02 ±0.14	-0.12 to 0.08	-0.1
0–20 m (s)	3.52 ±0.11	3.52 ±0.11	0.01 ±0.11	-0.07 to 0.08	0.0
20–40 m (s)	2.79 ±0.14	2.80 ±0.14	0.01 ±0.09	-0.07 to 0.05	-0.1
CMJ (cm)	28.3 ±4.2	29.9 ±5.6	1.7 ±3.1	-3.9 to 0.5	0.3
SJ (cm)	25.9 ±2.7	27.5 ±4.1	1.7 ±2.1	-3.1 to -0.2*	0.5
Beep-test (Level)	9.7 ±1.3	10.9 ±1.2	1.2 ±0.7	-1.7 to -0.6**	1.0
Body mass (kg)	57.5 ±5.3	59.0 ±6.3	1.5 ±2.7	-3.4 to 0.5	0.3

* = $P < 0.05$, ** = $P < 0.01$, **E.S.** = Cohen's d (effect size), **CMJ** = Countermovement vertical jump; **SJ** = Squat vertical jump.

The within group results from study IV showed that the agility training group (Table 14) had a significant improvement in 10 x 40 m linear repeated sprint time, agility time and Yo-Yo Intermittent Recovery level 1 distance covered. The repeated sprint group (Table 15) showed significant improvements in 10 x 40 m repeated linear sprint time, 20–40 m linear sprint time, 40 m linear sprint time, countermovement vertical jump, and Yo-Yo Intermittent Recovery level 1 distance covered.

Table 14: Repeated agility training group pairwise comparison from the pre- and post-test (Study IV).

Variable	Pre-test	Post-test	Change (Std. Err.)	95% CI	P.E.S.	Pearson *r*
10x40 m mean (s)	6.15 (0.40)	5.95 (0.33)	0.203 (0.047)	0.92 to 0.313*	0.728	0.952**
Agility (s)	10.02 (0.34)	9.7 (0.35)	0.326 (0.041)	0.230 to 0.423**	0.901	0.945**
0–20 m (s)	3.15 (0.18)	3.11 (0.15)	0.041 (0.035)	-0.41 to 0.123	0.169	0.846**
20–40 m (s)	2.71 (0.19)	2.69 (0.12)	0.022 (0.035)	-0.060 to 0.105	0.056	0.876**
0–40 m (s)	5.86 (0.35)	5.80 (0.25)	0.064 (0.051)	-0.057 to 0.185	0.182	0.945**
CMJ (cm)	26.4 (4.4)	28.2 (4.6)	1.79 (0.78)	-3.643 to 0.058	0.428	0.882**
Yo-Yo IR1 (m)	1025 (274)	1120 (285)	95 (37)	5 to 184*	0.475	0.928**
Body weight	66.3 (5.7)	66.3 (5.6)	0.15 (0.453)	-1.05 to 1.09	0.001	0.975**

* = $P < 0.05$, ** = $P < 0.01$, **P.E.S.** = Partial Eta Squared, **CMJ** = Countermovement vertical jump.

Table 15: Repeated sprint training group pairwise comparison from the pre- and post-test (Study IV).

Variable	Pre-test	Post-test	Change (Std. Error)	95% CI	P.E.S.	Pearson *r*
10x40 m mean (s)	6.19 (0.25)	5.94 (0.24)	0.248 (0.038)	0.161 to 0.335**	0.844	0.895**
Agility (s)	9.81 (0.45)	9.91 (0.42)	0.108 (0.085)	-0.304 to 0.088	0.167	0.832**
0–20 m (s)	3.15 (0.13)	3.10 (0.13)	0.057 (0.042)	-0.040 to 0.154	0.185	0.514
20–40 m (s)	2.75 (0.15)	2.67 (0.18)	-0.072 (0.026)	0.013 to 0.132*	0.494	0.896**
0–40 m (s)	5.90 (0.24)	5.77 (0.26)	0.129 (0.040)	0.036 to 0.221*	0.563	0.891**
CMJ (cm)	24.9 (4.6)	26.8 (4.6)	1.98 (0.427)	0.941 to 2.912**	0.718	0.961**
Yo-Yo IR1 (m)	920 (293)	1173 (288)	253 (35)	171 to 334**	0.866	0.934**
Body weight	61.9 (5.5)	62.7 (5.3)	0.722 (0.368)	-0.127 to 1.57	0.324	0.961**

* = $P < 0.05$, ** = $P < 0.01$, **P.E.S.** = Partial Eta Squared, **CMJ** = Countermovement vertical jump.

5.4 Relationship between measures of aerobic and anaerobic performances (Study V)

The stepwise regression analysis showed that squat vertical jump in absolute terms had the highest shared variance with 0–40 m and 0–20 m linear sprint times, with 22% and 17%, respectively. The variable with the highest shared variance with 20–40 m linear sprint time was countermovement vertical jump height with a shared variance of 26%. The stepwise regression analysis relative to body weight showed that the highest shared variance with 0–40 m linear sprint time and 20–40 m linear sprint time was countermovement vertical jump peak power with 19% and 22%, respectively. Table 16 shows the relationship found between jumping performances and measures of sprinting and aerobic capacity.

The stepwise regression analysis showed that linear sprint time over 0–40 m was correlated with repeated linear sprint fastest time, mean time, and total time with a shared variance of 68%, 74%, and 74%, respectively. Stepwise analysis also showed that sprint with change of direction had the highest correlation with linear sprint time from 0–20 m with a shared variance of 18%. Table 17 shows the relationships between sprinting measures.

The results indicate further that Beep test distance covered had a significant moderate correlation with linear repeated sprint ability fastest time (r = -.483, p ≤ 0.01), sprint with change of direction time (r = -.430, p ≤ 0.05), and a significant large correlation with 0–40 m linear sprint time (r = -.510, p ≤ 0.01), 20–40 m linear sprint time (r = -.595, p ≤ 0.01), linear repeated sprint mean time (r = -.552, p ≤ 0.01), and linear repeated sprint total time (r = -.552, p ≤ 0.01). Furthermore, the stepwise regression analysis showed that the shared variance between Beep test distance covered and linear repeated sprint fastest time, mean time, and total time were 24%, 31%, and 31%, respectively. The shared variance between Beep test distance covered and linear sprint times over 0–40 m and 20–40 m were 26% and 36%, respectively. Finally, the shared variance between sprint with change of direction and distance covered during the Beep test was 19%.

Table 16: Correlation coefficients between measures of jumping performance, sprinting abilities and measures of aerobic fitness (Study V).

	0-40 m (s)	0-20 m	20-40 m	RSA FT	RSA MT	RSA TT	COD	S_{dec} (%)	MSFT DC
In absolute terms									
SJ Height (cm)	-.468**	-.406*	-.446**	-.260	-.290	-.288	-.127	.097	.169
SJ PP	.057	.102	.026	-.111	-.033	-.035	-.034	-.302	-.051
SJ F	-.030	.050	-.071	-.141	-.087	-.089	-.142	-.221	.130
CMJ Height (cm)	-.457*	-.305	-.508**	-.241	-.264	-.264	-.260	.081	.316
CMJ PP	-.348	-.227	-.395*	-.295	-.241	-.244	-.291	-.211	.211
CMJ F	-.168	-.097	-.166	-.193	-.147	-.151	-.267	-.181	.210
RS (cm)	.063	.169	-.031	.051	.062	.060	-.154	-.031	.166
Relative to Body mass									
SJ Height (cm)	-.294	-.272	-.249	-.115	-.172	-.169	.115	.202	.042
SJ PP	.081	.116	.061	-.075	-.012	-.013	.080	-.247	-.112
SJ F	.029	.125	-.020	-.077	-.052	-.053	.094	-.113	.091
CMJ Height (cm)	-.304	-.210	-.313	-.097	-.159	-.157	.047	.228	.162
CMJ PP	-.434*	-.295	-.466**	-.303	-.278	-.280	-.035	-.104	.108
CMJ F	-.168	-.085	-.157	-.170	-.151	-.155	-.079	-.073	.175
RS (cm)	.066	.174	-.031	.061	.068	.066	-.139	-.015	.179

PP = Peak Power, **F** = Force, **RSA** = Repeated sprint ability, **FT** = Fastest time, **MT** = Mean time, **TT** = Total time, **COD** = Change of direction speed, S_{dec} = Percentage decrement score, **RS** = Reactive strength **MSFT DC** = Multi stage fitness test distance covered. * = $P \leq 0.05$, ** = $P \leq 0.01$.

Table 17: Correlation coefficients between sprinting variables (Study V).

	0-40 m (s)	0-20 m	20-40 m	RSA FT	RSA MT	RSA TT	COD	S_{dec} (%)
0-40 m (s)	1	.917**	.914**	.823**	.860**	.859**	.387*	-.086
0-20 m (s)		1	.691**	.705**	.733**	.730**	.428*	-.052
20-40 m (s)			1	.797**	.845**	.845**	.291	-.137
RSA FT (s)				1	.969**	.969**	.343	.187
RSA MT (s)					1	.999**	.416*	-.062
RSA TT (s)						1	.415*	-.061
COD (s)							1	-.269
S_{dec} (%)								1

FT = Fastest time, **MT** = Mean time, **TT** = Total time, **COD** = Change of direction speed, **RSA** = Repeated sprint ability, **S_{dec} (%)** = Percentage decrement score. * = $P \leq 0.05$, ** = $P \leq 0.01$.

6 General discussion

The results of the present thesis demonstrate that repeated sprint training appears to be an efficient form of anaerobic conditioning training which helps to improve soccer players' anaerobic characteristics with minimum effect on soccer specific training time available. The results across the part studies presented in this thesis suggest that the outcome of the conditioning program depends on the correct use of training principles such as specificity, variation, progression, periodization (mainly the timing of the implementation) and the correct manipulation of the training load variables such as intensity, volume, frequency. However, the use of the training principles should be in line with the ultimate goal of the teams training program. The results from this thesis are in accordance with other reports that have found that linear sprint and agility are separated skills and should be treated separately when planning the conditioning program. Furthermore, in line with other reports, strength training has been found to improve strength and power in the leg extensors. Finally, the relationship observed in the present study and in other studies between repeated sprint ability on one side and linear sprint and aerobic capacity on the other side, confirm that repeated sprint ability is a function of single linear sprint speed and the ability maintain speed over time.

6.1 Testing and evaluation

To effectively monitor physical performance after implementing a training program, construct validity and reliability are essential (79). Furthermore, a basic requirement of any test is that repeated measurements yield consistent results. Reliability refers to the reproducibility of a measurement; measures should be reproducible so that there is neither marked systematic (learning, motivation, fatigue) nor random variation (89). Poor reliability degrades the ability to track changes in measurements in clinical or in experimental studies (9). The paired t-test results (Table 10) indicate that the test-retest reliability did not show any marked systematic bias ($P < 0.05$) for repeated measures on all testing systems, and the limits of agreement indicate a negligible random error variation (Table 10). Therefore, for any individual from the population tested in this study, assuming that the bias that is present is negligible, any two tests on the Powertimer testing system will differ due to measurement error by no more than ±3.2%, ±3.3%, ±1.1%, and ±1.5% for countermovement vertical jump, squat vertical jump, 0–20 m sprint time, and 0–40 m sprint time, respectively (Table 10). In contrast, for any individual from the population, assuming that the bias that is present is negligible, any two tests with the NOC testing system will differ due to measurement error by no more than ±1.0%, ±0.9%, ±1.6%, and ±1.1% for countermovement vertical jump, squat vertical jump, 0–20 m sprint time, and 0–40 m sprint time, respectively (Table 10). One explanation for the small systematic bias found in this study could be that the reliability for those skills (vertical jumping and sprinting performances) have been reported to be achieved through test-retest and without the need for practice sessions with physically active men (7, 122, 152, 181). This suggests that any active person would perform similarly on these tests even if they have never performed the skills before. However, the test-retest results from the Newtest Powertimer contact mat indicate that the error associated with the test is high, and therefore the contact mat was found not to be reliable enough to monitor the small changes in vertical jump height that could result from training ofthe players. Consequently, the Newtest Powertimer contact mat was not used in further studies during the course of this Ph.D. project.

6.2 The effect of repeated sprint training

Evaluating the results across study II, III, and IV, reveals that two weekly repeated sprint sessions that is not combined with other forms of anaerobic training, gave the best outcome on soccer players' physical performance.

6.2.1 Single linear sprint

The performance of linear sprint was measured as a function of sprinting 40 m. The results across the studies indicate an improvement in linear sprint in study II (Figure 3) and study IV (Table 15). However, no significant improvement was detected in study III (Table 12). To better understand the improvement in linear sprint, the tested distance of 40 m across the studies was divided into start and acceleration time (0–20 m linear sprint time) and maximum speed (20–40 m linear sprint time). The split time of the 0–40 m linear sprint shows that the improvement occurred in both start-acceleration and maximum speed phases in study II (Figure 3) and in maximum speed phase in study IV (Table 15). Considering that there was no improvement in start-acceleration speed in study IV suggests that the stimuli (training load) was not sufficient to cause improvement in the players start and acceleration sprinting time compared to study II. The absence of improvement in start and acceleration phase in study IV could be attributed to the training volume implemented and the number of sprints conducted per week. Evaluation of the repeated sprint training implemented across the studies in this thesis and prior similar studies (41, 164) indicate that the only difference between those studies and study II is the total weekly training volume implemented. In study II the players performed a total of 40 sprints per week compared to an average of 18 sprints per week in study III, 14 sprints per week in study IV, an average of 15 sprints per week in Tønnessen et al. (164), and 15 sprints per week in Buchheit et al. (41).

Soccer players could be considered well-trained athletes on start and acceleration because they conduct several short accelerations during soccer training, and it is therefore not expected that they will respond to a training stimulus at the same rate as a beginner or less trained soccer players (90). Therefore, with improvements in the players' physical performance, the response and rate of adaptation to training becomes slower over time. In this sense, the high number of sprints per week could be considered as a form of progressive load that was added to the soccer players training program, which consequently, could have stimulated and improved the players ability on start and acceleration in study II compared to the other studies. However, the improvement observed in the control group in study II indicates that the high improvement in start and acceleration in the training group was caused by both, the implemented repeated sprint training and the players' regular soccer training. In contrast the improvement in maximum speed (20–40 m) could be explained by the fact that repeated sprinting over a long distance (40 m) could be viewed as a new and unaccustomed training stimulus for soccer players, which again could result in an improvement in metabolic, muscular and neural responses (118, 149, 154).

6.2.2 Repeated linear sprint ability

The choice of the training programs implemented in study II, III and IV was based on the principle of specificity. The training programs were designed based on the observations made in match analyses showing that the total high intensity running comprises between 20–30% of the total distance covered with ~11% at very high intensity running and ~2.5% sprinting, with an average of 2–4 s per run occurring every 60–90 s (5, 35, 57, 85, 120, 136, 154, 159, 176). The observed improvement in repeated sprint ability within the training group in study II and IV is substantial, especially considering that the subjects typically performed ~13 hours of soccer training per week and only engaged in a specific speed training twice and once a week, respectively, over the intervention period. Nevertheless, the results from study II and IV demonstrate that this type of specific training based on match analyses data is useful, and that repeated sprint ability appears to be trainable using only a repeated sprint training with no combination with other forms of anaerobic training (41, 61, 91, 164).

The differences observed between the results from the groups who performed only repeated sprint training from both study II (Figure 3) and study IV (Table 15) suggest that this difference could be explained by the training volume used in both studies and the fact that study II involved male soccer players and study IV involved female soccer players. However, examination of the results closely revealed that sex differences have minimal effect compared to the fact that the female players in study IV trained half the volume (400–720 m) that was implemented for the males players in study II (1600 m). Hence, it is possible that, had both groups had similar training volume, the improvement would have been similar. One previous study that supports this explanation is the study by Tønnessen et al. (164). Their study used a similar training program to the program implemented in study IV and similar improvements were detected in terms of sprint performance. It is important to note that neither study IV nor Tønnessen et al. (164) detected improvements in the start and acceleration speed time (0–20 m). Beside the training volume of repeated sprint training implemented in both studies (Study II and IV), indicate that the improvement in sprinting abilities observed could be due to a positive change in the anaerobic metabolic contribution (66, 92) and/or an improvement in the participants' ability to utilize the stored elastic energy in leg extensors caused by the plyometric work in leg extensors during repeated sprint training (92, 100, 119). Additionally, the participants limited previous experience in sprint training, may also have contributed to the sprinting performance improvements observed in the repeated sprint training groups from both studies.

The combined agility with repeated sprint training in study III did not result in any significant improvements in physical performance compared to study II and IV. One of the major questions that might arise is, since study III (320–800 m) and IV (400–720 m) had very similar training volumes, why there were no improvements in the repeated sprint training group in study III? This could be explained by the periods during which these studies were implemented. Study II and IV were implemented in the pre-season period, while study III was implemented in the in-season period. Kraemer et al. (101) reported that the basal concentration of testosterone significantly increases one week after the season, reflecting a dramatic reduction in total stress related to the season, which would cause a faster adaptation to training stimuli in the pre-season period. This explanation presented by Kraemer et al. (101) highlight the importance of periodization of training and the importance of choosing the right time of the year to effectively implement training for the purpose of improvement and not maintenance. Furthermore, the fact that there were no significant declines in performances observed in study III, points out that this type of training, if implemented in-season, could help soccer players to maintain their physical performance level, but would not impact negatively on their performance (Table 12 & 13). Hence, the balance between the implementation period, progression of the conditioning program and the soccer specific training program could help in giving better results over time as well as minimizing undesired outcomes such as injury (78).

Between groups comparison across study II, III and IV revealed that the training group in study II exhibited a considerably larger improvement in repeated sprint ability, 20–40 m linear sprint time, and 0–40 linear sprint time compared to the control group (Table 11). No significant differences were observed between groups in study III and IV. Despite the fact that speed is believed to be a skill with a genetic quality, and less dependent on training (149), one could speculate from the results presented in study II that a specialized, specific repeated sprint training with the correct manipulation of loading variables implemented at the correct time of the year could result in an improvement in soccer players' sprinting speed (41, 59, 91, 164). The sprinting abilities improvement within the control group in study II (Figure 3) could be attributed to the timing of the study as indicated earlier, and the impact of players' daily soccer training. One of the explanations for the absence of differences between groups in study III and IV is the fact that both groups in these studies conducted extra training besides their normal soccer training. Nevertheless, considering that test-retest reliability was assessed for all groups, the differences in improvements from the within groups results could be attributed to the conditioning program implemented and the daily soccer training.

6.2.3 Agility

No notable improvements in agility performance following repeated sprint training were detected across the studies. Based on the results from study V, the agility results within repeated sprint training groups in study II, III, and IV were expected, since the relationship between sprinting and agility had been shown to be moderate (Table 17). Furthermore, considering the specificity of training, it is well documented that the training methods used to enhance agility and speed are specific and produce limited interactive effects (108, 182, 183). This could be due to the differences in performing each skill. The repeated sprint ability-training program used in study II and IV involved only linear sprints (closed skill), whereas agility often involves actions requiring change of direction and rapid start and stop (183). In study III, the effect of training on agility performance (Table 12) was notably moderate (d = 0.8) compared to the strength training group (Table 13) and across the studies in this thesis, but not statistically significant. However, this moderate improvement in agility in study III was expected as the repeated sprint training was combined with agility training. It is possible to speculate that the absence of significance was caused by the combination of repeated sprint training with agility training which caused the training to be less specific and therefore, did not cause performance transpiring in the tissues and movement pattern that were exposed to training (142). Therefore, comparing the training program from study III (Table 5 & 6) with the training program from study IV (Table 8), suggest that, hypothetically, had the training in study III not been combined, the results may have reached a statistical significance in improving agility performance. Since study III was conducted in-season, it is expected that the lack of improvement in sprinting and agility performance is due to the total training load (games, soccer training, and repeated sprint) may not have provided the appropriate stimulus to cause adaptation (102).

6.2.4 Vertical jump performance

Vertical jump performance was used as a measure of the players' strength and power in the lower limbs. Examination of the within group results from the repeated sprint interventions in study II (1.3 ±1.2 cm) and IV (Table 15) showed a positive and significant effect on countermovement vertical jump performance. On the other hand, no significant improvement caused by combined agility with repeated sprint training in study III was observed (Table 12). Relating the results from vertical jump performance to the results from linear sprint and examining the relationship found between 0–20 m, 20–40 m and vertical jump performances in study V (Table 16) suggest that, as described earlier, soccer players could be considered well-trained athletes on start and acceleration because they conduct several short accelerations during soccer training and matches. It is therefore not expected that they will respond to a training stimulus at the same rate as a beginner and/or less trained soccer player (90).

The start and acceleration phase in sprinting and the squat vertical jump are both forms of concentric contraction, and the fact that there is a relationship between squat vertical jump and start-acceleration phase suggest that the repeated sprint training is not a strong enough stimuli to cause adaptation of the concentric contraction only of leg extensors. However, the observed results across the studies suggest that repeated sprint training is a strong stimulus in improving stretch-shortening cycle contraction of leg extensors based on the improvement observed in both 20–40 m linear sprint and countermovement vertical jump, as both skills are a form of stretch-shortening cycle contraction. This is also supported by the stepwise regression analysis in study V were it was found that the highest shared variance with 20–40 m linear sprint was countermovement vertical jump height, while the highest shared variance with 0–20 m linear sprint time was squat vertical jump. Therefore, the improvement in countermovement vertical jump across the studies could be attributed to the repeated sprinting over a long distance (40 m) that could be considered a new and unaccustomed stimulant for soccer players that caused adaptation in the stretch-shortening cycle contraction abilities.

The improvement in countermovement vertical jump reflects an enhancement (as with repeated sprint ability) in the ability to utilize the stored elastic energy which indirectly assists in the first phase of force–time curve initiated by the rate of force development occurring in the first 180–250 ms in leg extensors within the repeated sprint training groups (126). It could be further explained by findings from other studies where speed, leaping power and strength has been reported to affect each other if an improvement in any one of them occurs (152, 159, 178). Finally, since no improvement in vertical jump performance was detected in the control group (Study II) and the agility group (Study IV) it could be assumed that the improvement in vertical jump performance is attributed to the extra weekly repeated sprint training implemented.

6.2.5 Aerobic capacity

No marked changes in Yo-Yo Intermittent Recovery level 1 results were observed within the repeated sprint training group in study II. This is in contrast to the results of study IV and Bravo et al. (66) that revealed improved Yo-Yo Intermittent Recovery level 1 following a repeated sprint training. Comparing the reduction of the control group Yo-Yo Intermittent Recovery level 1 test results from 17.1 to 16.5 (Level) to the reduction of the repeated sprint training group from 17.3 to 17.1 (Level) suggest that the lack of performance improvement in the repeated sprint training group could be due to the daily soccer training program effecting aerobic performance negatively, and did not trigger the aerobic energy system enough to cause adaptation (22). Therefore, the better maintenance of performance in the repeated sprint training group could be as a result of the repeated sprint training implemented.

This could be further explained by analyzing the results from the Yo-Yo Intermittent Recovery level 1 test results from between groups in study IV where the agility training group (Table 14) improved half the distance that the repeated sprint training group demonstrated (Table 15). Considering the relationship observed between aerobic performance and repeated linear sprint measures from study V and other studies (11, 12, 53,

96) suggest that the differences between the groups' improvements can be attributed to the repeated sprint training implemented in the repeated sprint training group. It is believed that the total working load combined (soccer training and repeated sprint training) in study IV was a more suitable stimulus for promoting aerobic energy production adaptation (11). Since the improvement in aerobic capacity was almost equal between the groups in study III and no other improvements were detected, the improvement could be attributed to the daily soccer training.

6.3 The effect of agility training

Within the three interventions implemented during the course of the present thesis, the agility training as a form of anaerobic conditioning was implemented in study III and IV. In study III however, the agility training was combined with repeated sprint training for the purpose of testing whether a variation in training in the form of exercise selection would give better results than in study II. The selection of the combined training was further based on specific movement patterns reported in time motion analyses (Figure 1).

6.3.1 Sprinting abilities

In study III the combined agility with repeated sprint training did not cause any significant improvement in the sprinting abilities measured (Table 12). Several possible factors may explain these limited effects on sprinting performance. Firstly, a perfectly designed conditioning program for certain capabilities may limit the improvements of other important qualities and vice versa. The combination of resisted-assisted agility with repeated sprint training has not been tested before, and since the majority of studies indicate that linear sprint and agility are separate skills, the combination of the two could have caused a delay in improvement. Therefore, it could be hypothesized that separate training groups would have resulted in better outcomes than the one observed. Furthermore, it is known that the continued stress experienced throughout the season combined with the conditioning program could be described as a "chronic catabolic environment for the neuromuscular system". Such an environment could result in minor or no improvements in other physical variables tested in study III because the study was conducted in-season (102). Secondly, in comparison to other studies, the outcome of a conditioning program may be affected by whether it is implemented by a training expert or not. All training sessions in study II, IV and Tønnessen et al. (164) were supervised by a former national coach in track and field sprinting. In study III the team soccer head coach supervised all the training sessions, which could be an explanatory factor in the lack of improvements observed. The continuous presence of a physical conditioning expert likely increases the odds of a more successful outcome (61).

The intervention length may have affected the results of the conditioning programs implemented in study III. Results from similar interventions suggest that longer intervention periods increase the likelihood for greater improvements in certain specific capabilities (59, 66, 124, 130). The repeated agility training group in study IV performed 15–20% fewer sprint repetitions and had 30 s longer recovery periods between each run compared to the repeated sprint training group. This difference in workload between the groups' training programs could have caused the lower improvement in sprint abilities compared to the repeated sprint group. This program design was chosen because each agility sprint lasted ~4 s longer on average than each linear sprint. Accordingly, the repeated agility training sessions were probably more anaerobic in terms of lactate production. However, since none of the linear sprint measures were improved (Table 14) and the relationship found between change of direction running and linear sprint are trivial (Table 17), the improvement in repeated sprint ability in the agility training group could be attributed to the regular soccer training since the improvement was not as high and significant as in the repeated sprint training group (Table 15).

6.3.2 Agility

The results in study III did not show a statistically significant improvement in agility performance, but it showed that the combined agility with repeated sprint training had a moderate effect on agility performance compared to the repeated sprint performance as indicated by the Cohen's *d* (Table 12). Furthermore, the agility training group in study IV reported a significant and high improvement in agility performance (Table 14). The improvement in agility performance was expected and in accordance with our hypothesis and the specificity of training (171, 183). However, besides the timing of the study and the absence of expert coach supervision, the lack of significant improvements in study III could be attributed to the combination of agility with repeated sprint training. It could be hypothesized that separated training groups would have resulted in better outcomes compared to study IV. However, the results from study III and IV are in line with the reported results from Young et al. (183) who demonstrated that linear sprint training did not improve performance in sprints with changes of direction. Furthermore, Wojtys et al. (180) found neuromuscular adaptations to agility training in the form of improved spinal reflex and cortical response times in typical lower limb muscles activated in sprinting. Since it is well documented that the physiological adaptation resulting from physical training transpires in the tissues and movement patterns that were exposed to training (142), the improvement observed in both studies (study III & IV) could be attributed to the specificity and variation of the movement pattern of the exercise implemented during the intervention period. It should also be noted that the differences between the studies could be as a result of the fact that the agility training implemented in study IV was identical to the agility test conducted. In contrast, the agility test in study III was different from the agility training that was implemented. However, the improvements were likely related to adaptations in specific coordination and agility of the neuromuscular system caused by the training programs implemented (149). No notable effects were observed in vertical jump performance as a result of agility training.

6.3.3 Aerobic capacity

The results from study III and IV indicate that the effect of agility training on aerobic performance was not entirely due to the intervention training program. Analyzing the results of study III further indicate that the combined agility with repeated sprint training group had similar development to the strength training group in the aerobic performance test (Table 12 & 13). The results of study IV reveals that the repeated agility training group developed ~50% less than the repeated sprint training group in aerobic performance test (Table 14 & 15). The results therefore, suggest that, while the repeated sprint training group development in aerobic performance (Study IV) could be attributed to the repeated sprint training, the fact that the results from the repeated agility training group had a trivial improvement suggest that the development in the repeated agility training group aerobic performance is highly attributed to the players regular soccer training. Moreover, since the strength training group had similar improvements in aerobic capacity compared to the combined agility with repeated sprint training group (Study III) suggests further that the improvement was due, at least in part, to the players' regular soccer training.

Investigating the results from study V indicate that the relationship between measures of sprinting with change of direction and aerobic performance is moderate, making the transfer between the two skills minimal. However, considering the specificity of training combined with the fact that the repeated agility training group in study IV performed on average ~4 s longer sprints, suggest that the repeated agility training sessions were probably more anaerobic in terms of lactate production, and therefore the aerobic system may not have been triggered sufficiently to cause the same level of improvement as the repeated sprint training group. On the other hand, the improvement in aerobic capacity in the repeated sprint-training group could be caused by the repeated sprint training, supported by the high relationship found between the two skills in study V. This is in accordance with the study of Burgomaster et al. (44) who reported an improvement in VO_{2peak} after six sessions of sprint interval training performed over two weeks. In study IV, the repeated sprint training group performed 8 high intensity repeated sprint training sessions over the course of 8 weeks, which could have caused the improvement observed. The lack of improvement in study III could be caused, as suggested earlier, by the timing of the study and the increased stress caused by soccer training, competition and repeated sprint training combined.

6.4 The effect of strength training

In the present thesis, strength training was implemented as a part of study III. The results of the study showed that only squat vertical jump was markedly improved. This is inline with what has been reported by Lamas et al. (106) where strength training were reported to effect squat vertical jump compared to countermovement vertical jump. They further showed that the improvement in squat vertical jump was as a result of faster extension of the lower limb joints caused by a higher rate of force in the concentric contraction of the leg extensors, but not in the eccentric followed immediately by concentric movement such as countermovement vertical jump (106). In contrast with similar investigations that reported improved sprinting skills in studies that were conducted in the pre-season period (110, 123). Chelly et al. (49) showed positive effects of a twice-weekly strength training program on 40 m linear sprint and countermovement vertical jump performance in mid-season. It should be noted that most coaches progressively increase the total load of regular soccer training throughout the pre-season conditioning, and the players might be more responsive to additional training at that time. Therefore, strength training for soccer players should be used with caution close to season start compared with off-season, early pre-season, and mid-season. Based on the observed reduction in players performance during the competitive period (102), it is likely that our strength training intervention would have resulted in similar effects to the above-mentioned studies if implemented in the pre-season period compared to in-season period. Since study III reported an improvement in squat vertical jump only, the lack of improvement in the other physical measures could be attributed firstly to the time of the study and the total stress caused by the combination of match play, soccer training and the added strength training, and secondly to the short intervention period as it has been reported that longer periods of strength training give better results on sprinting abilities (98).

7 Conclusion

The present thesis demonstrates that greater training volume with high intensity close to the observed intensity during match play in form of total distance covered during repeated sprint training appears to impact positively on players' physical performance. Analyzing the results indicate that the frequency of two training sessions per week gives better results compared to one session. The results from the present thesis demonstrate that improvements in soccer players' physical performance and the rate of adaptation to anaerobic training depend on specificity, progression, intensity, volume and frequency in the form of movement pattern, repetition per session and the number of training sessions per week to be able to stimulate improvements in already trained skills.

The results from study II and IV demonstrate that repeated sprint training as a form of anaerobic conditioning is useful in improving soccer players repeated sprint ability, indicating that this skill appears to be trainable using only a repeated sprint training program not combined with other forms of anaerobic training. Furthermore, the present thesis confirms that the specificity of the exercise choice can highly effect the improvement of the players. Similar to previous studies, the present thesis suggests that agility training induces specific agility enhancement and linear sprint training improves linear sprint abilities. Comparing the outcomes across the part studies indicates that improvements in the players conditioning is highly connected to the total stress level. Hence, the time of implementing the training program for the purpose of improvement is crucial, and the correct use of periodization, progression and the total training load is of high importance. Sprinting abilities appear to depend greatly on technical elements, and the continuous presence of a physical conditioning expert likely increases the odds of a more successful outcome of the training program.

Since the combination of agility with repeated sprint training has not been tested before the present thesis, future research could investigate if similar combination would give superior effects compared to the one in the present study. Furthermore, future research could test if individualization of training in team sport and designing the intervention studies based on the individual need of improvement would reflect more positively on the physical performance variables being tested. Further research also needed in examining the effect of anaerobic training frequency on soccer players' performance.

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9 Tables and figures legend

9.1 Tables:

9.2 Figures:

Appendix A: Copyright transfer

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I am preparing my doctoral (PhD) thesis, which is intended to be a compilation of an overall summary (overview) and research papers – bound together.

I would greatly appreciate your permission to include:

Shalfawi, S., Young, M., Tønnessen, E., Haugen, T., & Enoksen, E. (2013). The effect of repeated agility training vs. repeated sprint training on elite female soccer players' physical performance. Kinesiologia Slovenica, 19(3), 29-42.

Yours sincerely,

Shaher Shalfawi

Norwegian School of sports sciences

Oslo/Norway

Appendix B: Norwegian Social Science Data Services (NSD) communication

Norsk samfunnsvitenskapelig datatjeneste AS
NORWEGIAN SOCIAL SCIENCE DATA SERVICES

MELDESKJEMA

Meldeskjema (versjon 1.4) for forsknings- og studentprosjekt som medfører meldeplikt eller konsesjonsplikt
(jf. personopplysningsloven og helseregisterloven med forskrifter).

1. Prosjekttittel		
Tittel	A study of the effect of different training models, duration, intensity and frequency on repeated sprint ability and agility ability on soccer players.	

2. Behandlingsansvarlig institusjon		
Institusjon	Norges idrettshøgskole	Velg den institusjonen du er tilknyttet. Alle nivå må oppgis. Ved studentprosjekt er det studentens tilknytning som er avgjørende. Dersom institusjonen ikke finnes på listen, vennligst ta kontakt med personvernombudet.
Avdeling/Fakultet	Seksjon for fysisk prestasjonsevne	
Institutt		

3. Daglig ansvarlig (forsker, veileder, stipendiat)		
Fornavn	Shaher	Før opp navnet på den som har det daglige ansvaret for prosjektet.Veileder er vanligvis daglig ansvarlig ved studentprosjekt. Veileder og student må være tilknyttet samme institusjon. Dersom studenten har ekstern veileder, kan biveileder eller fagansvarlig ved studiestedet stå som daglig ansvarlig.Arbeidssted må være tilknyttet behandlingsansvarlig institusjon, f.eks. underavdeling, institutt etc. NB! Det er viktig at du oppgir en e-postadresse som brukes aktivt. Vennligst gi oss beskjed dersom den endres.
Etternavn	Shalfawi	
Akademisk grad	Doktorgrad	
Stilling	PhD Candidat	
Arbeidssted	Norges Idrettshøgskole	
Adresse (arb.sted)	Postboks 4014 Ullevål Stadion	
Postnr/sted (arb.sted)	0806 Oslo	
Telefon/mobil (arb.sted)	45660660 /	
E-post	shaher.shalfawi@nih.no	

4. Student (master, bachelor)		
Studentprosjekt	Ja ○ Nei ●	

5. Formålet med prosjektet		
Formål	Hensikten med denne studien er å måle effekten av to ukentlig hurtighetstreninger (1,5-2 timer) med repetert hurtighetstrening og agilitytrening på følgende testøvelser: 1.Utholdende løpshurtighet (7x30m med 30sek pause) 2.Akselerasjonshurtighet (0-20m) 3.Maksimalhurtighet (20-40m) 4.Agillityløype 5.Vertikal spenst (svikthopp / CMJ) 6.Beinpress (1RM) 7.Aerob utholdenhet (beep test) Hypotesen er at denne treningen vil gi en positiv utvikling av utholdende løpshurtighet, agillity, akselerasjonshurtighet og maksimalhurtighet, men at treningen ikke vil ha effekt på vertikal spenst og beinstyrke.	Redegjør kort for prosjektets formål, problemstilling, forskningsspørsmål e.l. Maks 750 tegn.

6. Prosjektomfang		
Velg omfang	● Enkel institusjon ○ Nasjonalt samarbeidsprosjekt ○ Internasjonalt samarbeidsprosjekt	Med samarbeidsprosjekt menes prosjekt som gjennomføres av flere institusjoner samtidig, som har samme formål og hvor personopplysninger utveksles.
Oppgi øvrige institusjoner		
Oppgi hvordan samarbeidet foregår		

7. Utvalgsbeskrivelse

Utvalget	Fotballspillere på høyt nivå (bedre enn 2. divisjon) (Kvinner = 37, and Menn = 35).	Med utvalg menes dem som deltar i undersøkelsen eller dem det innhentes opplysninger om. F.eks. et representativt utvalg av befolkningen, skoleelever med lese- og skrivevansker, pasienter, innsatte.
Rekruttering og trekking	Deltakere ble rekruttert gjennom å ta kontakt med trenere og klubber i Norge.	Beskriv hvordan utvalget trekkes eller rekrutteres og oppgi hvem som foretar den. Et utvalg kan trekkes fra registre som f.eks. Folkeregisteret, SSB-registre, pasientregistre, eller det kan rekrutteres gjennom f.eks. en bedrift, skole, idrettsmiljø, eget nettverk.
Førstegangskontakt	Førstegangskontakt var gjennom å ta direkte kontakt med hovedtrener til de klubber som har de kriterier for å gjennomføre forsøket. De klubber som var interessert å delta i studiet ble bedt om å sette tidspunkt for informasjonsmøte. Gjennom informasjonsmøte ble alle spillere og trenere informert om studien (se vedlegg). De spillere som godtatt å delta ble tatt med og dem som ønsket ikke å delta ble ikke tatt med.	Beskriv hvordan førstegangskontakten opprettes og oppgi hvem som foretar den. Les mer om dette på våre temasider.
Alder på utvalget	□ Barn (0-15 år) ■ Ungdom (16-17 år) ■ Voksne (over 18 år)	
Antall personer som inngår i utvalget	72 delt til Kvinner = 37, and Menn = 35.	
Inkluderes det myndige personer med redusert eller manglende samtykkekompetanse?	Ja ● Nei ○	Begrunn hvorfor det er nødvendig å inkludere myndige personer med redusert eller manglende samtykkekompetanse. Les mer om Pasienter, brukere og personer med redusert eller manglende samtykkekompetanse
Hvis ja, begrunn	Foreldre samtykke ble tatt for alle deltakere som var under 18 år gammel på studiet tidspunktet.	

8. Metode for innsamling av personopplysninger

Kryss av for hvilke datainnsamlingsmetoder og datakilder som vil benyttes	□ Spørreskjema □ Personlig intervju □ Gruppeintervju □ Observasjon □ Psykologiske/pedagogiske tester □ Medisinske undersøkelser/tester □ Journaldata □ Registerdata ■ Annen innsamlingsmetode	Personopplysninger kan innhentes direkte fra den registrerte f.eks. gjennom spørreskjema, intervju, tester, og/eller ulike journaler (f.eks. elevmapper, NAV, PPT, sykehus) og/eller registre (f.eks. Statistisk sentralbyrå, sentrale helseregistre).
Annen innsamlingsmetode, oppgi hvilken	1.Utholdende løpshurtighet (7x30m med 30sek pause) 2.Akselerasjonshurtighet (0-20m) 3.Maksimalhurtighet (20-40m) 4.Agillityløype 5.Vertikal spenst (svikthopp / CMJ) 6.Beinpress (1RM) 7.Aerob utholdenhet (beep test)	
Kommentar	Bare fysisk tester.	

9. Datamaterialets innhold

Redegjør for hvilke opplysninger som samles inn	deltakere fysisk prestasjoner I football.	Spørreskjema, intervju-/temaguide, observasjonsbeskrivelse m.m. sendes inn sammen med meldeskjemaet. NB! Vedleggene lastes opp til sist i meldeskjema, se punkt 16 Vedlegg.
Samles det inn direkte personidentifiserende opplysninger?	Ja ○ Nei ●	Dersom det krysses av for ja her, se nærmere under punkt 11 Informasjonssikkerhet. Les mer om hva personopplysninger er
Hvis ja, hvilke?	□ 11-sifret fødselsnummer □ Navn, fødselsdato, adresse, e-postadresse og/eller telefonnummer	

Spesifiser hvilke		NB! Selv om opplysningene er anonymiserte i oppgave/rapport, må det krysses av dersom direkte
Samles det inn indirekte personidentifiserende opplysninger?	Ja ○ Nei ●	En person vil være indirekte identifiserbar dersom det er mulig å identifisere vedkommende gjennom bakgrunnsopplysninger som for eksempel bostedskommune eller arbeidsplass/skole kombinert med opplysninger som alder, kjønn, yrke, diagnose, etc. Kryss også av dersom ip-adresse registreres.
Hvis ja, hvilke?		
Samles det inn sensitive personopplysninger?	Ja ○ Nei ●	
Hvis ja, hvilke?	□ Rasemessig eller etnisk bakgrunn, eller politisk, filosofisk eller religiøs oppfatning □ At en person har vært mistenkt, siktet, tiltalt eller dømt for en straffbar handling □ Helseforhold □ Seksuelle forhold □ Medlemskap i fagforeninger	
Samles det inn opplysninger om tredjeperson?	Ja ○ Nei ●	Med opplysninger om tredjeperson menes opplysninger som kan spores tilbake til personer som ikke inngår i utvalget. Eksempler på tredjeperson er kollega, elev, klient, familiemedlem.
Hvis ja, hvem er tredjeperson og hvilke opplysninger registreres?		
Hvordan informeres tredjeperson om behandlingen?	□ Skriftlig □ Muntlig □ Informeres ikke	
Informeres ikke, begrunn		

10. Informasjon og samtykke

Oppgi hvordan utvalget informeres	■ Skriftlig ■ Muntlig □ Informeres ikke	Vennligst send inn informasjonsskrivet eller mal for muntlig informasjon sammen med meldeskjema. NB! Vedlegg lastes opp til sist i meldeskjemaet, se punkt 16 Vedlegg. Dersom utvalget ikke skal informeres om behandlingen av personopplysninger må det begrunnes. Last ned vår veiledende mal til informasjonsskriv
Begrunn		
Oppgi hvordan samtykke fra utvalget innhentes	■ Skriftlig ■ Muntlig □ Innhentes ikke	Dersom det innhentes skriftlig samtykke anbefales det at samtykkeerklæringen utformes som en svarslipp eller på eget ark. Dersom det ikke skal innhentes samtykke, må det begrunnes.
Innhentes ikke, begrunn		

11. Informasjonssikkerhet

Direkte personidentifiserende opplysninger erstattes med et referansenummer som viser til en atskilt navneliste (koblingsnøkkel)	Ja ○ Nei ●	Har du krysset av for ja under punkt 9 Datamaterialets innhold må det merkes av for hvordan direkte personidentifiserende opplysninger registreres. NB! Som hovedregel bør ikke direkte personidentifiserende opplysninger registreres sammen med det øvrige datamaterialet.
Hvordan oppbevares navnelisten/ koblingsnøkkelen og hvem har tilgang til den?		
Direkte personidentifiserende opplysninger oppbevares sammen med det øvrige materialet	Ja ○ Nei ●	

Hvorfor oppbevares direkte personidentifiserende opplysninger sammen med det øvrige datamaterialet?		
Oppbevares direkte personidentifiserbare opplysninger på andre måter?	Ja ○ Nei ●	
Spesifiser		
Hvordan registreres og oppbevares datamaterialet?	□ Fysisk isolert datamaskin tilhørende virksomheten □ Datamaskin i nettverkssystem tilhørende virksomheten □ Datamaskin i nettverkssystem tilknyttet Internett tilhørende virksomheten □ Fysisk isolert privat datamaskin □ Privat datamaskin tilknyttet Internett □ Videoopptak/fotografi □ Lydopptak □ Notater/papir □ Annen registreringsmetode	Merk av for hvilke hjelpemidler som benyttes for registrering og analyse av opplysninger. Sett flere kryss dersom opplysningene registreres på flere måter.
Annen registreringsmetode beskriv		
Behandles lyd-/videoopptak og/eller fotografi ved hjelp av datamaskinbasert utstyr?	Ja ○ Nei ●	Kryss av for ja dersom opptak eller foto behandles som lyd-/bildefil. Les mer om behandling av lyd og bilde.
Hvordan er datamaterialet beskyttet mot at uvedkommende får innsyn?	Ingen personidentifiserende opplysninger ble lagret.	Er f.eks. datamaskintilgangen beskyttet med brukernavn og passord, står datamaskinen i et låsbart rom, og hvordan sikres bærbare enheter, utskrifter og opptak?
Dersom det benyttes mobile lagringsenheter (bærbar datamaskin, minnepenn, minnekort, cd, ekstern harddisk, mobiltelefon), oppgi hvilke	bærbar datamaskin	NB! Mobile lagringsenheter bør ha mulighet for kryptering.
Vil medarbeidere ha tilgang til datamaterialet på lik linje med daglig ansvarlig/student?	Ja ● Nei ○	
Hvis ja, hvem?	Hovedveileder; Eystein Enoksen. Bi-veileder: Espen Tønnessen	
Overføres personopplysninger ved hjelp av e-post/Internett?	Ja ○ Nei ●	F.eks. ved bruk av elektronisk spørreskjema, overføring av data til samarbeidspartner/databehandler mm.
Hvis ja, hvilke?		
Vil personopplysninger bli utlevert til andre enn prosjektgruppen?	Ja ○ Nei ●	
Hvis ja, til hvem?		
Samles opplysningene inn/behandles av en databehandler?	Ja ○ Nei ●	Dersom det benyttes eksterne til helt eller delvis å behandle personopplysninger, f.eks. Questback, Synovate MMI, Norfakta eller transkriberingsassistent eller tolk, er dette å betrakte som en databehandler. Slike oppdrag må kontraktsreguleres Les mer om databehandleravtaler her
Hvis ja, hvilken?		
12. Vurdering/godkjenning fra andre instanser		
Søkes det om dispensasjon fra taushetsplikten for å få tilgang til data?	Ja ○ Nei ●	For å få tilgang til taushetsbelagte opplysninger fra f.eks. NAV, PPT, sykehus, må det søkes om

Kommentar		dispensasjon fra taushetsplikten. Dispensasjon søkes vanligvis fra aktuelt departement. Dispensasjon fra taushetsplikten for helseopplysninger skal for alle typer forskning søkes Regional komité for medisinsk og helsefaglig
Søkes det godkjenning fra andre instanser?	Ja ○ Nei ●	F.eks. søke registereier om tilgang til data, en ledelse om tilgang til forskning i virksomhet, skole, etc.
Hvis ja, hvilke?		

13. Prosjektperiode

Prosjektperiode	Prosjektstart:01.01.2013 Prosjektslutt:01.01.2016	Prosjektstart Vennligst oppgi tidspunktet for når førstegangskontakten med utvalget opprettes og/eller datainnsamlingen starter. Prosjektslutt Vennligst oppgi tidspunktet for når datamaterialet enten skal anonymiseres/slettes, eller arkiveres i påvente av oppfølgingsstudier eller annet. Prosjektet anses vanligvis som avsluttet når de oppgitte analyser er ferdigstilt og resultatene publisert, eller oppgave/avhandling er innlevert og sensurert.
Hva skal skje med datamaterialet ved prosjektslutt?	■ Datamaterialet anonymiseres □ Datamaterialet oppbevares med personidentifikasjon	Med anonymisering menes at datamaterialet bearbeides slik at det ikke lenger er mulig å føre opplysningene tilbake til enkeltpersoner.NB! Merk at dette omfatter både oppgave/publikasjon og rådata. Les mer om anonymisering
Hvordan skal datamaterialet anonymiseres?	Alle orginal data vil ble slettet etter publisering.	Hovedregelen for videre oppbevaring av data med personidentifikasjon er samtykke fra den registrerte. Årsaker til oppbevaring kan være planlagte oppfølgningsstudier, undervisningsformål eller annet. Datamaterialet kan oppbevares ved egen institusjon, offentlig arkiv eller annet. Les om arkivering hos NSD
Hvorfor skal datamaterialet oppbevares med personidentifikasjon?		
Hvor skal datamaterialet oppbevares, og hvor lenge?		

14. Finansiering

Hvordan finansieres prosjektet?	Gjennom Norges idrettshøgskole og Olympiatoppen. Oslo	

15. Tilleggsopplysninger

Tilleggsopplysninger		

16. Vedlegg

Antall vedlegg	2	

Norsk samfunnsvitenskapelig datatjeneste AS
NORWEGIAN SOCIAL SCIENCE DATA SERVICES

Harald Hårfagres gate 29
N-5007 Bergen
Norway
Tel: +47-55 58 21 17
Fax: +47-55 58 96 50
nsd@nsd.uib.no
www.nsd.uib.no
Org.nr. 985 321 884

Shaher Shalfawi
Seksjon for fysisk prestasjonsevne Norges idrettshøgskole
Postboks 4014
0806 OSLO

Vår dato: 24.02.2014 Vår ref: 37679 / 3 / LT Deres dato: Deres ref:

TILBAKEMELDING PÅ MELDING OM BEHANDLING AV PERSONOPPLYSNINGER

Vi viser til melding om behandling av personopplysninger, mottatt 15.02.2014. Meldingen gjelder prosjektet:

37679	*A study of the effect of different training models, duration, intensity and frequency on repeated sprint ability and agility ability on soccer players*
Behandlingsansvarlig	*Norges idrettshøgskole, ved institusjonens øverste leder*
Daglig ansvarlig	*Shaher Shalfawi*

Personvernombudet har vurdert prosjektet og finner at behandlingen av personopplysninger er meldepliktig i henhold til personopplysningsloven § 31. Behandlingen tilfredsstiller kravene i personopplysningsloven.

Personvernombudets vurdering forutsetter at prosjektet gjennomføres i tråd med opplysningene gitt i meldeskjemaet, korrespondanse med ombudet, ombudets kommentarer samt personopplysningsloven og helseregisterloven med forskrifter. Behandlingen av personopplysninger kan settes i gang.

Det gjøres oppmerksom på at det skal gis ny melding dersom behandlingen endres i forhold til de opplysninger som ligger til grunn for personvernombudets vurdering. Endringsmeldinger gis via et eget skjema, http://www.nsd.uib.no/personvern/meldeplikt/skjema.html. Det skal også gis melding etter tre år dersom prosjektet fortsatt pågår. Meldinger skal skje skriftlig til ombudet.

Personvernombudet har lagt ut opplysninger om prosjektet i en offentlig database, http://pvo.nsd.no/prosjekt.

Personvernombudet vil ved prosjektets avslutning, 01.01.2016, rette en henvendelse angående status for behandlingen av personopplysninger.

Vennlig hilsen

Katrine Utaaker Segadal

Lis Tenold

Kontaktperson: Lis Tenold tlf: 55 58 33 77
Vedlegg: Prosjektvurdering

Dokumentet er elektronisk produsert og godkjent ved NSDs rutiner for elektronisk godkjenning.

Personvernombudet for forskning

Prosjektvurdering - Kommentar

Prosjektnr: 37679

Det gis skriftlig informasjon og samtykke for deltakelse er ensbetydende med aktiv deltakelse.
Personvernombudet finner i utgangspunktet skrivet godt utformet, men forutsetter at følgende endres/tilføyes;
- overskriften må endres til "Forespørsel om deltakelse i forskningsprosjektet "A study of the effect of different training models, duration, intensity and frequency on repeated sprint ability and agility ability on soccer players."" (anbefaler forøvrig at det gis en norsk tittel)
- det må innledningsvis også gå frem hvordan utvalget er rekruttert og hvor mange som skal delta
- avsnittet "Dataene som fremkommer....." må endres slik at det går frem at publisering skjer på en slik måte at ingen enkeltpersoner gjenkjennes.
- setningen "I henhold til etiske retningslinjer ...." ta vekk
- det må gå frem at innsamlete opplysninger vil bli anonymisert ved prosjektslutt, senest 01.01.2016

Personvernombudet legger til grunn for sin godkjenning at revidert skriv ettersendes personvernombudet@nsd.uib.no før det tas kontakt med utvalget (merk eposten med prosjektnummer).

Innsamlede opplysninger registreres på privat pc. Personvernombudet legger til grunn at forsker setter seg inn i og etterfølger Norges idrettshøgskole sine interne rutiner for datasikkerhet, spesielt med tanke på bruk av privat pc til oppbevaring av personidentifiserende data.

Prosjektet skal avsluttes 01.01.2016 og innsamlede opplysninger skal da anonymiseres. Anonymisering innebærer at direkte personidentifiserende opplysninger som navn/koblingsnøkkel slettes, og at indirekte personidentifiserende opplysninger (sammenstilling av bakgrunnsopplysninger som f.eks. yrke, alder, kjønn) fjernes eller grovkategoriseres slik at ingen enkeltpersoner kan gjenkjennes i materialet.

Til: Forsøkspersonen
Fra: Shaher Shalfawi

Forespørsel om deltakelse i forskningsprosjektet

Bakgrunn og hensikt med studien:

De siste årene har det blitt rettet mer og mer fokus på hurtighet i fotball. Norton et.al. (1999) hevder at hastigheten og tempoet i spillet har "doblet seg" fra 1961 til 1997. Fotballspillere gjennomfører 60-90 maksimale eller nær maksimale løp gjennom en kamp. Løpene har en midlere varighet på 2-4 sekunder. Det er disse aksjonene som avgjør kampresultatet. Intensitet og varighet varierer imidlertid mellom kamper, omganger, type motstander og spillernes posisjoner.

Hurtige spillere har større potensiale for antall involveringer i kampsituasjon. I den offensive delen av spillet prøver angriperen å skaffe seg størst mulig avstand til forsvarsspilleren for å skape målsjanser. I den defensive delen av spillet forsøker forsvareren å hindre rom og dermed avverge at motstanderen kommer til målsjanser. Et sentralt spørsmål blir dermed om hvordan en skal optimalisere treningen for å utvikle hurtige fotballspillere.

Hensikten med denne studien er å måle effekten av agility, styrke eller hurtighetstreninger på følgende testøvelser:

1. Utholdende løpshurtighet
2. Akselerasjonshurtighet
3. Maksimalhurtighet
4. Agillityløype
5. Vertikal spenst (svikthopp / CMJ)
6. Beinpress (1RM)
7. Aerob utholdenhet (beep test)

Hypotesen er at denne treningen vil gi en positiv utvikling av utholdende løpshurtighet, agillity, akselerasjonshurtighet og maksimalhurtighet, men at treningen ikke vil ha effekt på vertikal spenst og beinstyrke.

Metode:

I studien vil det totalt delta 60-70 kvinnelige og mannelig fotballspillere på høyt nivå (bedre enn 2. divisjon). Disse vil bli delt i en intervensjonsgruppe (hurtighet) og en kontrollgruppe (styrke). Forsøkspersonene matches og deles inn på grunnlag av pre-testen.

Kontrollgruppen skal gjennomføre vanlig fotballtrening, og 1-2 ukentlige styrketreninger eller agility. Intervensjonsgruppen skal istedenfor styrketreningene gjennomføre 1-2 ukentlige treningsøkter med hurtighetstrening:
Økt 1: 2-5 x 4-5 x 40m sprintløp rett frem, P=90s, SP=10 min.
Økt 2: 2-5 x 4-5 x 30m sprintløp med/uten strikk og retningsforandringer P=90s, SP=10 min

Inklusjonskriteriene for å være med i datagrunnlaget i treningsgruppen vil være:

1. Gjennomføre minst 80 % av treningene.
2. Gjennomføre alle testene i pre- og posttesten.

Ved å delta i studien får du en systematisk og ekspertoppfølging på hurtighetstrening og styrketrening. Denne hjelpen tror vi kan gjøre deg til en bedre fotballspiller.

Informert samtykke

Dataene som fremkommer i studien vil i hovedsak bli benyttet i publiseringen i en internasjonal tidsskrift, men vil også bli presentert på nasjonale og internasjonale konferanser og seminar, og i forelesninger på høgskoler på en slik måte at ingen enkeltpersoner gjenkjennes

For forskning på mennesker er det anbefalt å få et skriftlig samtykke på at du frivillig deltar som forsøksperson i prosjektet. Innsamlete opplysninger vil bli anonymisert ved publisering eller prosjektslutt (den som kommer først), senest 01.01.2016

Jeg, ________________________________, bekrefter at jeg har mottatt både muntlig og skriftlig informasjon og samtykker herved i å delta i prosjektet, og har muligheten til å trekke meg når som helst uten noen som helst form for konsekvenser.

Oslo,____________

_ _
Forsøksperson

Shaher Shalfawi

Jeg, Shaher Shalfawi, forplikter meg kun til å bruke dataene fra studiet til de formålene som er skissert i avtalen/informasjonsskrivet.

På forhånd hjertelig takk for at du vil stille opp!

Dersom det er noe som du lurer på kan du kontakte meg på mail eller telefon:

- E-mail: shaher.shalfawi@me.no
- Mobil: 45660660

Vennlig hilsen

_ _ _ _ _ _ _ _ _ _ _ _
Shaher Shalfawi

Endringsskjema

for endringer i forsknings- og studentprosjekt som medfører meldeplikt eller konsesjonsplikt

(jf. personopplysningsloven og helseregisterloven med forskrifter)

Endringsskjema sendes per e-post til: personvernombudet@nsd.uib.no

1. PROSJEKT	
Navn på daglig ansvarlig: Shaher A. I. Shalfawi	Prosjektnummer: 37679/3/LT
Evt. navn på student: Shaher A. I. Shalfawi	

2. BESKRIV ENDRING(ENE)	
Endring av daglig ansvarlig/veileder: Ingen endring.	*Ved bytte av daglig ansvarlig må bekreftelse fra tidligere og ny daglig ansvarlig vedlegges. Dersom vedkommende har sluttet ved institusjonen, må bekreftelse fra representant på minimum instituttnivå vedlegges.*
Endring av dato for anonymisering av datamaterialet: Alle rådata ble anonymisert og slettet etter publisering av artiklene som beskrevet i opprinnelig prosjekt melding. Ingen flere rådata er igjen, alt ble anonymisert og totalt slettet. For videre bruk i undervisning er det original publiserte artikler som skal brukes.	*Ved forlengelse på mer enn ett år utover det deltakerne er informert om, skal det fortrinnsvis gis ny informasjon til deltakerne.*
Gis det ny informasjon til utvalget? Ja: ____ Nei: __X__ Hvis nei, begrunn: Ingen endring ble gjennomført i forhold til opprinnelig melding som ble sendt til NSD. En studie som ble publisert i 2009 ble tatt med i den endelige avhandling.	
Endring av metode(r): Ingen endring.	*Angi hvilke nye metoder som skal benyttes, f.eks. intervju, spørreskjema, observasjon, registerdata, osv.*
Endring av utvalg: Det endelige antallet på forsøkspersoner på del-studiene som er med på dette prosjektet, er n=105 fordelt på 38 menn og 67 kvinner.	*Dersom det er snakk om små endringer i antall deltakere er endringsmelding som regel ikke nødvendig. Ta kontakt på telefon før du sender inn skjema dersom du er i tvil.*

Annet:

Utfra innsamlet data fra dette prosjektet er følgende artikler publisert:

1. Enoksen, E., Tønnessen, E., & **Shalfawi, S.** Validity and reliability of the Newtest Powertimer 300- series (R) testing system. *Journal of Sports Sciences*, 27, 77-84 (2009).

2. **Shalfawi, S.,** Ingebrigtsen, J., Dillern, T., Tønnessen, E., Delp, T. K. & Enoksen, E. The effect of 40 m repeated sprint training on physical performance in young elite male soccer players. *Serbian Journal of Sports Sciences*, 6(3), 111-116 (2012).

3. **Shalfawi, S.**, Haugen, T., Jakobsen, T. A., Enoksen, E., & Tønnessen, E. The Effect of Combined Resisted Agility and Repeated Sprint Training Vs. Strength Training on Female Elite Soccer Players. *The Journal of Strength & Conditioning Research*, 27(11), 2966-2972 (2013).

4. **Shalfawi, S.**, Young, M., Tønnessen, E., Haugen, T., & Enoksen, E. The effect of repeated agility training vs. repeated sprint training on elite female soccer players' physical performance. *Kinesiologia Slovenica*, 19(3), 29-42 (2013).

5. **Shalfawi, S.**, Enoksen, E., & Tønnessen, E. The relationship between measures of sprinting, aerobic fitness, and lower body strength and power in well-trained female soccer players. *International Journal of Applied Sport Sciences*, 26(1), 18-25 (2014).

3. TILLEGGSOPPLYSNINGER

Tittel av avhandling ble endret:

Fra: "A study of the effect of different training models, duration, intensity and frequency on repeated sprint ability and agility ability on soccer players."

Til hovedtittel: "Anaerobic conditioning of soccer players"
Og
undertittel: "The evaluation of different anaerobic training methods on soccer players' physical performance"

Forventet disputas er planlagt til medio desember 2014.

4. ANTALL VEDLEGG

	Legg ved eventuelle nye vedlegg (informasjonsskriv, intervjuguide, spørreskjema, tillatelser, og liknende.)

Study I in full text

Enoksen, E., Tønnessen, E., & **Shalfawi, S.** (2009). Validity and reliability of the Newtest Powertimer 300- series (R) testing system. *Journal of Sports Sciences*, 27, 77-84.

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Validity and reliability of the Newtest Powertimer 300-series® testing system

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Abstract

The aim of the present study was to assess the reliability and validity of the Newtest Powertimer 300-series® portable contact mat and photocells (Newtest Oy, Finland). The participants were 20 male soccer players aged 19.1 ± 3.5 years. The validity and reliability of the Powertimer (contact mat and photocells) were assessed in a comparison of a laboratory testing method (force platform and photocells) and the Newtest Powertimer system. All participants were tested on 40-m sprint, countermovement jump, and squat jump. The results showed that the Powertimer was a reliable instrument for both jumping and running. The system did not show any marked systematic bias ($P < 0.05$) and the random error associated with it was negligible. A comparison of the laboratory testing method with the Powertimer revealed that the Powertimer contact mat and photocells had poor validity and the bias in measurement differed from that of the laboratory testing method ($P < 0.05$). The Newtest Powertimer testing system was shown to be a useful instrument for measuring jump height and running speed. However, if a comparison of overall values of jumping height is intended, it is important to use the same testing system, because different systems give different results. It is also advisable to use this equipment only if no other ''gold standard'' equipment is available.

Keywords: *Vertical jump, flight time, physical therapists, athletic trainers, rehabilitation*

Introduction

The use of vertical jump and sprint performance to monitor athletes or assess the response to a training intervention is widespread in the literature (Blazevich, 2000; Chelly & Denis, 2001; Moir, Button, Glaister, & Stone, 2004; Prilutsky & Zatsiorsky, 1994; Weyand, Sternlight, Bellizzi, & Wright, 2000; Young, McLean, & Ardagna, 1995). Furthermore, vertical jump tests have largely been used to assess maximal-intensity exercise capabilities of the extensor muscles of the lower limbs. They have also been used to estimate anaerobic power and capacity (Carlock et al., 2004; Hoffman, Epstein, Einbinder, & Weinstein, 2000; Sayers, Harackiewicz, Harman, Frykman, & Rosenstein, 1999). Several protocols and systems have been designed and proposed to assess jump height: jump-and-reach method (Sargent, 1921); video recording of displacement of top of head; time-in-flight method (Bosco, Luhtanen, & Komi, 1983; Garcia-Lopez et al., 2005; Viitasalo et al., 1997); length of cord pulled, which was first presented by Abalakov, who considered the vertical displacement of the centre of mass to be an indicator of the jumping height attained (Garcia-Lopez et al., 2005); and determinations of impulse and thus velocity at take-off using a force platform. These five methods can be subdivided based on the following: with or without assistance from the arms, and with or without a countermovement.

Thus there are three main methods: the first considers jumping height as a vertical difference between two body landmarks or points; the second estimates jumping height once flight time has been measured; and the third calculates jumping height using the appropriate equations for take-off velocity and impulse. With the second method described above, contact mats and laser beams have been used to measure the flight and contact time. One of the most common systems for testing an athlete's jumping height and running speed is the Newtest Powertimer 300-series®. The use of this portable system is well documented in the literature (Balciunas, Stonkus, Abrantes, & Sampaio, 2006; Hennessy & Kilty, 2001; Kyrolainen, Belli, & Komi, 2001;

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Kyrolainen et al., 2003). It is also used in institutes of physical education, sport and health sciences, health care and rehabilitation, and training centres. However, the validity and reliability of this instrument have yet to be verified; only its accuracy in recording time has been considered.

Validity implies that values for a new method are consistent with those from a "gold standard" system. Garcia-Lopez et al. (2005) validated one type of mat with other types of contact mat and force platforms. The validation was for contact time and not jump height obtained. Other studies of contact mats have focused on the reliability of the instrument rather than the validity. Thus there is limited literature on the validity of contact mats.

The reliability of performance tests refers to the reproducibility of the measure of performance provided by the test when the test is administrated on several occasions. Measures should be reproducible so that there is neither marked systematic nor random variation (Hopkins, 2000). Reliability is a focus of interest in sport sciences, because it determines how well a test can track changes in athletes' performance in practical settings or in studies of factors that influence performance (Schabort, Hawley, Hopkins, & Blum, 1999). Differences between cinematic variables obtained from force–time and photogrammetric data have been reported (Hatze, 1998; Kibele, 1998). The use of time in flight to assess jump height has a fundamental requirement: the configuration of the body at take-off and landing should be identical. It has been reported that assessing jump height by this method results in error (2.3 ± 0.9 cm) (Kibele, 1998). This error was attributed to the different knee and ankle angles during the take-off and landing phases (Hatze, 1998). The use of a portable system that measures jumping height and running speed is a simple method that allows for daily control of the progress of an athlete throughout a training or rehabilitation programme. Therefore, the aim of this study was to assess the validity and reliability of the Newtest Powertimer 300-series® measuring system, which is portable and widely used in functional performance tests in rehabilitation, sport science, and research.

Materials and methods

Participants

In this study, 20 players aged 16–30 years from a Norwegian third division soccer team were tested as part of their athletic training programme in the middle of the second preparation phase. The players were healthy and free of injuries at the time of testing. Their mean age, body mass, and stature ($\pm s$) were 19.1 ± 3.5 years, 72.6 ± 7.8 kg, and 1.79 ± 0.08 m, respectively. The stature of the participants was measured to the nearest 0.01 m using a wall-mounted scale. This scale can measure stature up to 2.25 m. Body mass was measured on a force platform. The institutional ethics committee of the Norwegian University of Sport Sciences approved the study. Written informed consent was obtained from all participants.

Instruments

Newtest Powertimer 300-series®. In this study, the Newtest Powertimer was used to measure countermovement and squat jump heights and sprint performances over 20 m and 40 m. The test results were converted into easy-to-understand and easy-to-compare numeric values. The Powertimer used in this study consists of a hand-held computer that is the control unit for the system, a contact mat that has a high density of sensors with a large measurement surface (84×95 cm), photocells that have a narrow infrared beam and no reflectors, and a portable briefcase with in-built connections and rechargeable batteries.

Laboratory testing system. Jump height was estimated in the laboratory of the Norwegian Olympic Committee and Confederation of Sports using force-platform-based determinations of impulse and thus velocity at take-off. The force platform used was an AMTI model OR6-5-1 (dimensions 122×62 cm). The data were amplified (AMTI Model SGA6-3), digitized (DT 2801), and saved to a computer (PC Pentium 3) with the aid of the special software program Biopack MP 100. The 20-m and 40-m sprints were measured at the Norwegian Olympic Committee and Confederation of Sports using a start mat and two pairs of double infrared photocells, which were connected via cables and connected to a computer (PC Pentium 3) that measures time to the nearest 0.001 s. The photocells were mounted on a 50-m sprint running track.

Measurement errors

The force platform at the Norwegian Olympic Committee and Confederation of Sports has been claimed by the manufacturer to have a maximum variation of $\pm 2\%$ of the overall measure according to the landing point. However, the manufacturer claimed that the error rarely exceeds 0.5% of the overall measure. The photocells have been claimed by the manufacturer to have 0.001 s error over a 5-m sprint at a speed of $10.0 \text{ m} \cdot \text{s}^{-1}$, which is about 0.2% of the overall time in a 40-m sprint.

Newtest OY in Finland has claimed the error in flight time measurement to be ± 0.001 s and ±2.0 mm of the jumping height when using the contact mat.

Test set-up

In this study, the force platform was covered by the contact mat in an attempt to register the vertical jumping height on the force platform and the contact mat simultaneously. The force platform had a time resolution of 1000 Hz and a force resolution of 0.1 N and was zeroed with the contact mat placed on the force platform. Therefore, measurements were not influenced by the weight of the contact mat. The Powertimer photocells were placed exactly at the same angle as the laboratory photocells mounted on the sprint track. All test instruments were checked and approved by experts at the Norwegian Olympic Committee and Confederation of Sports before the testing took place.

Test procedure

Following their usual warm-up, the participants were asked to perform three maximum attempts in the following order: countermovement jump, squat jump, and 40-m sprint. In this study, all jumps were performed with hands placed on the hips. The hands-on-hips method was adopted to restrict performance to leg and hip explosiveness and to minimize differences in jumping technique. The participants performed the squat jump from a semi-squat position with no countermovement. At the start, the knee was restricted to approximately 90° with the plantar part of the foot contacting the ground. The hands were on the hips and the trunk was erect. After the jump, at the moment of impact, the knee was kept extended at a knee angle of 180° and the contact with the ground started with the toes. The countermovement jump was performed from a standing position with the plantar part of the foot contacting the ground with the hands on the hips and from an erect standing position with a knee angle of 180°, a countermovement was performed until the knee angle reached approximately 90°. Then, immediately the athlete jumped. After the jump, at the moment of impact, the knee was kept extended at a knee angle of 180° and the contact with the ground started with the toes.

The 40-m sprint was performed from a standing position on the starting mat. Time for the acceleration phase (0–20 m) and full speed phase (20–40 m) was measured at the same run. Measurement of the 40-m sprint started when the participant took off from the starting mat, which was situated at the beginning of the sprint running track (time 0). Three attempts each were allowed for the squat jump, countermovement jump, and 40-m sprint, with at least 3 min recovery between attempts. The following criteria were used to determine successful trials: performance of the trials as described in the procedures (Participant), acceptable force platform and contact mat registration (Instrument), and acceptable laboratory photocells and Powertimer photocells registration (Instrument). When the participants fulfilled these three requirements, the best result was retained for analysis. To test reliability, all measurements of variables were performed on two separate days at the same place and time of the day with the same settings and configurations.

Statistics

The purpose of this study was to assess the validity of the Newtest Powertimer testing system and not to establish an equation to predict a new participant's criterion. A sample size of 20 participants was thus considered satisfactory for this study (Hopkins, 2000). Therefore, the results are valid only for those who took part and cannot be generalized to another population. Raw data were transferred to SPSS 13.0 for Windows and Analyse-it for Microsoft Excel (version 2.11). Bland and Altman's 95% limits of agreement, described by Atkinson and Nevill (1998), were used to assess the reliability of both test methods. To examine validity between the Powertimer (contact mat and photocells) and laboratory testing method (force platform and photocells), the method of comparison described by Altman and Bland (1983) and Bland and Altman (1986) was used. A paired *t*-test was used to assess the hypothesis of zero bias in both reliability and validity. If heteroscedasticity (the differences depends on the magnitude of the mean) was suspected or the data did not follow normality, a logarithmic (natural) transformation of the data was performed before calculating bias and limits of agreement. Then the data were presented after antilog was performed. A paired *t*-test was then applied to the log transformed data. Pearson's *r* was used to examine heteroscedasticity between absolute differences and individual means. Statistical significance was set at $P < 0.05$ throughout. To determine whether the Powertimer is of practical use, the analytical goals regarding reliability were set based on physical performance improvement judgement according to our school. Therefore, the analytical goals were set to a total error (systematic bias and random error) that did not exceed ±0.2 s and ±1.5 cm for sprint measures and jumping measures, respectively.

Results

Reliability

Test–retest reliability did not show any marked systematic bias for either Powertimer testing or laboratory testing. Heteroscedasticity was suspected in all measures obtained by the Powertimer except for 0–40 m sprint (Table I). However, the measurement of 0–40 m sprint did not follow a normal distribution when examined by histogram of the difference (Figure 1). Therefore, log transformation was applied on all measures obtained by the Powertimer. Results are presented on a ratio scale. Systematic variation is presented as bias and the random variation as 95% limits of agreement (Table I and Table II).

Altman and Bland (1983) suggested that it is preferable to perform the same transformation for measurement by each method if the purpose of the study is to compare two testing methods. Therefore, log transformation was carried out on both testing methods even if the gold standard method (laboratory testing method) did not show heteroscedasticity.

Validity

Heteroscedasticity was suspected in the measurement of 0–20 m sprint (Table III). A clear outlier was also apparent in the 0–20 m sprint (Figure 2) and 0–40 m sprint data (Figure 3). Therefore, this participant was omitted from the study for both the 0–20 m and 0–40 m sprint. Heteroscedasticity was not observed in countermovement jump, squat jump, top running speed over 20–40 m sprint, and running speed over 0–40 m sprint (Table III).

Discussion

Reliability

A basic requirement of any test is that repeated measurements yield consistent results. Reliability refers to the reproducibility of a measurement; measures should be reproducible so that there is neither marked systematic (learning, motivation, fatigue) nor random (sampling) variation (Hopkins, 2000). Poor reliability degrades the ability to track changes in measurements in clinical or in experimental studies (Atkinson & Nevill, 1998). The paired *t*-test indicated that the test–retest reliability did not show any marked systematic bias ($P < 0.05$) for repeated measures on Newtest Powertimer and laboratory testing, and the limits of agreement indicated a negligible random error variation (Table I and Table II) that did not exceed our analytical goals. Therefore, for any individual from the population tested in this study, assuming that the bias that is present is negligible, any two tests on the Powertimer will differ due to measurement error by no more than ±3.2%, ±3.3%, ±1.1%, and ±1.5% for countermovement jump, squat jump, 0–20 m sprint, and 0–40 m sprint, respectively (Table I). In contrast, for any individual from the population, assuming that the bias that is present is negligible, any two tests with the laboratory system will differ due to measurement error by no more than ±1.0%, ±0.9%, ±1.6%, and ±1.1% for countermovement jump, squat jump, 0–20 m sprint, and 0–40 m, respectively (Table II). One explanation for

Table I. Reliability measures for the Newtest Powertimer (data are presented on a ratio scale after antilog).

	Test	Retest	Bias	95% limits of agreement	Paired *t*-test *P*-value
Jumping height, CMJ (cm)	39.3 ± 3.8	39.1 ± 3.4	1.002 (0.2%)	×/÷ 1.032 (±3.2%)	0.776
Jumping height, SJ (cm)	37.0 ± 3.3	36.2 ± 3.4	1.007 (0.7%)	×/÷ 1.033 (±3.3%)	0.303
0–20 m sprint (s)	3.00 ± 0.11	3.01 ± 0.12	0.996 (−0.4%)	×/÷ 1.011 (±1.1%)	0.081
0–40 m sprint (s)	5.35 ± 0.20	5.39 ± 0.18	0.996 (−0.4%)	×/÷ 1.015 (±1.5%)	0.156

Notes: Pearson's r between the absolute difference and the average mean was: CMJ ($r = 0.15$, $n = 20$, $P = 0.70$), SJ ($r = 0.18$, $n = 20$, $P = 0.64$), 0–20 m ($r = 0.79$, $n = 20$, $P = 0.02$), and 0–40 m ($r = 0.01$, $n = 20$, $P = 0.97$). CMJ = countermovement jump, SJ = squat jump.

Table II. Reliability measures for the laboratory system (data are presented on a ratio scale after antilog).

	Test	Retest	Bias	95% limits of agreement	Paired *t*-test *P*-value
Jumping height, CMJ (cm)	39.5 ± 2.1	39.2 ± 2.2	1.004 (0.4%)	×/÷ 1.010 (±1.0%)	0.069
Jumping height, SJ (cm)	35.7 ± 1.0	35.6 ± 0.9	1.001 (0.1%)	×/÷ 1.009 (±0.9%)	0.616
0–20 m sprint (s)	2.84 ± 0.08	2.84 ± 0.09	1.001 (0.1%)	×/÷ 1.016 (±1.6%)	0.699
0–40 m sprint (s)	5.22 ± 0.15	5.23 ± 0.17	1.000 (0.0%)	×/÷ 1.011 (±1.1%)	0.852

Notes: Pearson's r between the absolute difference and the average mean was: CMJ ($r = -0.22$, $n = 20$, $P = 0.57$), SJ ($r = -0.66$, $n = 20$, $P = 0.11$), 0–20 m ($r = 0.21$, $n = 20$, $P = 0.62$), and 0–40 m ($r = -0.11$, $n = 20$, $P = 0.79$). CMJ = countermovement jump, SJ = squat jump.

Table III. Measures of variables from laboratory testing and Powertimer testing and the differences between the two systems.

	Laboratory testing	Powertimer testing	Bias	95% limits of agreement Upper	95% limits of agreement Lower	95% confidence interval Upper	95% confidence interval Lower	Paired *t*-test *P*-value
Jumping height, CMJ (cm)	39.1 ± 4.7	41.9 ± 5.1	2.8	8.0	−2.4	5.9 to 10.2	−4.5 to −0.2	<0.001
Jumping height, SJ (cm)	36.6 ± 4.6	38.2 ± 4.6	1.7	6.8	−3.4	4.6 to 8.9	−5.6 to −1.3	0.010
0–20 m sprint (s)	2.83 ± 0.11	2.85 ± 0.10	1.2%	2.1%	0.3%	1.7% to 2.5%	−0.1% to 0.7%	<0.001
20–40 m sprint (s)	2.38 ± 0.10	2.38 ± 0.09	0.00	0.05	−0.04	0.03 to 0.07	−0.06 to −0.02	0.428
0–40 m sprint (s)	5.21 ± 0.20	5.23 ± 0.16	0.04	0.10	−0.02	0.07 to 0.12	−0.04 to 0.01	<0.001

Notes: Pearson's r between the absolute difference and the average mean was: CMJ ($r = -0.08$, $n = 20$, $P = 0.75$), SJ ($r = 0.07$, $n = 20$, $P = 0.65$), 0–20 m ($r = 0.23$, $n = 19$, $P = 0.33$), 20–40 m ($r = -0.26$, $n = 20$, $P = 0.34$), and 0–40 m ($r = -0.28$, $n = 19$, $P = 0.17$). CMJ = countermovement jump, SJ = squat jump.

the small systematic bias found in this study could be that the reliability for squat jump, countermovement jump, and sprint can be achieved through test–retest and without the need for practice sessions with physically active men (Arteaga, Dorado, Chavarren, & Calbet, 2000; Moir et al., 2004; Young, MacDonald, Heggen, & Fitzpatrick, 1997). The test–retest results for the Powertimer contact mat indicate that the test is not reliable enough to monitor the small changes in jump height that result from increasing the training of a national or international elite athlete.

Validity

Validity refers to the agreement between the value of a measurement and its true value (Hopkins, 2000). The first objective of this study was to compare the performance characteristics of the jumping and sprinting obtained with the force platform and laboratory photocells (gold standard) method with the corresponding values determined using the Powertimer (contact mat and photocells). In the Methods section above and from the reliability results found in this study, it has been shown that the errors associated with the force platform are negligible, thus the use of this method as a reference procedure is justified. The results related both to jumping and sprinting, which were obtained through laboratory testing and Powertimer testing, are presented in Table III. Comparison of the results between the force platform and Powertimer contact mat reveal that for countermovement jump, the mean response latency for the Powertimer contact mat was greater than the mean for the force platform (Table III). A paired *t*-test showed a marked systematic bias of 2.8 cm ($P < 0.05$; Table III). For the squat jump, the mean response latency for the Powertimer contact mat was greater than the mean for the force platform (Table III). A paired *t*-test showed a notable systematic bias of 1.7 cm ($P < 0.05$; Table III). From the results presented in Table III, it can be seen that in both jumps (squat jump and countermovement jump), the jump height determined by the Powertimer was always higher than for the laboratory-based assessment (2.8 cm for countermovement jump and 1.7 cm for squat jump). This could be related to the fact that the leg joints are more flexed during landing than at take-off, resulting in a longer flight time and thus greater apparent jump height. Furthermore, the bias observed can be traced back to the assumptions made by Bosco et al. (1983): (a) take-off and landing configuration are identical; (b) vertical centre of gravity velocity increases in a linear fashion during the propulsion phase; and (c) the propulsion phase is equal to half the contact time. According to Hatze (1998), these assumptions do not hold true. The errors introduced by assumption (a) were clarified by the fact that the joints are more flexed at landing than at take-off; assumption (b) was justified by indicating that vertical velocity does not increase linearly during the propulsion phase, but it increases in a highly non-linear fashion and finally decreases just before take-off; and for assumption (c) Hatze (1998) concluded that the propulsion phase is not equal to half the contact time. Also, Aragón (2000) found that the time the body centre of mass travels downward after jumping is not equal to the time it travels upward. Furthermore and from analysis of jumping performance at a camera speed of 200 frames per second and a shutter speed of 1/600 s, Kibele (1998) concluded that the centre of gravity position was lower at landing than at take-off, that the time from take-off to peak was less than the time from peak to landing, and that the difference can be attributed to a different landing position than that at take-off. However, the measures of jump height obtained by the two systems differed ($P < 0.05$). The 95% limits of agreement show that the Powertimer contact mat may be −2.4 cm below or 8.0 cm above that of the force platform when performing countermovement jump, and −3.4 cm below or 6.6 cm above that of the force platform when performing squat jump. This

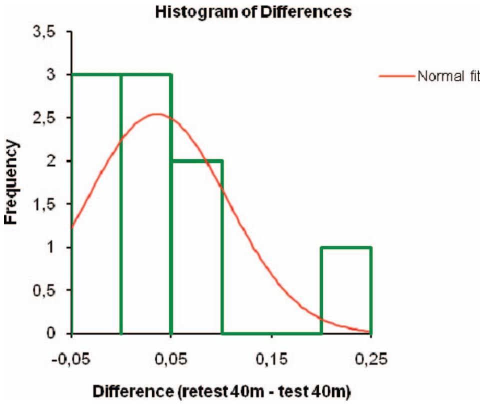

Figure 1. Histogram of the differences for test–retest of 0–40 m sprint.

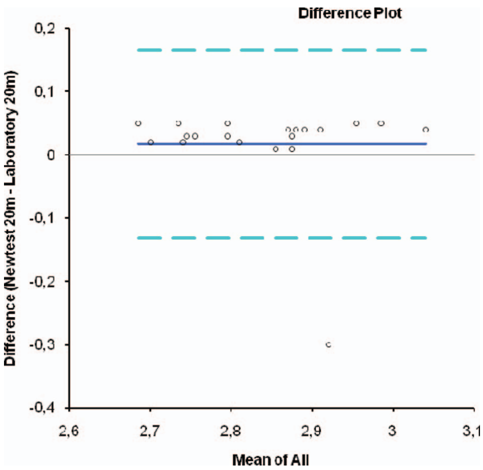

Figure 2. Bland-Altman plot with bias and limits between the Newtest Powertimer and laboratory testing method for start and acceleration phase (0–20 m). Thin solid line = line of identity; bold solid line = bias (0.017); dashed lines = 95% limits of agreement (−0.131 to 0.166).

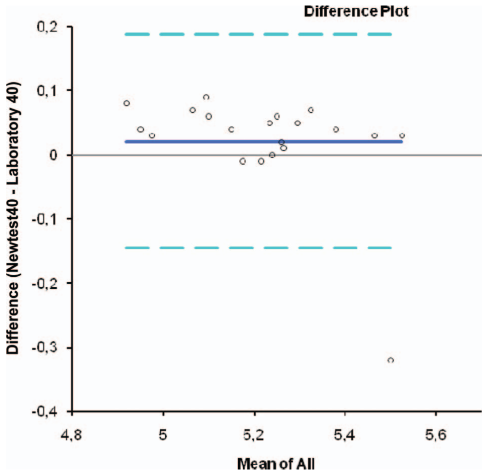

Figure 3. Bland-Altman plot with bias and limits between the Newtest Powertimer and laboratory testing method for start, acceleration phase, and top running speed (0–40 m).Thin solid line = line of identity; bold solid line = bias (0.021); dashed lines = 95% limits of agreement (−0.145 to 0.188).

random variation between the testing methods is unacceptable for clinical purposes. The variation in jumping height 95% limits of agreement between the two jumps could be due to the difference in performing the jumps. The limits of agreement are only estimates of the values that apply to the participants being studied. Another sample would give different limits (Bland & Altman, 1986). In this study, 95% confidence intervals were calculated to determine how precise the limits of agreement are. For the upper limit of agreement in countermovement jump, the 95% confidence interval is 5.9 cm to 10.2 cm, and for the lower limit of agreement it is −4.5 cm to −0.2 cm. For the upper limit of agreement in squat jump, the 95% confidence interval is 4.6 cm to 8.9 cm, and for the lower limit of agreement it is −5.6 cm to −1.3 cm. The intervals for countermovement jump and Squat jump are wide, reflecting the small sample size and the large variation in the difference. They show, however, that even on the most optimistic interpretation, there can be considerable discrepancies between the two methods and that the level of agreement is not acceptable (Table III). Therefore, we suggest using the Powertimer contact mat only if no other accurate instruments are available and it is important to use the same system when measuring jumping heights, because from the results of this study and others, different systems give different results and contain errors.

Regarding the start and acceleration phase (0–20 m), the mean response latency for the Powertimer was greater than the mean for laboratory photocells by 1.2% (Table III). A paired *t*-test showed a notable systematic bias ($P < 0.05$). The 95% limits of agreement were 0.3% and 2.1% for the lower limit and the upper limit, respectively. It is also apparent from Table III that there was a marked systematic bias (0.04 s) for speed over 0–40 m and the Powertimer measures were higher than for the laboratory photocells (Table III). Furthermore, measurement of the 40-m sprint started when the participant took off from the starting mat that was situated at the beginning of the sprint running track (time 0). Therefore, one explanation for the marked bias detected in both speed measures (0–20 m and 0–40 m) can be traced back to the errors associated with the Powertimer contact mat (Table I), which was used to measure speed over 0–40 m. Furthermore, when we compared the testing methods before we omitted the outlier detected by the Bland-Altman plot (Figure 2 and Figure 3), the results did not show any marked bias on either measure (0–20 m and 0–40 m). Therefore, it is important to omit from the analysis any individual suspected of being technically unsatisfactory (Bland & Altman, 1986), otherwise the results may be misleading. For the top running speed (20–40 m), the mean response latency for the Powertimer photocells was equal to the mean for laboratory photocells (0.00 s) (Table III). A paired *t*-test showed no notable systematic bias ($P > 0.05$). The 95% limits of agreement were negligible for the lower limit (-0.04 s) and the upper limit (0.05 s) (Table III). Regarding Powertimer photocells and laboratory photocells, there was a notable systematic bias between the photocells of both instruments. And the limits of agreement were wide enough for the start and acceleration phase for us to be confident that the Powertimer photocells cannot be used in the place of the laboratory photocells for clinical purposes except for the top running speed (20–40 m), which we do not recommend because of the variation observed in both the 0–20 m sprint and 0–40 m sprint.

Conclusions

The Newtest Powertimer 300-series® has been shown to be a useful instrument for estimating vertical jumping height and running speed. The results from this investigation reveal that the Powertimer is a reliable testing instrument. However, the quantitative difference observed between the Powertimer contact mat and force platform suggests that the Powertimer contact mat is useful if comparison of overall values of jump height is the goal. Therefore, we suggest use of the Powertimer contact mat only if no other gold standard instruments are available. It is important to use the same system in pre- and post-test, because different systems give different results and contain errors. The validity of the Powertimer contact mat and photocells has not been confirmed. In the present study, the force platform was zeroed with the Powertimer contact mat placed on the force platform. However, this would most likely have modified the ground reaction forces. Nevertheless, this was not important here because it did not bias the detection of the time for take-off and landing. The system has its advantages, as it possesses high applicability on the sports field, supports functional performance testing in rehabilitation, and displays immediate results.

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Study II in full text

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THE EFFECT OF 40 M REPEATED SPRINT TRAINING ON PHYSICAL PERFORMANCE IN YOUNG ELITE MALE SOCCER PLAYERS

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Abstract The purpose of this study was to investigate the effect of eight-week repeated sprint training program on maximum sprinting speed, endurance sprinting speed, jump height and the ability to repeat and recover from high-intensity exercise (Yo-Yo IR1). Fifteen young, well-trained, elite male soccer players aged (±SD) 16.3 ±0.5 years, body mass 68.1 ±9.4 kg, and stature 178.5 ±7.3 cm, volunteered to participate in this study. All subjects were tested on 40 m sprint, 10x40 m repeated sprint, 3–6–9 agility with a 180° turn, countermovement jump (CMJ), squat jump (SJ), and Yo-Yo IR1 test. Subjects were randomly assigned to one of two groups: a training group and a control group. The training group followed a repeated sprint training program twice a week. The results indicate significant improvement within the training group from pre- to post-test in 10x40 m repeated sprint time (-0.29 s), 40 m sprint time (-0.33 s), 0–20 m sprint time (-0.19 s), 20–40 m sprint time (-0.15 s) and CMJ (1.3 cm). The control group results showed notable improvements in 0–40 m sprint time (-0.11 s), 10x40 m repeated sprint time (-0.09 s) and 0–20 m sprint time (-0.10 s). A comparison between groups indicates that there were marked differences between the two groups in 40 m sprint time (-0.22 s), 10x40 m repeated sprint time (-0.20 s) and 20–40 m sprint time (-0.15 s). We concluded that repeated sprint ability is trainable and the larger improvement within the training group as compared to the control group could be explained by the extra weekly repeated sprint training.

Key words: RSA, CMJ, YoYo-IR1, recovery, training load

INTRODUCTION

Research indicates that physical performance in soccer depends on various characteristics [4]. Specifically, endurance, strength, speed, power and agility must all be well developed in order to achieve a high performance level in soccer [12, 13, 19, 23]. Soccer match activities cover a range of intensities from low through moderate to high [19, 25]. Hence, a well-developed aerobic energy delivery system is important as it can assist players to maintain high-intensity and total work, and also help them to adjust the distance covered at low intensities so they perform at higher intensities when the game demands [5, 9, 24, 32]. Previous research has revealed that the most successful teams in modern soccer have the ability to perform and repeat high-speed actions more often than less successful teams [14]. These actions have been reported to characterise the crucial moments of a soccer match (e.g. scoring, winning position of scoring or likewise losing important defensive position) [26]. Furthermore, high-speed running and sprinting activities during a soccer match are proven to relate both to the ability to repeatedly sprint and the Yo-Yo IR1 test performance [1, 17, 22]. Such a merging relationship could be caused by both the similarities in the energy production of the two activities [1, 5, 8] and the concurrent demands on a certain degree of muscular power [8].

Analyses of elite soccer matches show that a player's sprint actions during a match can be categorised into actions of acceleration, deceleration, maximal speed and agility (alternation in the direction of motion) [19, 25]. Further analyses reveal that high-speed sprinting actions represent 1-11% of the total distance covered during a soccer match [19, 21, 29]. The majority of players conduct short sprints (2-4 s) every 60-90 s depending on the role and position of the player [4, 6, 26, 33, 34]. Hence, the duration of these high-speed sprinting actions highlights a major demand on acceleration speed. However, as sprints in soccer mainly start while the players are already running, the demand for maximum speed (flying speed above 20 m) can be high as well [19, 26, 29, 34]. The fact that the distance covered and the amount of high-intensity running and repeated sprinting decrease from the first to the second half of a soccer match [18, 21] suggests a high demand on speed endurance. Thus, the practice of repeated sprints (< 10 s) with short breaks that allow for near full recovery (30-120 s) is required to maintain soccer players' sprinting speed over time [2, 3]. An improvement in running speed has been observed following speed endurance training combined with resistance training [11]. Such training has previously been reported to be linked to an enhanced anaerobic metabolism [8, 14], fibre hypertrophy and beneficial neural adaptations [10, 29], and an improvement in the ability to store elastic energy in leg extensors [15, 20]. However, to date, the effect of specialised repeated sprint training stimuli, which do not involve strength, plyometric or agility training, on soccer players' repeated sprint ability (RSA) has not been explored except in one study [31].

Consequently, the main purpose of this study was to investigate the effect of an eight-week specialised repeated sprint training programme on elite junior soccer players' RSA. A secondary purpose of the study was to examine if this repeated sprint training programme would have any effect on other physical performance abilities such as Yo-Yo Intermittent Recovery test Level 1 (Yo-Yo IR1), 40 m maximum sprinting speed, agility, countermovement jump (CMJ) and squat jump (SJ).

MATERIALS AND METHODS

Subjects

One team of eighteen young, well-trained elite male soccer players who volunteered to participate in this study. Three subjects dropped out and the study continued with fifteen subjects aged 16.3 ±0.5 years, body mass 68.1 ±9.4 kg, and stature 178.5 ±7.3 cm. The subjects trained for 12.4 ±2.5 hours per week and their team played among the four best junior teams in the country. All participants gave their voluntary and informed written consent approved by their parents, and the study was approved by our University Committee.

Instruments and Testing Setup

The stature was measured using a wall-mounted stadiometer (KaWe Medizintechnik, Asperg, Germany); jump height was estimated using force platform-based determinations of impulse and velocity at take-off. The force platform used was an AMTI model OR6-5-1. The data were amplified (AMTI Model SGA6-3), digitised (DT 2801), and saved to a stationary computer (PC Pentium 4 running Windows XP) using the special software program, Biopack MP 100. The agility sprint 3–6–9 m with a 180° turn, 40 m maximal sprints and repeated sprint were measured on artificial grass in an indoor soccer stadium using Newtest Powertimer 300s infrared photocells. The photocells were connected to a laptop (PC Pentium 3 running Windows XP) using PowertimerPC, a special program that measures time to the nearest 0.001 s. The Yo-Yo IR1 test was conducted on an indoor basketball court following the procedure previously described by Krustrup et al [17]. A CD-player (DC 1015, Denon Brand Company, Japan) with an amplifier (F590ES) and loudspeakers (SS-E420, Sony Corporation, Japan) was used to play the Yo-Yo IR1 CD track. Two digital video cameras (SDR-H80, Panasonic Corporation, Japan) were used to record the Yo-Yo IR1-test in order to maximise objectivity when analysing the results.

The subjects were matched according to their 40 m sprint time from the pre-test. Then they were randomly assigned to one of the two groups: the training group (n=8) and the control group (n=7). The study took part in the pre-competition phase of the subjects' training program and ended 13 weeks before the start of the season; the duration of the pre-competition period was 26 weeks. The length of the mesocycle was eight weeks. Each test round was conducted on two consecutive days with no training in between. On test day one, 3-6-9 m agility with a 180° turn, 40 m maximal sprint, and 10x40 m repeated sprint were measured; on test day two, countermovement jump (CMJ), squat jump (SJ), and Yo-Yo IR1 test performance were assessed.

Testing Procedures

To familiarise themselves with the tests, the subjects completed a training session on the testing procedure one week prior to the pre-test.

On the first day of the pre-test, stature was measured before the subjects started with a 15 min general warm-up running at 60-70% of maximum heart rate, which ended with 4-5 accelerations over 50 m. Next, 3-6-9 m agility with a 180° turn and maximum running speed over 40 m were tested; a 5 min recovery was allowed between each of the tests. On both agility and 40 m sprint, the subjects were allowed three attempts each, with at least 3 min recovery between attempts. The 3-6-9 m agility with a 180° turn test used in this study involved positioning three lines on the field: one at 3 m, 6 m, and 9 m each. A photocell was placed at the start/finish line. The subject would sprint to the first line (3 m) and touch it with his foot, do a 180° turn and sprint back to the starting line, touching it with his foot again. Next, the subject would sprint to the second line (6 m) and repeat the procedure described above; finally, the subject would do the same with the third line (9 m) and sprint back to complete the test by crossing the start/finish line. The timer started when the subject passed the photocell at the start/finish line (time zero) and stopped when the subject passed the photocell after finishing the last run. In the 40 m maximum sprint test, the subjects started from a standing position by placing the front foot on the starting line, and when the test leader gave the signal, the subject started the sprint to the finish photocell (40 m). The time started automatically when the subject broke the beam from the first photocell, placed at the starting line (time zero), and stopped when he passed the photocells at both 20 m and 40 m. Times were measured for the 0-20 m sprint and the 20-40 m sprint. The best results were retained for analysis. The endurance sprinting time test was measured by 10x40 m maximum sprints with 60 s recovery between each sprint, using the same procedure as in the maximum 40 m sprint. The subjects were asked to sprint as fast as possible in each run. The mean time for the 10 sprints was used for analysis as it had been described as a good indicator of a player's ability to perform several sprints [30].

On the second day of the pre-test, the subjects started with the same warm-up procedure as described on the first pre-test day. The subjects were then asked to complete the CMJ and the SJ tests before the Yo-Yo IR1 test. The CMJ was performed by the subject standing on the force platform with the plantar part of the foot in contact with the ground, hands on hips; from an erect standing position with a knee angle of 180°, a countermovement was performed until the knee angle decreased to approximately 90°; an immediate jump followed. The SJ test was performed from a semi-squat position with no countermovement. At the start, the knee was restricted to approximately 90°, with the plantar part of the foot in contact with the ground. The hands were on the hips and the trunk was erect. Next, the subject would jump immediately. On both CMJ and SJ, three attempts each were allowed with at least 3 min recovery between attempts. The best result from both jumping tests was retained for analysis.

The Yo-Yo IR1 test started after the test leader had measured and marked the running lanes with cones to 2 m width and 20 m length, and a recovery area, where cones were placed 5 m behind the finishing line. Then the Yo-Yo IR1 CD (the soundtrack) and the CD player were checked (by timing of the intervals) to ensure the soundtrack would be played at the right speed [17] between the sound signals (Beep). Then, the Yo-Yo IR1 test was conducted by two experienced test leaders who were responsible for making sure that the participants fulfilled the testing criteria according to the procedures described by Krustrup et al [17]. Verbal encouragement was given from both test leaders and team coaches prior to and continuously during the test, with the purpose of motivating the participants to work to exhaustion.

The Training Intervention

Both groups in this study performed Nordic hamstring exercise, balance training (ankle strength on balance board), sit-ups, the plank, push-ups and the alternating back and arm rise twice a week during their regular soccer team training. Furthermore, the control group was instructed to continue with the team's original training plan. The training group completed two extra training sessions with repeated speed training. The training program completed by the training group included sprinting four sets of 5x40 m with 90 s recovery between repetitions and 10 min recovery between sets. The training was conducted every Monday at 10:00 AM and every Thursday at 06:00 PM. The team had soccer trainings on Mondays, Tuesdays, Wednesdays and Fridays. Before the speed training, the subjects completed both general and specific warm-up. The participants had to complete at least 90% of the training period and had to be able to complete all the tests to be included in further analysis.

Statistical Analysis

Raw data were transferred to the SPSS 16.0 for Windows and Microsoft Excel for analysis. The normality of the data was examined by assessing the Shapiro-Wilk test on all measured variables in this study for both groups; the results indicated that all measured variables followed normality. Therefore, to detect differences in measurements between the pre- and post-tests, the paired sample t-test was performed to evaluate the difference in means between the paired samples (within group). To test for a difference in means between groups, the independent sample t-test was assessed. In order to determine the effectiveness of the applied RSA training, the effect size (Cohen's d) was calculated according to Rosnow and Rosenthal [27]. Furthermore, to determine whether the effect size was trivial (d>0.2), small (d=0.2-0.6), moderate (d=0.6-1.2), large (d=1.2-2.0), or very large (d>2.0), the scale developed by Batterham and Hopkins [7] was used. Differences were considered significant at P≤0.05, and the results were expressed as means and standard deviations. The 95% confidence interval was also calculated for all measurements.

RESULTS

Differences within and between groups in a variety of physiological measures are shown in Table 1. The results indicate that there were significant improvements within the training group from pre- to post-test in 10x40 m repeated sprint time, 40 m sprint time, 0–20 m sprint time, 20–40 m sprint time and CMJ. The results also showed significant improvements within the control group in 40 m sprint time, 10x40 m repeated sprint time and 0–20 m sprint time. A comparison between groups demonstrates statistically marked differences between the two groups in 40 m sprint time, 10x40 m repeated sprint time and 20-40 m sprint time.

Table 1. Mean results of 10x40m repeated sprint, 40m sprint, 20m acceleration, 20m top speed, SJ, CMJ, Yo-Yo IR1 , agility and body mass between and within groups from pre to post-test (±SD)

	Training-Group				Control-Group				Between Groups differences				
Variable	Pre-test	Post-test	Change	95% CI	Pre-test	Post-test	Change	95% CI	TG	CG	Difference	95% CI	E.S.
10x40 m (s)	5.92 ±0.26	5.63 ±0.15	-0.29 ±0.13	-0.39 to -0.19**	5.84 ±0.27	5.74 ±0.25	-0.09 ±0.03	-0.12 to -0.07**	-0.29 ±0.13	-0.09 ±0.03	-0.20 ±0.05	-0.30 to -0.09**	2.1
0-40 m time (s)	5.82 ±0.27	5.49 ±0.18	-0.33 ±0.13	-0.44 to -0.22**	5.69 ±0.25	5.58 ±0.23	-0.11 ±0.06	-0.17 to -0.06**	-0.33 ±0.13	-0.11 ±0.06	-0.22 ±0.05	-0.34 to -0.10**	2.1
0-20 m time (s)	3.29 ±0.14	3.10 ±0.08	-0.19 ±0.10	-0.27 to -0.10**	3.22 ±0.17	3.11 ±0.12	-0.10 ±0.06	-0.16 to -0.04**	-0.19 ±0.10	-0.10 ±0.06	-0.08 ±0.04	-0.18 to 0.01	1.1
20-40 m time (s)	2.53 ±0.16	2.39 ±0.14	-0.15 ±0.08	-0.21 to -0.08**	2.46 ±0.11	2.46 ±0.13	-0.00 ±0.05	-0.05 to 0.05	-0.15 ±0.08	-0.00 ±0.05	-0.15 ±0.03	-0.22 to -0.07**	2.2
CMJ (cm)	31.1 ±2.6	32.3 ±2.6	1.3 ±1.2	0.28 to 2.27*	33.0 ±5.1	32.1 ±5.4	-0.9 ±2.6	-3.23 to 1.49	1.3 ±1.2	-0.9 ±2.6	2.2 ±1.0	-0.03 to 4.32	1.1
SJ (cm)	30.9 ±3.5	31.8 ±1.7	0.9 ±2.0	-0.81 to 2.59	30.7 ±4.8	30.2 ±5.5	-0.5 ±2.5	-2.85 to 1.80	0.9 ±2.0	-0.5 ±2.5	1.4 ±1.2	-1.12 to 3.96	0.6
Yo-Yo IR1 (level)	17.3 ±0.8	17.1 ±0.9	-0.2 ±0.6	-0.66 to 0.26	17.1 ±1.4	16.5 ±1.4	-0.5 ±0.8	-1.26 to 0.23	-0.2 ±0.6	-0.5 ±0.8	0.3 ±0.4	-0.45 to 1.08	0.4
Agility (s)	9.29 ±0.24	9.19 ±0.22	-0.10 ±0.15	-0.22 to 0.03	9.50 ±0.47	9.42 ±0.49	-0.08 ±0.23	-0.29 to 0.14	-0.10 ±0.15	-0.08 ±0.23	-0.02 ±0.10	-0.23 to 0.19	0.1
Body mass (kg)	68.0 ±10.0	68.7 ±9.0	0.8 ±1.4	-0.39 to 1.88	68.3 ±9.4	69.0 ±9.1	0.7 ±0.9	-0.08 to 1.56	0.8 ±1.4	0.7 ±0.9	0.0 ±0.6	-1.29 to 1.31	0.1

* = $p < 0.05$, ** = $p < 0.01$, TG =Training-Group, CG= Control-Group, E.S.= Effect size (Cohen's *d*)

The effect size of the training program between the groups shows that even though there were no statistically significant differences between the groups in 0–20 m sprint time, CMJ and SJ, the effect of repeated sprint training on the training group was large and close to very large in 0–20 m sprint time and CMJ (Table 1).

DISCUSSION

The observed improvement in the RSA within the training group is substantial, especially considering that the subjects trained soccer for 13 hours per week on average and only engaged in a specific speed training twice a week over eight weeks. Nevertheless, the results demonstrate that this type of training is effective, and that the RSA appears to be trainable using only a repeated sprint training program with no involvement of strength, plyometric or agility training. Previous research indicated that the improvement in the RSA could be due to a positive change in the anaerobic metabolic contribution [8, 14] and/or an improvement in the participants' ability to utilise the stored elastic energy in leg extensors caused by the negative and then positive work in leg extensors during repeated sprint training [14, 15, 20]. Furthermore, the subjects' limited previous experience in sprint training, combined with the timing of the study may also have contributed to the RSA improvement observed in the training group. Kraemer et al [16] reported that the basal concentration of testosterone significantly increased one week after the season, reflecting a dramatic reduction in total stress related to the season, which would cause a faster adaptation to training stimuli. On the other hand, the RSA improvement detected within the control group could be attributed to the timing of the study, as well as to the impact of players' daily soccer training [30]. These explanations could also apply to the improvement noted in the training group's 0-40 m sprint time; the split time shows that the improvement occurred in both 0-20 m and 20-40 m sprint times. Comparison with the control group reveals that the training group exhibited a considerably larger improvement in the 20-40 m sprint time (Table 1). Despite the fact that speed is believed to be a skill with a genetic quality, and less dependent on training [28], one could speculate from the results presented here that specialised training of running speed could result in an improvement in soccer players' sprinting speed. Similar results indicating a gain in acceleration following a similar but resisted sprint training programme have been reported [11].

Concerning jumping ability, the RSA training programme had a positive and significant effect on CMJ performance within the training group (Table 1). The control group, on the other hand, experienced no significant change in CMJ performance, which could be discerned from the very large SD within this group (Table 1). The lack of improvement within the control group CMJ could have been caused by not performing the two extra weekly training sessions of the training group, which may have affected the strength–velocity, force–time, or SSC contractile abilities of leg extensors. The improvement in CMJ reflects an enhancement (as with the RSA) in the ability to utilise the stored elastic energy and indirectly assists in the first phase of force–time curve initiated by the rate of force development (RFD) occurring in the first 180-250 ms in leg extensors within the training group. The improvement in CMJ could be further explained by findings from other studies where speed, leaping power and strength have been reported to affect each other if an improvement in any one of them occurs [29, 34]. Neither group experienced a statistically significant change in SJ.

No marked changes in Yo-Yo IR1 performance were observed within the training group in this study. This is in contrast to the results of Bravo et al [8] that revealed improved Yo-Yo IR1 performance following repeated sprint training. We speculate that the lack of Yo-Yo IR1 performance improvement within our training group could be due to the long breaks between the sprints in our training programme, resulting in the aerobic energy production not being sufficiently triggered to cause any effect [1, 36]. No changes in Yo-Yo IR1 performance were detected in the control group.

No notable improvement in the performance of the 3-6-9 (m) agility test with a 180° turn was exhibited by either group. This was expected because the relationship between sprinting and agility had been shown to be weak, and the training methods used for enhancing agility and speed are specific and produce limited interactive effects [19, 35, 36]. This could be due to the differences in performing each skill – the RSA training programme used here involved only sprints in a straight line (closed skill), whereas agility often involves actions requiring change of direction and rapid start and stop [36].

CONCLUSION AND PRACTICAL APPLICATION

In the present study, two weekly sessions of repeated sprint training (10.7% of the total training time) were only a small part of the subjects' total training load. However, the marked improvement observed within the training group compared to the control group could be explained by the extra repeated sprint training, confirming that the RSA is trainable. However, due to the fact that the results of this study demonstrate a positive effect on RSA, it would be of interest to repeat the study on elite soccer players from a higher division and examine whether it would lead to similar improvements.

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Shalfawi, S., Haugen, T., Jakobsen, T. A., Enoksen, E., & Tønnessen, E. (2013). The Effect of Combined Resisted Agility and Repeated Sprint Training Vs. Strength Training on Female Elite Soccer Players. *The Journal of Strength & Conditioning Research*, 27(11), 2966-2972.

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The Effect of Combined Resisted Agility and Repeated Sprint Training Vs. Strength Training on Female Elite Soccer Players

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Abstract

Shalfawi, SAI, Haugen, T, Jakobsen, TA, Enoksen, E, and Tønnessen, E. 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, 2013—The aim of this study was to compare the effects of in-season combined resisted agility and repeated sprint training with strength training on soccer players' agility, linear single sprint speed, vertical jump, repeated sprint ability (RSA), and aerobic capacity. Twenty well-trained elite female soccer players of age ± *SD* 19.4 ± 4.4 years volunteered to participate in this study. The participants were randomly assigned to either the agility and repeated sprint training group or to the strength training group. All the participants were tested before and after a 10-week specific conditioning program. The pretest and posttest were conducted on 3 separate days with 1 day of low-intensity training in between. Test day 1 consisted of squat jump (SJ), countermovement jump (CMJ), and RSA. Test day 2 consisted of a 40-m maximal linear sprint and an agility test, whereas a Beep test was conducted on test day 3 to assess aerobic capacity. The agility and repeated sprint training implemented in this study did not have a significant effect on agility, although there was a tendency for moderate improvements from 8.23 ± 0.32 to 8.06 ± 0.21 seconds ($d = 0.8$). There was a significant ($p < 0.01$) and moderate-positive effect on Beep-test performance from level 9.6 ± 1.4 to level 10.8 ± 1.0, and only a trivial small effect on all other physical variables measured in this study. The strength training group had a positive, moderate, and significant ($p < 0.01$) effect on Beep-test performance from level 9.7 ± 1.3 to level 10.9 ± 1.2 ($d = 1.0$) and a significant ($p < 0.05$) but small effect ($d = 0.5$) on SJ performance (25.9 ± 2.7 to 27.5 ± 4.1 cm). Furthermore, the strength training implemented in this study had a trivial and negative effect on agility performance ($d = -0.1$). No between-group differences were observed. The outcome of this study indicates the importance of a well-planned program of conditioning that does not result in a decreased performance of the players, the great importance of strength and conditioning specialist in implementing the training program, and the importance of choosing the time of the year to implement such conditioning training programs. However, the fact that the present training program did not cause any decline in performance indicates that it is useful in maintaining the soccer players' physical performance during the competition period.

Key Words physical conditioning, sprint ability, vertical jump, beep test

Introduction

Performance in soccer depends on a variety of technical, physical, and tactical skills. Considering the physical skills among soccer players, research has pointed out the demands for agility, repeated sprint ability (RSA), power, and aerobic capacity, because these qualities have been reported as distinguishing performance factors between elite athletes and players of lower standard (11,18,21).

The majority of elite players conduct 60–90 high-intensity actions during a game each lasting 2–3 seconds on average (16,27). Intensity and duration vary between matches, opponents' level, and playing positions (4). Although sprinting and high-intensity actions represent only 10–15% of the covered running distance, they are decisive for the outcome of the game in male and female soccer (1,9,14). Within this decisive portion of movement performed during a match, it is likely that maximal sprint situations represent particularly critical moments.

A large number of intervention studies, including off-field physical conditioning in addition to regular soccer training, have been reported. Strength training programs of leg extensor muscles are reported to have a positive effect on jumping height and single sprint performance during the preseason (6,15,22,24,29,30), in-season (7), and off-season conditioning (17). Despite the fact that during the in-season

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players' development could be limited, caused by the stress of the training and competition they are exposed to (13), it has been observed that linear sprint training with or without resistance had positive effects on soccer players' in-season (12,18,25). Furthermore, agility in addition to soccer training has improved single sprint performance, power, agility, and RSA (3,19). Finally, repeated sprint training has shown positive effects on soccer players' RSA, power, and aerobic capacity (5,8,28).

To the authors' knowledge, no studies to date have evaluated the use of resisted agility training in combination with repeated sprint training on soccer players. Therefore, the aim of this study was to compare the effects of in-season combined resisted agility and repeated sprint training against strength training on soccer players' linear single sprint speed, vertical jump performance, agility, RSA, and aerobic capacity. We hypothesized that resisted agility in combination with repeated sprint training would induce more positive changes in agility, RSA, and aerobic capacity, whereas strength training would result in more positive effects on vertical jump and linear sprint performance.

Methods

Experimental Approach to the Problem

To compare the effects of combined resisted agility and repeated sprint training against strength training on linear single sprint, vertical jump performance, RSA, and aerobic capacity, the participants were tested on these capabilities before and after a 10-week specific conditioning program. Based on 40-m sprint pretest results, the participants were randomly assigned to either an agility or repeated sprint training group or a strength training group. The intervention took place at the beginning of the competition season (April–June). To ensure familiarization with the test procedure, all the athletes completed a full training session 1 week before the pretest. The pretest and posttest were conducted on 3 separate days with 1 day of low-intensity training in between. Test day 1 consisted of squat jump (SJ), countermovement jump (CMJ), and RSA. Test day 2 consisted of 40-m maximal linear sprint and an agility test, whereas a Beep test was conducted on test day 3 to assess the aerobic capacity. Both intervention programs were designed by a former national coach in track and field sprinting holding a PhD in training methodology. The participants had to complete at least 90% of the training sessions, and all tests to be included in the analyses.

Subjects

Twenty well-trained elite female soccer players (mean ± *SD*; age: 19.4 ± 4.4 years, body mass: 59.1 ± 5.6 kg, and stature: 167.6 ± 5.0 cm) volunteered to participate in this study. The participants trained on average 10 ± 2.5 $h \cdot wk^{-1}$ plus match (4–7 training sessions a week). The duration of the soccer trainings was 2 hours divided into 30 minutes for warming up and cooling down. Approximately 1.5 hours was spent on pure soccer training. Usually, the soccer practice consisted of playing using different spaces (small and large areas on the field). The practice was performed with 3v3, 4v4, and 7-11v7-11.

The participants' team played in the second highest division level in Norway, and they were ranked top 3 in this division at the time of the study. All the participants older than 18 years gave their written voluntary informed consent, and the parents of all the participants younger than 18 years gave their written voluntary informed consent on behalf of their daughters. The local ethics committee of the University of Nordland approved the study.

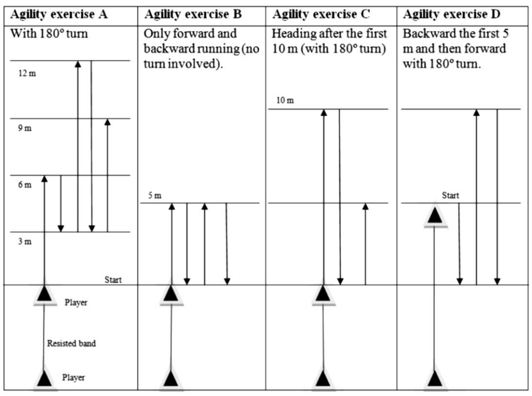

Figure 1. The 4 agility exercises performed during the resisted running band sessions.

TABLE 1. Periodization of speed training using resistance running band (session 1 of every week).*

Week 1	2 Sets–R = 1 min, SR = 10 min, *I* = 100%
Week 2	3 Sets–R = 1 min, SR = 10 min, *I* = 100%
Week 3	4 Sets–R = 1 min, SR = 10 min, *I* = 100%
Week 4	3 Sets–R = 1 min, SR = 10 min, *I* = 100%
Week 5	3 Sets–R = 1 min, SR = 10 min, *I* = 100%
Week 6	4 Sets–R = 1 min, SR = 10 min, *I* = 100%
Week 7	2 Sets–R = 1 min, SR = 10 min, *I* = 100%
Week 8	3 Sets–R = 1 min, SR = 10 min, *I* = 100%
Week 9	3 Sets–R = 1 min, SR = 10 min, *I* = 100%
Week 10	2 Sets–R = 1 min, SR = 10 min, *I* = 100%

*R = recovery between exercises; SR = recovery between sets; *I* = intensity.

Procedures

Instruments. All the tests were performed at an indoor track and field and soccer arena. The linear sprint, RSA, and agility tests were performed on an 8-mm Mondotrack FTS surface (Mondo, Conshohocken, PA, USA) using a Newtest Powertimer portable system (Oy, Finland) infrared photocells (Model 300s), which were mounted on the sprint running track and connected via cables and to a computer (PC Pentium 3) that measures time to the nearest 0.001 seconds. Jump height was also estimated on the field using force platform-based determinations of impulse and thus velocity at take-off. The force platform used was a portable AMTI model AccuPower (Watertown, MA, USA). The force platform had a built-in amplifier and digitizer, and the data were saved to a computer (PC Pentium 4) with the aid of the AccuPower software (according to the manufacture, the lowest natural frequency of the platform is >100 Hz). Finally, aerobic capacity was measured using the Beep test; the Beep test was conducted on an indoor artificial grass pitch following a procedure that was developed by Ramsbottom et al. (20). JVC Boomblaster (RVNB51WEN) was used to play the Beep-test CD that came with the test package.

Testing. Standard warm-up procedures on all test days consisted of 15 minutes of general warm-up, comprised running at 60–70% of the maximum heart rate, 4–5 accelerations over 50 m, stretching, and cooldown during the last 5–6 minutes before test start. On test day 1, the participants were required to perform 2 maximum effort trials of SJ, CMJ, and 1 trial of 7 × 30-m RSA. During vertical jump performance, the participants were instructed to keep their hands on their hips. The SJ was performed from a semisquat position with a knee angle of 90°, which represents a pure concentric contraction. For the CMJ, the subjects were required to bend their knees to approximately 90° and then rebound in a maximal vertical jump. Five minutes of recovery was provided between trials. The RSA was performed from an upright position placing the tip of the toe of the front foot on the starting line, and when the test leader gave the start signal, the participant started the sprint using the shortest time possible to finish the 30 m. Immediately after 30 seconds of recovery, the participant started sprinting the next 30 m, and the procedure continued until the participant completed the 7 repeated sprints. The athletes' center of gravity was directly above the start line when the timer was initiated. Meaningful comparisons of this standing start procedure with formerly published sprint performance results are possible by the correction factors generated by Haugen et al. (10). On test day 2, the linear maximum running speed was tested by performing 2 trials of 40-m sprint with a 5-minute recovery between trials. During the 40-m linear sprint test, times were measured for both 0- to 20-m acceleration speed and 20- to 40-m maximum sprinting speed. Then, the S180° Agility test was performed as described by Sporis et al. (26). Two trials were allowed with a minimum of a 5-minute recovery in between, and the best result was retained for the analysis. On test day 3, the test leader measured and marked a distance of 20 m with cones to perform the Beep test. The

TABLE 2. Periodization of repeated sprint training (session 2 of every week).*

Week 1	3 Sets of 4 × 40 m, R = 1:30 min, SR = 10 min, *I* = 95%
Week 2	4 Sets of 4 × 40 m, R = 1:30 min, SR = 10 min, *I* = 95%
Week 3	5 Sets of 4 × 40 m, R = 1:30 min, SR = 10 min, *I* = 95%
Week 4	2 Sets of 5 × 40 m, R = 1:30 min, SR = 10 min, *I* = 95%
Week 5	3 Sets of 5 × 40 m, R = 1:30 min, SR = 10 min, *I* = 95%
Week 6	4 Sets of 5 × 40 m, R = 1:30 min, SR = 10 min, *I* = 100%
Week 7	2 Sets of 5 × 40 m, R = 1:30 min, SR = 10 min, *I* = 100%
Week 8	3 Sets of 5 × 40 m, R = 1:30 min, SR = 10 min, *I* = 100%
Week 9	4 Sets of 5 × 40 m, R = 1:30 min, SR = 10 min, *I* = 100%
Week 10	2 Sets of 4 × 40 m, R = 1:30 min, SR = 10 min, *I* = 100%

*R = recovery between exercises; SR = recovery between sets; *I* = intensity.

Table 3. Strength training program followed by the strength training group.*

Exercise	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Leg press	2 × 10RM	3 × 10RM	3 × 8RM	3 × 8RM	3 × 8RM	3 × 6RM	3 × 6RM	3 × 6RM	3 × 4RM	3 × 4RM
Squat jump	2 × 6	3 × 6	3 × 5	3 × 5	3 × 5	3 × 5	3 × 5	3 × 5	3 × 4	3 × 4
Nordic hamstring	2 × 10R	3 × 10R	3 × 8R	3 × 8R	3 × 8R	3 × 6R	3 × 6R	3 × 6R	3 × 4R	3 × 4R
Leg extension	2 × 10RM	3 × 10RM	3 × 8RM	3 × 8RM	3 × 8RM	3 × 6RM	3 × 6RM	3 × 6RM	3 × 4RM	3 × 4RM
Cable hip flexion	2 × 10RM	3 × 10RM	3 × 8RM	3 × 8RM	3 × 8RM	3 × 6RM	3 × 6RM	3 × 6RM	3 × 4RM	3 × 4RM
Cable hip extension	2 × 10RM	3 × 10RM	3 × 8RM	3 × 8RM	3 × 8RM	3 × 6RM	3 × 6RM	3 × 6RM	3 × 4RM	3 × 4RM

*Recovery between sets = 2 minutes; RM = the maximum repetition that the player could achieve using the weight being used; in the squat jump, the players used a weight between 20–50 kg depending on the player strength level and technical abilities; R = Reps.

participants were then informed about the test procedure, and 6 test leaders observed the performance to make sure that the participants fulfilled the testing criteria. The CD (the soundtrack) and the CD player were examined before the start of the test to make sure the soundtrack played at the correct speed between the sound signals (Beep).

Intervention Programs. Both groups in this study were instructed to continue the teams' original training plan. The agility and repeated sprint training group completed 2 additional training sessions a week; 1 with resistance running band, and 1 with pure repeated sprint training. The players performed the resisted running band session in pairs. The band was connected with belts around each player's waist. When 1 player performed the resisted running band exercise, the teammate stood still and controlled the band. The following 4 agility exercises with standing starts were performed during the resisted running band sessions: (a) 6-3-9-9-6 m with a 180° turn after each distance, (b) 5-5-5-5 m with alternating backward and forward running, (c) 10-10-5 m with a 180° turn, a vertical jump (heading) was performed after the first 10 m, (d) 5-10-10 m with a 180° turn, the first 5 m was backward, and the remainder was forward running. After the first 5 m backward, the athletes had to drop down on the ground and then rise (Figure 1).

Table 1 describes the weekly resisted running band program. Table 2 describes the repeated linear sprint training performed in the second weekly session. Before each training, the participants performed a general warm-up with 15 minutes of jogging at a low intensity, and then a specific warm-up with 5–7 accelerations over 40–50 m, separated by 2–3 minutes of recovery between each run.

The strength training group completed 2 weekly strength training sessions in addition to the regular soccer training. Table 3 describes the strength training program completed by the strength training group.

Statistical Analyses

The data were explored by a histogram plot, and the normality of distribution was tested using Shapiro-Wilk's test for all groups in this study. Then, descriptive statistics were calculated and reported as mean ± *SD* of the mean (*SD*) for each group of players on each variable. For the data that were found to follow a normal distribution, the paired sample *t*-test was used to test differences in central location (mean) between the paired samples (within group). Then, the difference in central location (mean) between groups was examined using the independent sample *t*-test. For the data that did not follow a normal distribution, the 2-independent-samples test (Mann-Whitney *U*-test) was used to measure the difference between groups. To determine whether the effect size was trivial ($d > 0.2$), small ($d =$ 0.2–0.6), moderate ($d =$ 0.6–1.2), large ($d =$ 1.2–2.0), or very large ($d > 2.0$), the scale developed by Batterham and Hopkins (2) was adapted in this study. The effect size was calculated according to Rosnow and Rosenthal (23). Significance was accepted at the $p \leq 0.05$ level. The 95% confidence interval

Table 4. Mean results of agility, 7 × 30-m repeated sprint, 40-m sprint, 20-m acceleration, 20-m fly, CMJ, SJ, Beep-test, and body mass between and within groups from pretest to posttest.*

	Resisted sprint training group					Strength training group				
Variable	Pretest	Posttest	Change	95% CI	ES	Pretest	Posttest	Change	95% CI	ES
Agility (s)	8.23 ± 0.32	8.06 ± 0.21	−0.17 ± 0.33	−0.07 to 0.41	0.8	8.14 ± 0.38	8.17 ± 0.30	0.04 ± 0.28	−0.24 to 0.17	−0.1
7 × 30-m Mean (s)	5.07 ± 0.20	5.16 ± 0.16	0.09 ± 0.14	−0.19 to 0.01	−0.5	5.01 ± 0.26	5.05 ± 0.21	0.04 ± 0.10	−0.11 to 0.03	−0.2
40-m Max (s)	6.45 ± 0.19	6.44 ± 0.26	−0.01 ± 0.22	−0.15 to 0.17	0.1	6.30 ± 0.23	6.32 ± 0.22	0.02 ± 0.14	−0.12 to 0.08	−0.1
20-m Acc. (s)	3.57 ± 0.12	3.59 ± 0.09	0.02 ± 0.12	−0.10 to 0.07	−0.2	3.52 ± 0.11	3.52 ± 0.11	0.01 ± 0.11	−0.07 to 0.08	0.0
20-m Fly (s)	2.87 ± 0.16	2.87 ± 0.15	−0.00 ± 0.13	−0.09 to 0.10	0.0	2.79 ± 0.14	2.80 ± 0.14	0.01 ± 0.09	−0.07 to 0.05	−0.1
CMJ (cm)	26.8 ± 3.3	27.7 ± 2.2	0.9 ± 2.9	−3.0–1.2	0.3	28.3 ± 4.2	29.9 ± 5.6	1.7 ± 3.1	−3.9 to 0.5	0.3
SJ (cm)	25.1 ± 2.8	26.3 ± 2.1	1.2 ± 2.9	−3.3 to 0.9	0.5	25.9 ± 2.7	27.5 ± 4.1	1.7 ± 2.1	−3.1 to −0.2†	0.5
Beep test (level)	9.6 ± 1.4	10.8 ± 1.0	1.2 ± 0.7	−1.7 to −0.7‡	1.0	9.7 ± 1.3	10.9 ± 1.2	1.2 ± 0.7	−1.7 to −0.6‡	1.0
Body mass (kg)	60.7 ± 5.6	61.3 ± 5.7	0.7 ± 1.8	−2.0 to 0.7	−0.1	57.5 ± 5.3	59.0 ± 6.3	1.5 ± 2.7	−3.4 to 0.5	0.3

	Between-group differences				
Variable	Sprint group	Strength group	Difference	95% CI	ES
Agility (s)	−0.17 ± 0.33	0.04 ± 0.28	0.21 ± 0.14	−0.08 to 0.50	0.7
7 × 30-m Mean (s)	0.09 ± 0.14	0.04 ± 0.10	−0.05 ± 0.05	−0.17 to 0.06	0.4
40-m Max (s)	−0.01 ± 0.22	0.02 ± 0.14	0.03 ± 0.08	−0.16 to 0.17	0.2
20-m Acc. (s)	0.02 ± 0.12	0.01 ± 0.11	−0.01 ± 0.05	−0.13 to 0.09	0.1
20-m Fly (s)	−0.00 ± 0.13	0.01 ± 0.09	0.02 ± 0.05	−0.09 to 0.12	0.1
CMJ (cm)	0.9 ± 2.9	1.7 ± 3.1	0.8 ± 1.4	−2.04 to 3.62	0.3
SJ (cm)	1.2 ± 2.9	1.7 ± 2.1	0.5 ± 1.1	−1.90 to 2.90	0.2
Beep test (level)	1.2 ± 0.7	1.2 ± 0.7	0.0 ± 0.3	−0.70 to 0.63	0.0
Body mass (kg)	0.7 ± 1.8	1.5 ± 2.7	0.8 ± 1.0	−1.37 to 2.99	0.4

*ES = Cohen's *d* (effect size); CI = confidence interval; SJ = squat jump; CMJ = countermovement jump.
†$p < 0.05$.
‡$p < 0.01$.

(95% CI) was also calculated for all measures. All statistical analyses were carried out using SPSS 17.0 for Windows (SPSS Inc., Chicago, IL, USA). Two-way mixed intraclass correlation (ICC) reliability was calculated for all the dependent measures in this study.

Results

The test retest reliability for SJ was intraclass correlated (ICC = 0.79, $p < 0.01$), for the CMJ (ICC = 0.85, $p < 0.01$), the 40-m sprint time (ICC = 0.83, $p < 0.01$), for the RSA sprint time (ICC = 0.91, $p < 0.01$), for the agility sprint time (ICC = 0.63, $p < 0.05$), and for the beep-test level (ICC = 0.91, $p < 0.01$).

The agility and repeated sprint training implemented in this study did not have any significant effect on the resisted sprint training group performance variables except for the beep-test performance (Table 4). On the other hand, the strength training group had a significant effect on beep-test performance and SJ performance (Table 4).

Between-group difference did not show any statistical significance among the measured physical variables, but the agility and repeated sprint training program had a larger effect on agility performance compared with that of strength training ($d = 0.7$).

Discussion

The main findings in this study were that resisted agility in combination with repeated sprint training had a tendency to improve agility performance, although this did not reach statistical significance, whereas strength training had a small and positive effect on SJ performance. Both intervention groups improved beep-test performance by a moderate margin, although there were no meaningful effects on the other physical variables.

The small to moderate specific adaptations reported are in accordance with other investigations performed on soccer players (3,6,7,15,17,19,22,24,29,30). However, the relatively comprehensive intervention programs in our study resulted in minor or no improvements in other physical variables, in contrast to other interventions that have shown larger effects across a broader range of variables (5,8,22,28). Most coaches and soccer players would most likely not perform the present training regimes based on the small benefits presented. Both intervention groups in this study improved their Beep-test performance. Bravo et al. (5) and Tønnessen et al. (28) reported beep-test improvement as a result of repeated sprint training, whereas no studies have shown improved aerobic capacity as a result of strength training. Therefore, we attribute the moderate beep-test improvements in this study to the soccer players' regular training sessions 4–7 times per week.

The strength training intervention in this study only led to improved SJ performance, whereas a large number of similar investigations have also reported improved sprinting skills (6,7,15,17,22,24,29,30). The conditioning program by Moore et al. (17) consisted of 3 weekly strength training sessions during off-season. Maio Alves et al. (15) reported practically identical effects for 1 and 2 strength training sessions per week during preseason. Chelly et al. (7) showed positive effects of a twice weekly strength training program on 40-m sprint and CMJ performance in midseason. Most coaches step up the total load of regular soccer training throughout the preseason conditioning, and the players might be more sensitive to additional training at that time. Therefore, strength training on soccer players should be used with caution close to season start compared with off-season, early preseason, and midseason. Our strength training intervention would probably have given a better effect if it were performed in another phase of the training year because it has been observed that soccer players experience a reduction in performance during the competitive period (13).

The agility and repeated sprint intervention group in this study improved agility performance, but not RSA, linear single sprint or vertical jump performance. Several possible factors may explain these limited effects. First, the total training load might have been too hard for the soccer players. Dupont et al. (8) improved elite soccer players' RSA by performing 1 repeated sprint session and 1 aerobic training session per week in addition to 1 match and 8–10 regular soccer training sessions in season. Tønnessen et al. (28) reported improved RSA, maximum sprint velocity, CMJ performance, and aerobic capacity among elite junior players as a result of once weekly repeated sprint training during early preseason in addition to their 5–7 regular soccer training sessions per week. Bravo et al. (5) improved elite juniors' RSA and aerobic capacity by performing repeated agility sprint twice a week in season. The athletes in this study only performed 4–7 weekly regular soccer training sessions in addition to the repeated agility intervention. Thus, a physical conditioning program must be well balanced with the remaining regular soccer training. A perfectly designed conditioning program for certain capabilities may limit other important qualities and vice versa. It is also known that the continued stress experienced throughout the season combined with the strength and conditioning program could be described as a "chronic catabolic environment for the neuromuscular system." This environment could result in a minor or no improvements in other physical variables tested in this study because this study was conducted in-season (13).

Second, the outcome of a conditioning program may be affected by whether it is implemented by a training expert or not. All training sessions in the intervention study by Tønnessen et al. (28) were supervised by a former national coach in track and field sprinting with a PhD in training methodology. The same expert planned the interventions in this study, but all the training sessions were supervised by the team coach. The continuous presence of a physical conditioning expert probably increases the odds for a more successful outcome.

Furthermore, the intervention length may affect the results of a conditioning program. Our training programs lasted for 10 weeks, identical to the study by Tønnessen et al. (28). Other performed repeated sprint or agility interventions had a duration of 6 weeks (18), 7 weeks (5), 12 weeks

(19), and 20 weeks (8). In theory, longer intervention periods would increase the likelihood for greater improvements in certain specific capabilities.

The majority of published intervention studies are performed on young, nonelite soccer players with a poorer training background. These more or less successful investigations may lead to an impression that all kinds of training works. However, a great deal of knowledge can be gathered from nonsuccessful conditioning programs for soccer players as well, which so far are underrepresented in research journals.

Practical Applications

In this study, the relatively comprehensive intervention programs resulted in minor or no improvements in several of the analyzed physical variables. Therefore, the conditioning program must be well balanced and adjusted to the remaining specific soccer training because 1 type of training may result in small positive effects on certain skills, whereas other training programs may not have a positive effect. Because it has been documented that performance improvement in well-trained athletes is very small and time consuming, coaches should take total training load, intensity, duration, athletes training status, and time of year into account when designing a conditioning training program. Furthermore, from this and other studies, it is highly advised that strength and conditioning specialist design and implement the conditioning training program for better results.

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Study IV in full text

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THE EFFECT OF REPEATED AGILITY TRAINING vs. REPEATED SPRINT TRAINING ON ELITE FEMALE SOCCER PLAYERS' PHYSICAL PERFORMANCE

UČINEK PONAVLJAJOČEGA SE TRENINGA AGILNOSTI NA TELESNO ZMOGLJIVOST VRHUNSKIH NOGOMETAŠIC V PRIMERJAVI S PONAVLJAJOČIM SE TRENINGOM ŠPRINTA

ABSTRACT

To compare the effects of repeated agility training along with repeated sprint training on elite female soccer players' linear single sprint speed, vertical jump, agility, repeated sprint ability and Yo-Yo Intermittent Recovery level 1 test (Yo-Yo IR1) performances.
Seventeen elite female soccer players aged 21.2 ± 2.6 years from the upper Norwegian league were randomised into one of two groups: a repeated agility group and a repeated sprint group. During the intervention period, both groups performed one extra weekly training session in addition to their regular soccer training. The study took place in the pre-season period and lasted for 8 weeks. The participants were tested before and after the intervention period.
The results from the within-group analysis showed significant improvements in 10 × 40 m RSA, agility, and Yo-Yo IR1 performances for the agility group. The repeated sprint group showed significant improvements in 10 × 40 m RSA, 20 m top speed, 40 m linear sprint, CMJ vertical jump, and Yo-Yo IR1. The between-groups comparison revealed no significant differences between groups in any of the measured variables. Further, the results indicate that the both training programmes had a similar effect on both groups.
The present study adds further support to the notion that common principles of training such as specificity, progression and periodisation are clearly present in the sprint training of soccer players.

Key words: physical conditioning, sprinting skills, training effects

IZVLEČEK

Cilj raziskave je bil raziskati učinke ponavljajočega agilnostnega teka, v primerjavi s ponavljajočim šprintom, na hitrost enega linearnega šprinta, vertikalen skok, agilnost, sposobnost ponavljajočih se šprintov (RSA) in intervalni prekinjajoči test 1. stopnje (Yo-Yo IR1) pri vrhunskih nogometašicah.
Sedemnajst vrhunskih nogometašic iz norveške prve lige, starih 21.2 ± 2.6 let, je bilo naključno razdeljenih v dve skupini: skupina s ponavljajočimi se agilnostnimi teki in skupina s ponavljajočimi se šprinti. V času raziskave sta obe skupini poleg svojih rednih treningov nogometa opravili še en dodaten trening na teden. Raziskava je potekala v obdobju pred nogometno sezono in je trajala osem tednov. Sodelujoče igralke so opravile teste pred obdobjem raziskave in po njem.
Rezultati analize znotraj skupine so pokazali pomembno izboljšanje v skupini, ki je opravila trening agilnosti, in sicer pri 10 x 10 m RSA, agilnosti in Yo-Yo IR1. V skupini, Ki je izvajala ponavljajoči se šprint, je prišlo do pomembnega izboljšanja pri 10 x 10 m RSA, hitrosti šprinta na 20 m, lineranem šprintu na 40 m, vertikalnem skoku z nasprotnim gibanjem in Yo-Yo IR1. Primerjava med skupinama ni pokazala nobenih pomembnih razlik med skupinama v katerikoli merjeni spremenljivki. Poleg tega rezultati kažejo, da je učinek obeh programov treninga podoben za obe skupini.
Raziskava tako še dodatno podpira ugotovitev, da so običajna načela treniranja, kot so specifičnost, napredovanje in periodizacija, nedvomno prisotna v treningu šprinta nogometašev.

Ključne besede: kondicijski trening, šprint, učinki treninga

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INTRODUCTION

Sprinting is the most frequent action in goal-scoring situations (Faude, Koch, and Meyer 2012). Top-class players perform 150 – 250 brief, intense actions such as sprinting, jumping, tackling and shooting during a match (Bangsbo, Mohr, & Krustrup, 2006) and high-intensity activity in the range of 1 – 4 s occur approximately once every 60 – 90 s during games (Di Salvo et al., 2007; Reilly, Bangsbo, & Franks, 2000).

In the research literature, sprinting skills are commonly categorised as linear sprint, agility and repeated sprint ability (RSA). Linear sprint is the ability to accelerate and maintain a high linear sprint speed (Chapman & Sheppard, 2011). Agility refers to the ability to rapidly change direction and speed of movement as a result of a stimulus (Bishop, Girard, & Mendez-Villanueva, 2011). RSA is the ability to perform repeated sprints with brief recovery intervals (Bishop et al., 2011; Glaister, 2005). Several studies have concluded that agility and linear sprint are specific and independent qualities (Little & Williams, 2005; Sporis, Jukic, Milanovic, & Vucetic, 2010; Vescovi & McGuigan, 2008; Young, McDowell, & Scarlett, 2001).

Professionals or elite players are reported to have better sprinting skills than players of a lower playing level (Haugen, Tønnessen, & Seiler, 2012a, 2012b; Impellizzeri et al., 2008; Reilly et al., 2000). Unfortunately, only a few intervention studies including agility or repeated sprint training of elite or professional soccer players have been reported. Mujika, Santisteban, and Castagna (2009) reported an improvement in 15 m sprint and vertical jump performance after 6 training sessions with repeated short sprints. Similarly, Spinks, Murphy, Spinks, and Lockie (2007) observed that short-sprint training with and without resistance over 8 weeks improved 15 m sprint and counter-movement vertical jump (CMJ vertical jump) performance. Jovanovic, Sporis, Omrcen, and Fiorentini (2011) reported improved 5 – 10 m sprint and CMJ vertical jump performance after an 8-week conditioning period consisting of speed, agility and quickness. In a study by Ferrari

Bravo et al., (2008), repeated shuttle sprints induced greater Yo-Yo Intermittent Recovery level 1 test (Yo-Yo IR1) and RSA improvement compared to high-intensity interval training, whereas 10 m sprint and vertical jump performance remained unchanged for both intervention groups.

Tønnessen, Shalfawi, Haugen, & Enoksen (2011) performed a repeated sprint training intervention similar to the model used by athletic sprinters. Their training group showed a significant improvement in RSA and peak velocity compared to the control group. The effect sizes were also moderate between the groups for CMJ vertical jump and the multi-stage fitness test (bleep test), although no significant differences were detected. However, the effect of repeated sprint training compared to repeated agility training on similar tests has so far not been explored. Wong del, Chan, & Smith, (2012) reported a relationship between repeated sprint ability and repeated change of direction. Therefore, it should be in the interest of coaches and soccer players to investigate whether repeated agility training within a similar periodisation model to repeated sprint training can lead to equivalent or even superior outcomes. Further, despite the high number of women participating in soccer, few studies have been conducted with female soccer players performing at the highest division level in traditionally leading soccer nations. Therefore, there is scope for more research on women's soccer.

The aim of the present study was to compare the effects of repeated agility training versus repeated sprint training on female soccer players' linear single sprint speed, vertical jump, agility, repeated sprint ability and Yo-Yo IR1 performances. This could provide valuable information for the planning of physical training in female soccer as well as other sports involving repeated explosive action demands. We hypothesised that repeated agility training would induce more positive effects on agility performance, while repeated sprint training would enhance RSA and single sprint performance.

MATERIALS AND METHODS

Participants

Twenty well-trained players volunteered to participate in the study. Three participants dropped out, leaving seventeen participants with the following age, body mass and stature (mean ± SD): 21.2 ± 2.6 years, 64.0 ± 5.9 kg and 168.8 ± 4.6 cm, respectively. Their regular weekly training programme consisted of 3 – 6 soccer sessions per week, plus one friendly match in some of the weeks during the intervention period. The soccer sessions had a typical duration of 1.5 hours and consisted of technical and tactical drills in addition to playing in small and large areas, usually with teams of 4 – 8 vs. 4 – 8. Further, all participants had 1 – 2 strength training sessions per week using bodyweight or 6 – 12 RM sets. In total, the participants trained on average for 9.3 ±2.0 hours per week distributed over 5 – 8 training sessions. All participants gave their written voluntary informed consent, and the institutional review board approval was granted.

Procedures

To compare the effects of repeated agility training compared to repeated sprint training on female soccer players, a pre-test–post-test randomised-group research design was applied. Participants were randomly assigned to either a repeated agility training group ($n = 8$) or a repeated sprint training group ($n = 9$). Both groups trained according to their team's original training plan. The repeated agility group completed one extra training session per week consisting of repeated agility training (Table 1), while the repeated sprint group completed one extra training session per week of repeated sprint training (Table 2). The intervention took place during the pre-season period (February and March). The programmes were planned and carried out by an expert at the Norwegian Olympic Training Centre who, amongst others, is a former national coach in track and field sprinting who holds a PhD in training methodology. The participants were required to complete at least 90% of the training sessions and all the tests in order to be included in further analyses. A soccer-specific test battery was completed by the participants before and after the 8-week intervention period. The pre- and post-tests were conducted on two consecutive days. All participants completed the pre- and post-tests in the same order and at the same location. Test day one consisted of a 40 m maximal sprint, agility, CMJ vertical jump and repeated sprint test. On test day two, the athletes completed the soccer-specific Yo-Yo IR1 test.

Prior to testing, the participants completed a standard warm-up programme consisting of a 10 min general warm-up at 50 – 70% of maximum heart rate either on a treadmill or spinning cycle, followed by 3 – 4 repetitions of 40 m sprints with a progressive increase in speed. To ensure familiarisation with the test procedures, all athletes completed 1 – 2 sub-maximal trials prior to each test. The timing system at the Norwegian Olympic Training Centre was used for all sprint tests. The tests were performed on a dedicated indoor 40 m track with 8 mm Mondo track FTS surface (Mondo, Conshohocken, USA) and electronic timing equipment. A 60 × 60 cm start pad was placed under the track at the start line. The clock was initiated when the front foot stepped off the pad. Infrared photocells with transmitters and reflectors were placed in pairs on each side of the running course with a 1.6 m transmitter-reflector spacing approximately 140 cm above the floor. The beams had to be broken to trigger each photo cell. Electronic times were transferred to computer software (Biorun, made in MatLab by Biomekanikk AS, Oslo, Norway). The timing system has recently been validated (Enoksen, Tønnessen, & Shalfawi, 2009; Haugen, Tønnessen, & Seiler, 2012c).

Linear single sprint

The distance of 40 m was chosen for the sprint tests in order to evaluate both acceleration and maximum sprint capabilities. The 0 – 20 m split time was defined as acceleration, while the 20 – 40 m split time was defined as the maximal sprint velocity. The participants started from a standing position. Two trials were permitted with a minimum 4 min recovery given between the trials, and the best result for each player was retained for analysis.

Agility

The agility tests were performed immediately after the linear sprint tests. The agility test had a total running distance of 40 m and included four 180° turns. Lines were marked with tape at 7.5 m, 12.5 m and at the finish line at 20 m. The participants sprinted from 0 – 12.5 m, back to the 7.5 m line, forward to the 12.5 m line, back to the 7.5 m line for the last time and finally forward to the finish line at 20 m. Two trials were permitted, separated by a minimum of 4 min recovery. The best result for each player was retained for analysis.

CMJ vertical jump

The CMJ vertical jump tests were performed after the agility test. Each athlete was weighed on a force platform for system calibration before performing the three trials of CMJ vertical jump with 45 – 60 s recovery in between. In order to isolate the test to leg extensor muscles and minimise technical elements, the jumps were performed with hands placed on the hips. The participants were required to bend their knees to approximately 90° and then rebound in a maximal vertical jump. The best result for each player was retained for analysis. All CMJ vertical jump tests were performed on a 122 × 62 cm AMTI force platform; model OR6-5-1 (Watertown, USA). Force data were sampled at 1000 Hz for 5 s with a resolution of 0.1 N. The data were amplified (AMTI Model SGA6-3), digitised (DT 2801) and saved in specially made computer software (Biojump, Oslo, Norway). The force platform has recently been assessed for its accuracy and reliability (Enoksen et al., 2009).

Repeated sprint test

After the vertical jump testing, the participants performed a 10 × 40 m repeated sprint test with 60 s recovery between each sprint. The distance of 40 m was chosen in order to include both acceleration and maximum sprinting velocity. In line with the frequency of all-out sprints reported from match analyses, the sprints were executed every 60 s. Starting and timing procedures were similar to the linear single sprint and agility tests. The mean 40 m sprint time was retained for analysis.

Yo-Yo IR1

On test day two, the Yo-Yo IR1 test was performed after a standard warm up of 10 min jogging with a progressive increase in running intensity from 70 – 80% of the maximum heart rate. The test set-up was in accordance with the guidelines by Krustrup et al. (2003).

The Yo-Yo IR1 test was performed in an indoor handball arena with a PULASTIC SP surface (Combi Floor and Roof technique AS, Oslo, Norway) at the Norwegian School of Sport Sciences. The standardised audio file for Yo-Yo IR1 was played by an iPod (Apple, CA, USA) connected to a JVC Powered Woofer CD-system (RV-NB51W).

Intervention programmes

The training intervention consisted of one extra weekly session of either repeated sprint training or repeated agility training over 8 weeks. For both groups the training sessions followed a stepwise increase in workload each week, interposed by a lighter workload in weeks 4 and 8. Photocells were used in each training session to control the running speed and thereby the training intensity. All participants received feedback from a sprint training expert regarding their technique during the training intervention. The repeated agility training involved a total running distance of 40 m and included four 180° turns, with the participants sprinting from 0 – 12.5 m, back to the 7.5 m line, forwards to the 12.5 m line, back to the 7.5 m line for the last time and finally forwards to the finish line at 20 m (Figure 1). Since the repeated agility run lasts approximately 4 s longer than the repeated sprint training, the repeated agility programme was designed to allow between 15 – 20% fewer repetitions and a 30 s longer recovery period between each run to better match the total training loads. Table 1 describes the periodised repeated agility training programme performed by the repeated agility group, while Table 2 describes the periodised repeated sprint training programme performed by the repeated sprint group. The programmes were designed to include warm-up procedures before each training session that were similar to the procedures prior to the sprint testing described above.

Table 1: Periodization of the repeated agility training.

Week 0	Pre-test
Week 1	2x4x agility run, R=2min, SR=10min, I=95-100%
Week 2	2x5x agility run, R=2min, SR=10min, I=95-100%
Week 3	2x6x agility run, R=2min, SR=10min, I=95-100%
Week 4	2x4x agility run, R=2min, SR=10min, I=95-100%
Week 5	2x6x agility run, R=2min, SR=10min, I=95-100%
Week 6	2x7x agility run, R=2min, SR=10min, I=100%
Week 7	2x8x agility run, R=2min, SR=10min, I=100%
Week 8	2x6x agility run, R=2min, SR=10min, I=100%
Week 9	Post-test

R = Recovery between exercises.
SR = Recovery between sets.
I = Intensity.

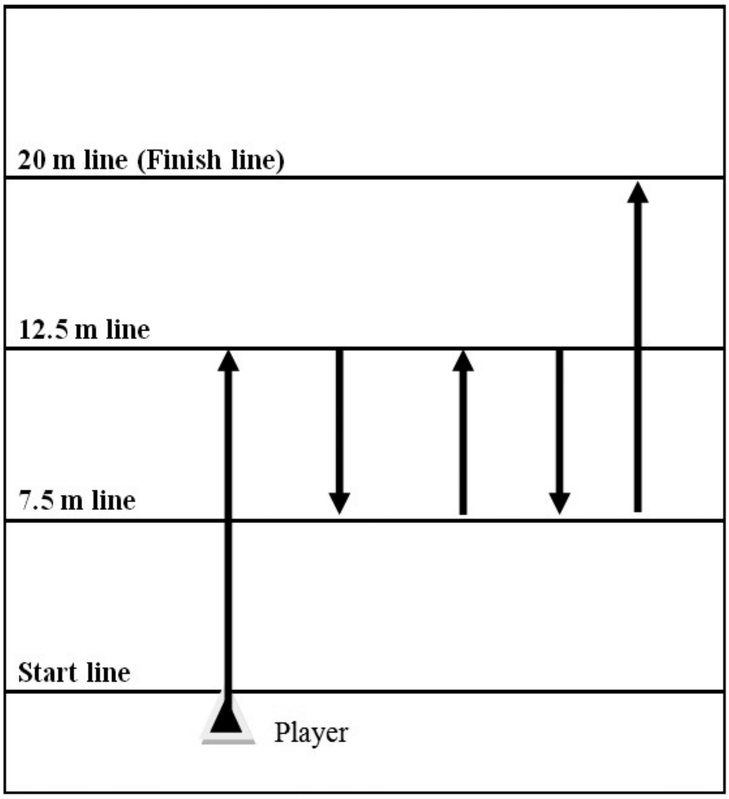

Figure 1: The repeated agility exercise performed by the repeated agility training group during the intervention period.

Table 2: Periodization of the linear repeated sprint training.

Week 0	Pre-test
Week 1	2x5x40m, R=1:30min, SR=10min, I=95-100 %
Week 2	2x6x40m, R=1:30min, SR=10min, I=95-100 %
Week 3	2x7x40m, R=1:30min, SR=10min, I=95-100 %
Week 4	2x5x40m, R=1:30min, SR=10min, I=95-100 %
Week 5	2x7x40m, R=1:30min, SR=10min, I=95-100 %
Week 6	2x8x40m, R=1:30min, SR=10min, I=100 %
Week 7	2x9x40m, R=1:30min, SR=10min, I=100 %
Week 8	2x7x40m, R=1:30min, SR=10min, I=100 %
Week 9	Post-test

R = Recovery between exercises.
SR = Recovery between sets.
I = Intensity.

Statistical Analyses

All statistical analyses were carried out using SPSS 17.0 for Windows (SPSS Inc., Chicago). A 2 x 2 mixed-model analysis of variance (also known as a split-plot ANOVA) was used to test for differences between the groups' results from pre- to post-test. To test the assumption of normality, the data were explored by a histogram plot and tested using the Shapiro-Wilk test for all groups. To test the assumption of homogeneity in variance, Levene's test of equality of error variances was applied. To test the assumption of differences in the quality of covariance's matrices, Box's test of equality of covariance matrices was applied. If the assumptions were met, the interaction effect (did both groups have a similar improvement from pre- to post-test?) was examined using Wilks' Lambda in Multivariate Tests. One-way repeated measures ANOVA was used to determine within-group differences from pre- to post-test. All descriptive statistics were calculated and reported as mean and standard deviations (SD) of the mean for each group of players on each variable. To determine whether the effect size was small (0.10), medium 0.25) or large (0.40), the scale developed by Cohen, J. (1988) was used. Significance was accepted at the $p \leq 0.05$ level. The 95% confidence interval (95% CI) was also calculated for all measures. Two-way mixed Intra-class Correlation (ICC) reliability was calculated for all the dependent measures in this study.

RESULTS

Reliability

The test-retest reliability for the CMJ vertical jump was intra-class correlated (ICC) (ICC = 0.96, $p < 0.01$), for the 40 m (ICC = 0.94, $p < 0.01$), the agility sprint time (ICC = 0.84, $p < 0.01$), for the RSA sprint time (ICC = 0.96, $p < 0.01$), and for the Yo-Yo IR1 (ICC = 0.94, $p < 0.01$).

Within-group analysis

The results from the agility training group showed significant improvements in 10 × 40 m RSA (a very large effect), agility (a very large effect) and Yo-Yo IR1 (a large effect) performances (Table 3). The repeated sprint group showed significant improvements in 10 × 40 m RSA (a very large effect), 20 m top speed (a large effect), 40 m linear sprint (a large effect), CMJ vertical jump (a very large effect), and Yo-Yo IR1 (a very large effect) (Table 4).

Table 3: Agility training group Pairwise comparison from the pre- and post-test results in all measured variables.

Variable	Pre-test	Post-test	Change (Std. Error)	95% CI	Partial Eta Squared	Pearson *r*
10x40m RSA (s)	6.15 (0.40)	5.95 (0.33)	0.203 (0.047)	0.92 – 0.313*	0.728	0.952**
Agility	10.02 (0.34)	9.7 (0.35)	0.326 (0.041)	0.230 – 0.423**	0.901	0.945**
20m acceleration (s)	3.15 (0.18)	3.11 (0.15)	0.041 (0.035)	-0.41 – 0.123	0.169	0.846**
20m top speed (s)	2.71 (0.19)	2.69 (0.12)	0.022 (0.035)	-0.060 – 0.105	0.056	0.876**
40m maximum (s)	5.86 (0.35)	5.80 (0.25)	0.064 (0.051)	-0.057 – 0.185	0.182	0.945**
CMJ	26.4 (4.4)	28.2 (4.6)	1.79 (0.78)	-3.643 – 0.058	0.428	0.882**
Yo-Yo IR1 (m)	1025 (274)	1120 (285)	95 (37)	5 – 184*	0.475	0.928**
Body weight	66.3 (5.7)	66.3 (5.6)	0.15 (0.453)	-1.05 – 1.09	0.001	0.975**

* = $P < 0.05$
** = $P < 0.01$
Partial Eta Squared = Effect size

Table 4: Repeated sprint group Pairwise comparison from the pre- and post-test results in all measured variables.

Variable	Pre-test	Post-test	Change (Std. Error)	95% CI	Partial Eta Squared	Pearson *r*
10x40m RSA (s)	6.19 (0.25)	5.94 (0.24)	0.248 (0.038)	0.161 – 0.335**	0.844	0.895**
Agility	9.81 (0.45)	9.91 (0.42)	0.108 (0.085)	-0.304 – 0.088	0.167	0.832**
20m acceleration (s)	3.15 (0.13)	3.10 (0.13)	0.057 (0.042)	-0.040 – 0.154	0.185	0.514
20m top speed (s)	2.75 (0.15)	2.67 (0.18)	-0.072 (0.026)	0.013 – 0.132*	0.494	0.896**
40m maximum (s)	5.90 (0.24)	5.77 (0.26)	0.129 (0.040)	0.036 – 0.221*	0.563	0.891**
CMJ	24.9 (4.6)	26.8 (4.6)	1.98 (0.427)	0.941 – 2.912**	0.718	0.961**
Yo-Yo IR1 (m)	920 (293)	1173 (288)	253 (35)	171 – 334**	0.866	0.934**
Body weight	61.9 (5.5)	62.7 (5.3)	0.722 (0.368)	-0.127 – 1.57	0.324	0.961**

* = $P < 0.05$
** = $P < 0.01$
Partial Eta Squared = Effect size

Between-groups analysis

The results from the 2 x 2 mixed-design analysis of variance model showed that the data presented in this study met the assumptions of homogeneity and the assumption of the equality of covariance matrices (Table 5). The between-groups comparison revealed that no significant differences between groups were observed for any of the measured variables (a very small effect by group differences), indicating that the effect of both training programmes was similar for both groups. The data also show that both groups had a similar improvement in the agility and Yo-Yo IR1 tests from pre- to post-test (Table 5).

Table 5: Tests of Between-Subjects Effects by group, Levene's Test of Equality of Error Variances and the Box's Test of Equality of Covariance Matrices.

	Levene's Test (P-value)	Box's Test (P-value)	Wilks' Lambda by group (P-value)	Between-groups (P-value)	Partial Eta Squared
10x40m RSA (s) Pre-test	0.193	0.653	0.459	0.908	0.001
10x40m RSA (s) Post-test	0.440				
Agility Pre-test	0.453	0.273	0.001	0.994	0.001
Agility Post-test	0.730				
20m acceleration (s) Pre-test	0.238	0.622	0.784	0.905	0.001
20m acceleration (s) Post-test	0.853				
20m top speed (s) Pre-test	0.817	0.254	0.264	0.876	0.002
20m top speed (s) Post-test	0.193				
CMJ Pre-test	0.755	0.600	0.879	0.503	0.031
CMJ Post-test	0.856				
Yo-Yo IR1 (m) Pre-test	0.784	0.994	0.008	0.852	0.002
Yo-Yo IR1 (m) Post-test	0.890				
Body weight Pre-test	0.745	0.979	0.222	0.156	0.130
Body weight Post-test	0.770				

- Levene's Test = Tests the null hypothesis that the error variance of the dependent variable is equal across groups.
- Box's Test = Tests the null hypothesis that the observed covariance matrices of the dependent variables are equal across groups.
- Partial Eta Squared = Effect size
- Wilks' Lambda = tests the interaction effect (did both groups have a similar improvement from pre- to post-test).

DISCUSSION AND CONCLUSIONS

In the present study, the intervention programmes resulted in different effects on the soccer players' physical capabilities only when examining each group separately (within groups). No differences between groups were observed. The improvement in agility and Yo-Yo IR1 was significantly similar for both groups ($p < 0.01$) as reported by the Wilk Lambda test.

The fact that no between-group differences were observed in any of the measured variables indicates that the within-group differences were as a result of the training programmes implemented in the present study. However, the improvement in agility from the within-group analysis for both groups (Tables 3 & 4) was expected and in accordance with our hypothesis and the principle of task specificity (Vescovi & McGuigan, 2008; Young, et al., 2001). In support of the present findings, Young, et al. (2001) demonstrated that linear sprint training did not improve performance in sprints with changes of direction. Wojtys, Huston, Taylor, and Bastian (1996) reported neuromuscular adaptations to agility training in the form of improved spinal reflex and cortical response times in typical lower limb muscles activated in sprinting. Since the agility training implemented in the present study was exactly the same as the test conducted, the improvements were likely related to adaptations in specific coordination and agility of the neuromuscular system (Ross, Leveritt, & Riek, 2001).

The repeated agility group performed 15 – 20% fewer sprint repetitions and had 30 s longer recovery periods between each run and this varying workload between the groups' training programmes could have caused the improvement of the repeated sprint training group's Yo-Yo IR1 performance with a very large effect margin compared to the improvement in the repeated agility group (Tables 3 & 4). Our conditioning expert chose this design because each agility sprint lasted ~4 s longer on average than each linear sprint. Accordingly, the repeated agility training sessions were probably more anaerobic in terms of lactate production. The present repeated sprint group results are in accordance with the results of Tønnessen et al. (2011) who reported a moderate improvement in bleep test performance as a result of repeated sprint training.

No significant RSA (10 × 40 m) differences were observed between the groups, and the absolute improvements were quite similar for the repeated agility group and repeated sprint group (~0.20 and ~0.25 s, respectively). However, the magnitude of the RSA improvement was small for both groups (Table 5). Running speed is a quotient of running distance covered and running time. Using this formula we calculated that both groups completed the 10 × 40 m pre-test sprinting at 95% of maximum running speed, and 97% at the post-test in both groups. This demonstrates the ability to complete repeated sprints with an intensity closer to maximum capacity. Similar developments were observed in the study by Tønnessen et al. (2011).

Even though the repeated sprint training group improved the 40 m single linear sprint and CMJ performance by a significant margin and with a very large effect (Table 4), no between-group differences were observed for these capabilities (Table 5). Since the effect size for both groups was > large for the single sprint and CMJ (Tables 3 & 4), the observed improvement in both groups can therefore be classified as a random effect, i.e. caused by the remaining soccer training. Sporis, Jovanovic, Omrcen, and Matkovic (2011) reported that soccer-specific training likely plays an important role in developing and maintaining sprinting abilities. Tønnessen et al. (2011) and Shalfawi et al. (2012) observed improved performance in a control group's single sprint caused by soccer training.

The athletes' initial training status may have affected the outcome of the present conditioning programme. In their review of strength training, Kraemer et al. (2002) reported a specific trend of slower progression rates of a trainable characteristic with training experience. Untrained individuals respond positively to most training interventions, making it more challenging to evaluate the training outcomes. A well-trained soccer player can be considered untrained in terms of sprint training. Further, sprinting skills depend heavily upon technical elements, increasing the need for feedback during practice. All training sessions in this study were supervised by a former national coach in track and field sprinting which possibly had an effect on the positive training outcomes in the present study (Coutts, Murphy, & Dascombe, 2004; Mazzetti et al., 2000). Research has shown that the basal concentration of testosterone significantly increases one week after the season, reflecting a dramatic reduction in total stress related to the season, which would cause a faster adaptation to training stimuli (Kraemer et al. 2004). Therefore, the improvements observed in both groups could have been influenced by the timing of the present study (the pre-season period).

Our findings confirm that common principles of training such as specificity, progression and periodisation are clearly present in the sprint training of soccer players. Repeated agility training induces specific agility enhancement, while repeated linear sprint training improves intermittent running ability to a greater extent than agility training. Those training principles could help improve the sequencing of muscle activation and improve the recruitment of muscle fibres involved in the exercise. The fact that sprinting abilities are depend greatly on technical elements suggests that direct supervision of sprint training is a factor of success. The fact that the present study did not have a control group made it harder for us to determine to what extent the training programmes contributed to the improvements observed within the groups. Therefore, repeating the study with a control group is highly advisable.

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The Relationship between Measures of Sprinting, Aerobic Fitness, and Lower Body Strength and Power in Well-Trained Female Soccer Players

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Abstract

The aim of this study was to investigate the relationship between measures of sprinting ability, fatigue index, lower body strength and power output, and aerobic fitness in well-trained, young, elite female soccer players. The descriptive cross-sectional design was applied to 30 well-trained female soccer players (mean ± SD: age 19 ± 4 years, body mass 57.5 ± 6.9 kg, height 167 ± 4 cm) who agreed to participate in the study. Tests of 40 m linear sprint, 7 x 30 m repeated sprint ability with 30 s recovery, sprint with change of direction, multi stage fitness test (MSFT), and vertical jump were conducted on a soccer field. The results showed that squat jump (SJ) had the strongest relationship with 0 - 20 m start and acceleration phases, while countermovement jump (CMJ) had the strongest relationship with maximal sprinting speed over 20 - 40 m. Aerobic fitness measures were significantly related to linear sprint over 0 - 40 m, 20 - 40 m sprint times, repeated sprint ability (RSA) fastest time, total time, mean time, and sprint with change of direction. Linear sprint over 40 m had a strong relationship with RSA fastest time, RSA mean time, and RSA total time. Finally, a significant relationship was observed between measures of linear sprint and sprint with change of direction. The relationship observed between aerobic capacity and sprinting abilities and the results from the stepwise analysis suggest that separate training strategies are necessary to specifically target and improve performance in these abilities.

Key words: Sports Performance, Fatigue, Physical Endurance, Muscle Strength

Introduction

Soccer is the most popular game in the world and the ability to perform at a top level depends on a number of characteristics. These include physical, physiological, psychological and psychomotor abilities, along with tactical and technical skills as the most important factors affecting performance (Reilly et al., 2000). However, in order to utilize these tactical and technical skills, players must be able to cope with the physical demands of the game (Bangsbo et al., 2006).

A number of authors agree that investigating intensity levels during a soccer match could be of great value in order to improve the quality of the players and the game (Bangsbo, 1994; Stolen et al., 2005). Hence, the physical demands placed on soccer players during a match have been extensively investigated in the literature (Bangsbo, 1994; Reilly et al., 2000; Stolen et

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al., 2005). The majority of these investigations have found that a soccer field player typically covers a distance of 10–14 km during a 90 min match (Reilly et al., 2000; Stolen et al., 2005). The distance covered indicates that aerobic metabolism is the major source of energy during a soccer match. Approximately 90% of the total energy expenditure during a match is provided by the aerobic energy system, with players, on average, working at ~70% of maximum oxygen uptake (Bangsbo & Iaia, 2013). Furthermore, several analyses have shown that the duration of high-intensity sprinting actions is typically between 2–4 s (Spencer, Bishop, Dawson, & Goodman, 2005) over a distance of ~10–23 m (Reilly & Thomas, 1976; Spencer et al., 2005). These high- intensity sprinting actions constitute 9–11% of total distance covered during match play (Bangsbo & Iaia, 2013), and take place every 40–90 s (Reilly et al., 2000; Spencer et al., 2005). These repeated high- intensity sprints, with short recovery times result in a decline in sprint performance (Girard et al., 2011) indicating that repeated sprint ability is a function of single sprint speed and the ability to resist fatigue (Bishop et al., 2011; Spencer et al., 2005; Stolen et al., 2005). Sprints with change of direction have also been observed in soccer analysis. Bloomfield et al. (2007) reported 5115 sprint actions involving change of direction and 514 actions involving deceleration events. Therefore, the sprinting actions in soccer can be categorized into linear sprint (acceleration, and maximum sprint velocity), sprint with change of direction, and the ability to repeat sprints over the duration of the match, known as repeated sprint ability (RSA).

Based on the presented literature, aerobic capacity could clearly play a key role in the recovery between high-intensity sprints during a match, highlighting the importance of developing players' aerobic capacity and repeated sprint ability in order to improve overall performance. Only a small number of studies have looked at the relationship between aerobic tests and anaerobic tests in soccer (Aziz et al., 2000; Meckel et al., 2009). Therefore, the main purpose of the current study was to investigate the relationship between measures of sprinting ability (40 m sprint time, 20 m acceleration, 20 m maximum velocity, repeated sprint ability, and sprint with change of direction), fatigue index, measures of lower body strength and power output (force, peak power), and aerobic fitness in well trained young female soccer players. A secondary purpose of the study was to conduct stepwise analyses to determine the physical parameters that most affect performance of RSA and sprint with change of direction.

Methods

Participants

Thirty well-trained female soccer players volunteered their written informed consent to participate in the study (Mean ± SD: age 19 ± 4 years, body mass of 57.5 ± 6.9 kg, height of 167 ± 4 cm). Participants below 18 years of age provided written consent signed by their parent. Participants were selected from a group of elite soccer players ranked amongst the top 3 teams in the second highest division in Norway at the time of the study. They were tested as part of their soccer training program at the beginning of the competition season (April 2011). All participants had been involved in intensive training for 6 ± 3 years (training, on average, 4–7 training sessions constituting 10 ± 2.5 hours per week, plus matches. They were considered to be in peak condition at the time of testing. The regional ethics committee of Southern Norway reviewed the study and concluded that, due to the nature of the study, it did not require their approval. The study was therefore submitted to and approved by the Norwegian Social Science Data Services (NSD), ref: 37679/3/LT.

Procedures

All tests were carried out at an indoor track & field and soccer arena. All tests were supervised by testing experts from the Norwegian Olympic Sport Center, and were preceded by a standardized warm up consisting of 15 minutes of running at 60–70% of maximum heart rate, 4–5 accelerations over 50 m and stretching, followed by 5–6 minutes rest immediately prior to the start of the test.

Vertical jump height was measured using force platform- based determinations of impulse and thus velocity at take-off. The force platform used was a portable AMTI model AccuPower (Massachusetts, USA). The force platform had a built-in amplifier and digitizer, and the data were saved to a computer with the aid of the AccuPower software (according to the manufacture, the lowest natural frequency of the platform is greater than 100 Hz). The participants were required to perform two maximum effort trials of squat jump (SJ), and countermovement jump (CMJ). Participants were instructed to keep hands on hips throughout the tests. The SJ was performed from a semi-squat position with a knee angle of 90° which represents a pure concentric contraction. For the CMJ, participants were required to bend their knees to approximately 90° and then immediately rebound in a maximal vertical jump. A 5 min recovery was provided between trials. The best jump heights from both SJ and CMJ and the associated peak power and force (N) production data were retained for further analysis.

All measures of sprinting ability were performed on an 8 mm Mondotrack FTS surface (Mondo, Conshohocken, USA) using Newtest Powertimer portable system Model 300s (OY, Finland). The Newtest Powertimer infrared photocells were mounted on the sprint running track and connected via cables to a computer. The system measures time to the nearest 0.001 s. All sprint tests were performed from an upright position placing the tip of the toe of the front foot on the starting line. Participants started when the test leader gave the start signal, and were instructed to cover the distance in the shortest time possible.

The RSA test was performed by sprinting 7 times 30 m with 30 s recovery in between. The fastest time, average time, total time, and percentage decrement score *(Sdec)* were retained for analysis. The Sdec was calculated using the formula presented below. Its validity and reliability has been tested by Glaister et al. (2008), and it considers all sprints when quantifying fatigue in RSA tests (Eq. 1).

$$S_{dec}(\%) = \frac{sprint1(S1) + S2 + S3 + S4 + \cdots + S_{final}}{S_{best} \times number\ of\ sprints} - 1 \times 100$$

(Eq. 1)

Linear sprint speed was determined by performing two trials of 40 m sprint separated by a 5 min recovery. During the 40 m linear sprint test, times were recorded for 0–20 m (acceleration speed) and 20–40 m (maximum sprinting speed). Sprint speed with change of direction was tested by sprinting 9-3-6-3-9 m with 180º turns (S180º). Five white lines, 2 m in length, and 5 cm in width were placed as the starting line, 6 m line, 9 m line, 12 m line, and 18 m line. As described by Sporis et al. (2010), the subjects started after a signal from the test leader and were instructed to run to the 9 m line and touch it with one foot before turning 180º either left or right (all the following turns had to be made in the same direction as the first turn). The players then ran 3 m to the 6 m line, made another 180º turn, and ran 6 m to the 12 m line, turned 180º and ran again to the 9 m line, and finally made the last 180º turn and ran to the 18 m line (finish line). The total distance of the test was 30 m. Each participant was given two attempts, with a minimum of 5 min recovery between, with the best result retained for analysis.

Aerobic fitness was measured using the Multi Stage Fitness Test (MSFT) conducted on an indoor artificial grass pitch following the protocol developed by Ramsbottom et al. (1988). A JVC Boomblaster (RVNB51WEN) was used to play the MSFT CD that came with the test package. The CD (the soundtrack) and the CD player were examined prior to the start of the test to ensure that the soundtrack played at the correct speed between the sound signals (Beeps). Distance covered from the MSFT was retained for further analysis. The test leader measured and marked a distance of 20 m with cones to perform the test. Subjects were required to perform shuttle running between the cones (20 m) at progressively increasing speeds, starting at 8.5 $km \cdot h^{-1}$. Six test leaders observed the performance to make sure that participants fulfilled the test criteria. Each participant's result was defined as the number of shuttle runs completed before the subject either withdrew voluntarily or failed to complete a shuttle runs in the required time for two consecutive beeps.

Statistical Analysis

Raw data were transferred to SPSS 17.0 for Windows for analysis. Correlation matrices between all variables were determined using Pearson's r. A stepwise linear regression analysis was used to determine the physical abilities that, to the greatest extent, explained performance of RSA and sprint with change of direction. The $p < 0.05$ level of significance was adopted for all statistical tests. Reliability was assessed using a 2-way mixed intraclass correlation (ICC) and the coefficient of variation (CV) between trials was calculated for all measures in this study according to the guidelines provided by Hopkins (2000).

Results

The between-trial reliability for SJ height had an intraclass correlation coefficient (ICC) of 0.83 with a CV of 2.7%, for the SJ peak power, ICC = 0.99 with a CV of 1.5%, for the SJ force production, ICC = 0.94 with a CV of 0.1%, for the CMJ height, ICC = 0.95 with a CV of 0.0%, for the CMJ peak power, ICC = 0.80 with a CV of 1.0%, for the CMJ force, ICC = 0.84 with a CV of 0.3%, for the 40 m sprint time, ICC = 0.96 with a CV of 0.3%, for the 20 m acceleration time, ICC = 0.90 with a CV of 0.6%, for the 20 m maximum speed time, ICC = 0.98 with a CV of 0.1%, and for the agility time, ICC = 0.86 with a CV of 2.3%.

Table 1: Descriptive statistics of aerobic and anaerobic variables in absolute terms and relative to body mass (N = 30).

Measures of Jumping abilities	Mean ± SD	Relative to BM
SJ Height (cm)	26.1 ± 3.8	0.46 ± 0.1
SJ PP (W)	2310 ± 818	40 ± 15
SJ F (N)	2010 ± 435	35 ± 6
CMJ Height (cm)	27.9 ± 3.5	0.49 ± 0.08
CMJ PP (W)	2221 ± 347	39 ± 4
CMJ F (N)	2037 ± 452	35 ± 6
Reactive strength (cm)	1.8 ± 2.8	0.03 ± 0.05
Measures of Sprinting abilities		
0-40 m (s)	6.36 ± 0.22	
0-20 m Acc. (s)	3.55 ± 0.12	
20-40 m Max. (s)	2.80 ± 0.12	
RSA FT (s)	4.93 ± 0.20	
RSA MT (s)	5.04 ± 0.20	
RSA TT (s)	35.25 ± 1.4	
COD (s)	8.26 ± 0.37	
Sdec (%)	-2.2 ± 1.0	
Measures of aerobic fitness		
MSFT DC (m)	1536.7 ± 261.7	

PP = Peak Power, F = Force, Acc = Acceleration, Max = Maximum velocity, FT = Fastest time, MT = Mean time, TT = Total time, COD = Change of direction speed, Sdec = Percentage decrement score, MSFT DC = Multi stage fitness test distance covered.

Table 2. Correlation coefficients between measures of jumping performance, sprinting abilities and measures of aerobic fitness (N = 30).

	0-40 m (s)	0-20 m Acc.	20-40 m Max	RSA FT	RSA MT	RSA TT	COD	Sdec (%)	MSFT DC
In absolute terms									
SJ Height	-.468**	-.406*	-.446**	-.260	-.290	-.288	-.127	.097	.169
SJ PP	.057	.102	.026	-.111	-.033	-.035	-.034	-.302	-.051
SJ F	-.030	.050	-.071	-.141	-.087	-.089	-.142	-.221	.130
CMJ Height	-.457*	-.305	-.508**	-.241	-.264	-.264	-.260	.081	.316
CMJ PP	-.348	-.227	-.395*	-.295	-.241	-.244	-.291	-.211	.211
CMJ F	-.168	-.097	-.166	-.193	-.147	-.151	-.267	-.181	.210
Reactive strength	.063	.169	-.031	.051	.062	.060	-.154	-.031	.166
Relative to Body mass									
SJ Height	-.294	-.272	-.249	-.115	-.172	-.169	.115	.202	.042
SJ PP	.081	.116	.061	-.075	-.012	-.013	.080	-.247	-.112
SJ F	.029	.125	-.020	-.077	-.052	-.053	.094	-.113	.091
CMJ Height	-.304	-.210	-.313	-.097	-.159	-.157	.047	.228	.162
CMJ PP	-.434*	-.295	-.466**	-.303	-.278	-.280	-.035	-.104	.108
CMJ F	-.168	-.085	-.157	-.170	-.151	-.155	-.079	-.073	.175
Reactive strength	.066	.174	-.031	.061	.068	.066	-.139	-.015	.179

PP = Peak Power, F = Force, Acc = Acceleration, Max = Maximum velocity, FT = Fastest time, MT = Mean time, TT = Total time, COD = Change of direction speed, Sdec = Percentage decrement score, MSFT DC = Multi stage fitness test distance covered.
*= $p \leq 0.05$, **= $p \leq 0.01$.

The stepwise regression analysis showed that SJ in absolute terms had the highest shared variance with 0 – 40 m and 0 – 20 m linear sprint times, with 22% and 17% shared variance, respectively. The highest shared variance with 20 – 40 m linear sprint time was through CMJ height with a shared variance of 26%. The stepwise regression analysis relative to body mass showed that the highest shared variance with 0 – 40 m sprint time and 20-40 m sprint time was CMJ peak power with 19% and 22%, respectively.

The results indicate that MSFT distance covered had a significant moderate correlation with RSA fastest time (r = -.483, $p \leq 0.01$), sprint with change of direction time (r = -.430, $p \leq 0.05$), and a significant

Table 3. Correlation coefficients between sprinting variables (N = 30).

	0-40 m (s)	0-20 m Acc.	20-40 m Max	RSA FT	RSA MT	RSA TT	COD	Sdec (%)
0-40 m (s)	1	.917**	.914**	.823**	.860**	.859**	.387*	-.086
0-20 m Acc.		1	.691**	.705**	.733**	.730**	.428*	-.052
20-40 m Max			1	.797**	.845**	.845**	.291	-.137
RSA FT				1	.969**	.969**	.343	.187
RSA MT					1	.999**	.416*	-.062
RSA TT						1	.415*	-.061
COD							1	-.269
Sdec (%)								1

Acc = Acceleration, Max = Maximum velocity, FT = Fastest time, MT = Mean time, TT = Total time, COD = Change of direction speed, Sdec = Percentage decrement score.
*= $p \leq 0.05$, **= $p \leq 0.01$.

large correlation with 0 - 40 m linear sprint ($r = -.510$, $p \leq 0.01$), 20 - 40 m sprint time ($r = -.595$, $p \leq 0.01$), RSA mean time ($r = -.552$, $p \leq 0.01$), and RSA total time ($r = -.552$, $p \leq 0.01$). The stepwise regression analysis of repeated sprinting abilities with measures of aerobic fitness showed that the shared variance between MSFT distance covered and RSA fastest time, RSA mean time, and RSA total time was 24%, 31%, and 31%, respectively. The shared variance between MSFT distance covered and linear sprint times over 0-40 m and 20-40 m were 26% and 36%, respectively. Finally, the shared variance between sprint with change of direction and distance covered during MSFT was 19%.

The stepwise regression analysis showed that linear sprint time over 0 - 40 m was correlated with RSA fastest time, RSA mean time, and RSA total time with a shared variance of 68%, 74%, and 74%, respectively. Stepwise analysis also showed that sprint with change of direction had the highest correlation with linear sprint time from 0-20 m with a shared variance of 18%.

Discussion

The relationships observed between jumping performances and linear sprints (Table 2) were in line with our hypothesis, and can be explained by the fact that sprinting involves high force production to support body mass during movement (Young et al., 1995). This also explains the differences between the relationships observed, namely that SJ was more strongly correlated with start and acceleration phases (0 - 20 m) than CMJ, while CMJ was more strongly correlated with maximal sprinting speed (20 - 40 m) than SJ. A possible explanation for this is that, during the start and acceleration phase, more force needs to be produced via maximal muscle effort action from the concentric contraction. However, as the player approaches maximal sprinting velocity, the foot contact time with the ground is reduced, indicating that, during this phase, the force produced by the legs becomes more important in maintaining running speed (Weyand et al., 2000; Young et al., 1995). Furthermore, the fact that peak power from CMJ (Table 2) is the only power measurement correlated with maximal sprinting speed over 20 - 40 m also suggests that the shortened contact time results in a larger proportion of low-velocity strength being available for high-velocity sprinting. Similar to previous studies, the results of the stepwise regression analysis suggest that concentric muscle action (as in SJ) is more critical for start and acceleration speed, while eccentric followed by concentric contraction (as in CMJ) is more important for maximal sprint speed (Shalfawi et al., 2011; Young et al., 1995).

Aerobic fitness (MSFT distance covered) was significantly correlated with linear sprint (0 - 40 m, and 20 - 40 m) time, repeated sprint ability, and sprint with change of direction. However, no significant association was observed between MSFT distance covered and start-acceleration time over 0 - 20 m during a 40 m linear sprint. Such a relationship was anticipated since a soccer match involves many high-intensity actions. High aerobic capacity likely accelerates recovery following such actions via removal of accumulated lactate during lower intensity phases of play (Reilly, 2007; Stolen et al., 2005). Previous studies indicate that aerobic fitness can significantly affect the ability to maintain a high intensity level during a soccer match (McMillan et al., 2005; Meckel et al., 2009). Similar to previous findings (Meckel et al., 2009), no significant relationships were observed between percentage decrement score from the RSA test and measures of aerobic fitness. This suggests that there is a minimum requirement for aerobic capacity in order to be able to cope with the recovery demands of the RSA test used in this study, above which no further performance benefit is seen (Bangsbo, 1994; Reilly et al., 2000). The shared variance from the stepwise analysis suggests that other factors in addition to aerobic fitness also contribute to sprinting performance.

The results of this study confirm that measures of linear sprint are highly correlated with measures of RSA (Table 3). This supports the assertion that repeated sprint ability is a function of single sprint speed and the ability to resist fatigue (Bishop et al., 2011; Reilly, 2007). However, the present study did not find a significant relationship between performance in the RSA test (7 × 30 m with a 30 s recovery) and fatigue expressed as the percentage decrement score. Hence, the rest period of 30 s in a 7 × 30 m repeated sprint test appears to be sufficient to restore the energy required to perform similarly from sprint to sprint. Fatigue has been defined as the "decline in maximal sprint speed over the number of sprint repetitions" (Girard et al. 2011). The findings of the current study contradict those of previous studies that have reported a performance decline during repeated sprint exercise (Girard et al., 2011), and a strong relationship between initial sprint speed (first sprint) and the occurrence of fatigue in repeated sprint exercise (Mendez et al., 2008). A suggested explanation for this relationship is that players with higher initial sprint speed have a greater contribution from anaerobic metabolism, which in turn, is strongly related to performance decrement (Girard et al., 2011; Mendez- Villanueva et al., 2008; Reilly, 2007). The discrepancy between the results of the current study and previous findings may be due to differences in test protocols; Aziz et al. (2000) used 8 x 40 m repeated sprints separated by 30 s recovery, while Owen et al. (2012) used a protocol consisting of 6 x 20 m maximal sprints with a recovery of 25 s. Rampinini et al. (2007), on the other hand, used 6 x 40 m (20+20) sprints with a recovery period of 20 s. The stepwise analysis showed that 0-40 m linear sprint time was the most strongly correlated with RSA fastest time, RSA mean time, and RSA total time with a shared variance of 68%, 74%, and 74%, respectively.

The relationship between sprint with change of direction and linear sprinting in elite soccer players has not been fully investigated. The results of the current study indicate that the relationship between measures of linear sprint and sprint with change of direction is significant but trivial, with the exception of sprint with change of direction and RSA fastest time and 20–40 m linear sprint time, where no significant relationships were observed (Table 3). These findings are in line with previous studies that have reported statistically significant but very low correlations, suggesting that these two skills can be considered as independent locomotors (Young & Farrow, 2006; Young et al., 2001).

Conclusions

The relationship observed between aerobic capacity and sprinting abilities and the results from the stepwise analysis suggest that separate training strategies are necessary to specifically target and improve performance in these abilities. Furthermore, the results of the present study demonstrate that: (1) reliable assessment of physical performance can be achieved using a single test design, (2) concentric contraction is important for start and acceleration speed, compared to eccentric followed by concentric contraction which is more important for maximal sprint speed, (3) aerobic capacity and linear sprint correlate significantly with repeated sprint ability, (4) sprint with change of direction and linear sprint are two independent locomotors skills, and (5) developing a standardized soccer-specific RSA test would likely result in more consistent results across studies.

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