

**Effects of combining repeated sprints and plyometric training on
repeated sprint ability in male youth soccer players**

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ABSTRACT

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The aim of this investigation was to compare short-term repeated sprint training (RST) and a combination of repeated sprints and plyometric training (COM) in addition to normal soccer training on the effect of repeated sprint ability (RSA) and several other performance measures in male youth soccer players. It was hypothesised that performing repeated sprints and plyometric training would enhance RSA and several other performance measures to a greater extent compared to repeated sprint training alone.

Twenty male subjects (aged 14.6 ± 0.32) participated in the study and were randomly placed into RST ($n = 9$) and COM ($n = 11$) experiment groups. RSA, countermovement jump (CMJ), reactive strength index (RSI), RSI drop jump height, RSI ground reaction force (GRF), RSI contact time, 10m and 30m sprint times, isometric leg press maximal voluntary contraction (MVC) and peak height velocity (PHV) were assessed. The duration of the intervention was 7 weeks, 2 sessions per week in pre-season.

The current study showed that both RST and COM groups significantly enhanced their RSA ($p < 0.05$) with a larger effect size in the RST group compared to COM group ($d = 1.6$ vs. 0.67). Both RST and COM groups also significantly reduced their RSI and RSI contact time ($p < 0.05$). The COM group experienced further significant differences in RSI jump height and GRF. Neither group significantly changed their 10m and 30m sprint times or leg press MVC values ($p > 0.05$). There were no significant interaction effects between groups.

Performing either repeated sprint training alone or combining repeated sprints with plyometric training can significantly improve RSA in male youth soccer player.

Keywords: Youth soccer, repeated sprint ability, plyometric training.

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ABSTRACT

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1. INTRODUCTION

Soccer is played by 250 million people in more than 200 countries, making it the world's most popular sport (Strudwick 2016). The worldwide influence and daily interest attract ever-increasing attention and there has been a major shift towards scientific methods of preparing youth soccer players for competition (Strudwick 2016). Increasing numbers and competitiveness within the game have driven a new scientific approach to youth soccer, and the sport is becoming progressively more athletic (Currell 2009).

Short-term muscle power has become crucial in many game situations and coaches and trainers are continually looking for ways to optimise the physical development of youth players. During a soccer match, it is common for a player to engage in numerous explosive movements, including some 15 tackles, 10 headings, frequent kicking, and changes of pace (Bangsbo et al. 2006; Stolen et al. 2005). Additionally, a 2-4 second sprint occurs every 90 seconds (Bangsbo et al. 1991); and although only 3% of a match is spent sprinting and it accounts for between 1-11% of the distance covered during a match (Stolen et al. 2005), it is an extremely important physical quality to develop. This is because the most crucial moments of a match, such as scoring a goal, winning ball possession or conceding goals is dependent on the ability of the athlete to perform high-speed explosive movements (Reilly 2000).

The analysis and understanding of the physical demands in youth soccer are of utmost importance to strength and conditioning coaches and technical coaches. This understanding can assist with the specificity of physical conditioning to help shape training responses (Kraemer and Fleck 2005). Physical training must resemble and be specific to conditions faced during competition (Davies et al. 2015).

2. Repeated sprint ability

Repeated sprint ability (RSA) is the capacity to perform repeated bouts of high intensity work with short/incomplete recovery periods between successive efforts (Impellizzeri et al. 2008). There is a strong statistical relationship between tests of RSA and the number of high-intensity efforts and total distance recorded during matches in soccer and is

widely considered as a critical parameter of endurance for team sports players (Rampinini et al. 2007). Many of these sprints are separated by active or passive recovery periods long enough (>1 min) to allow complete or near complete recovery and therefore subsequent sprint performance is not significantly impaired (Balsom et al. 1992). However, analysis of matches has shown that a proportion of these sprints are separated by short rest periods (<30 s) (Spencer et al. 2004), which have been shown to have a negative effect on subsequent sprint performance (Bishop and Spencer 2004). Therefore, one of the fitness requirements of team-sport athletes is the ability to perform short-duration sprints (<6 s) with a short recovery time (<30 s), and this has been termed RSA (Mujika et al. 2009).

RSA from a physiological point of view is a complex quality, related to both neuromuscular (e.g., neural drive or motor unit activation) and metabolic related factors (e.g., oxidative capacity for PCr recovery and H^+ buffering) (Glaister 2005; Spencer et al. 2005). Achieving a high average sprint performance over successive sprint efforts constitutes a good RSA capacity (Gamble, 2013). This requires a player to be fast in order to record good sprint times for individual bouts and to be able to maintain a high level of sprinting performance during each successive bout (Bishop et al. 2011). RSA is therefore related to neuromuscular aspects associated with speed performance, in addition to physiological and metabolic components (Pyne et al. 2008).

2.1 Neuromuscular factors contributing to enhanced repeated sprint ability

Neuromuscular factors that can contribute to endurance performance include neural and elastic components of the SSC capabilities, intermuscular co-ordination which can influence running mechanics and movement economy, and the strength qualities of locomotor and postural muscles (Paavolainen et al. 1999). Independently improving these anaerobic endurance parameters can enhance endurance performance (Paavolainen et al. 1999, Mikkola et al. 2007). Improving an athletes strength, speed-strength and strength-endurance should have a positive influence on their economy and performance (Gamble, 2013), Furthermore, neuromuscular control and co-ordination aspects that can influence the stiffness and elasticity of the muscle-tendon complex during the foot strike when running (Paavolainen et al. 1999). Improvement of such capacities via appropriate forms of strength training such as plyometrics can increase the non-contractile contribution to

work output during locomotion (Gamble 2013) and could possibly enhance the RSA of athletes.

In rugby league, developing lower body strength has been shown to enhance the recovery from high intensity sprinting bouts, total distance covered during a match, low and high speed distance, number of contacts, tackle proficiency in elite rugby league players compared to developing high-intensity running ability alone (Johnson et al. 2014).

2.2 Methods of assessing repeated sprint ability

Methods of testing RSA commonly involves evaluating the ability of an athlete to perform a series of maximal efforts. Test protocols in the literature employ either a series of sprint bouts of 5-6 seconds or a distance of 30m or 40m (see table 1). The rest intervals vary between RSA assessment protocols. Variation in recovery intervals strongly influences the metabolic and physiological responses and effects subsequent sprint performance during successive bouts (Oliver et al. 2009; Spencer et al. 2005). Regarding performance of RSA, the literature provides two indices. The sum of all sprint efforts (either distance covered or sprint time) or a relative decrement in performance across the recorded sprint bouts. Calculating the relative decrement provides a fatigue index. Oliver et al. (2009) argues that this method does not offer a reliable measure of RSA.

TABLE 1. RSA test protocols (adapted from Gamble 2013)

Test mode	Distance/duration	Protocol	Outcome measure	Reference
Cycle ergometer	6s bouts	Repeated every 30 seconds	Work output scores	Bishop et al. (2001)
Non-motorised treadmill	5s sprints		Power output values expressed relative to body mass	Bishop et al. (2004)
Over-ground straight line running	30m sprints	7x5s sprints with 20s recovery between bouts	Maximum speed recorded in 1 second interval each sprint. Combined mean speed (all sprints). Total work each sprint trial	Oliver et al. (2009)
Over-ground straight line running	30m sprints	6x30m sprints every 20s	Sum of sprint times, percentage change in times from first to last sprint	Pyne et al. (2008)
Over-ground straight line running	30m sprints	6x30m sprints every 25s	Sum of sprint times	Spencer et al. (2006)
Over-ground shuttle running	40m shuttle sprints (2x20m)	6x40m shuttle sprints with 20s recovery between bouts	Mean sprint time. Best sprint time and % decrement score	Impellizzeri et al. (2007)
Over-ground shuttle running	30s shuttle sprint	Sprints over 5m and 10m alternatively for 30s, 6 sets performed with 35s rest between each set	Sum of distances covered during each 30 second bout.	Boddington et al. (2001)

Although RSA is widely recognised as a critical parameter of endurance for team sport players (Impellizzeri et al. 2008), it may not represent the true RSA of an individual. An athlete may be able to perform a number of horizontal repeated sprints without any change of direction well, but could perform poorly during the RSA test due to having a poor combination of change of direction, acceleration ability and eccentric strength. Some protocols include a 180° change of direction (Impellizzeri et al. 2007; Boddington et al. 2001). This requires a large eccentric component and braking forces. It could be possible that an individual has a good aerobic and anaerobic capacity but due to a lack of eccentric strength do not perform as well during the RSA as they are not able to change direction efficiently, thus, negatively influencing their RSA score.

Furthermore, Stolen et al. (2005) states that 96% of sprints in soccer are shorter than 30m, and 49% are 10m or less and the velocity achieved during the first step is has been identified as a key indicator of player potential (Chelly et al. 2010). Atan et al. (2016) reported that the average distance per sprint in youth soccer was 16m.

2.3 Youth athletes' responses to metabolic conditioning

Prior to puberty, it is believed that youth athletes have a less well developed capacity for high intensity anaerobic activity (Naughton et al. 2000). However, this view is being challenged and there are studies that have shown youth athletes can improve their high intensity performance (Sperlich et al. 2010). McManus and Armstrong (2008) argue that often the training prescribed to youth athletes and children during such interventions and testing are not sufficiently taxing enough to elicit a significant response. While the responses of youth athletes to metabolic conditioning may differ to that of adults, they are capable of performing this form of exercise and can adapt positively to high intensity training (McManus and Armstrong 2008). Pre-pubescent athletes are able to recover more rapidly between exercises bouts due to reduced levels of acidosis due to lower glycolytic enzyme activity (Lloyd and Oliver 2013). Furthermore, Phippaerts et al. (2006) found that the rate of maturation related improvements in aerobic capacity peaks at the same time of peak height velocity (PHV). Adolescents have been reported to have 50% less anaerobic capacity than adults (Nikolaidis 2011), therefore the average distance per sprint in youth soccer is slightly lower in comparison to adult players (Di Salvo et al. 2007). Elite youth soccer players also cover a greater distance and perform more sprints when

compared to non-elite youth soccer players (Harley, 2010; Rebelo et al. 2012). It also appears that younger age groups (under 13's and 14's) perform more high intensity running and sprinting compared to under 15's, though this is likely due to reduced match playing time (Atan 2016). Despite the increased interest in RSA, there is a lack of data with highly trained, developing, team-sport athletes (Mujika et al. 2009). Although the anaerobic capacity of youth athletes appears to be lower than compared to adults, there is research providing evidence that high intensity conditioning can be effective (Helgerud et al. 2001; Hoff 2005).

3. Plyometric training

Plyometric training is a popular form of physical conditioning and involves the stretch-shortening cycle (SSC) (Komi 2000). The SSC occurs when a pre-activated muscle is first stretched (eccentric contraction) and is then immediately followed by a shortening (concentric contraction) action (Komi 2000). The purpose of plyometric exercise is to increase the power of movements by utilising both the natural elastic components of the muscle and tendon and the stretch reflex.

The major advantage of the SSC is that if a muscle can actively stretch before shortening, it can perform more positive work and produce more power (Kawakami et al. 2002). This is achieved by developing the athlete's capacity to harness the SSC augmentation of concentric power output (Gamble 2013). The SSC training stimulus provided by plyometric training has shown to enhance the shortening velocity and peak power output (Malisoux et al. 2006).

This increased production of power is best explained by two proposed models: the mechanical model and the neurophysiological model (Wilk 1993). Regarding the mechanical model, elastic energy in the musculotendinous components can be increased with a rapid stretch and then stored (Asmussen and Bonde-Peterson 1974). When a concentric muscle action immediately follows this movement, the stored elastic energy is released, increasing the total force production (Asmussen and Bonde-Peterson 1974). If the amortisation/transition phase is too long or if a concentric muscle action does not occur immediately following the eccentric action, or requires too great a motion about the given joint, the stored energy dissipates and is lost as heat (Cavagna et al. 1977).

The neurophysiological model involves the potentiation of the muscles contractile components caused by a stretch of the concentric muscle action due to the stretch reflex (Enoka 2008). During plyometric exercise, the reflex component is primarily composed of the proprioceptive organs, muscle spindles (Enoka 2008). During a rapid stretch, the muscle spindles are stimulated causing a reflexive muscle action which potentiates the activity in the agonist muscle, resulting in increased force production (Bosco et al. 1979; Bosco et al. 1981; Bosco et al. 1982). When the muscle spindles are stretched, they send a signal via the type Ia afferent nerve fibres to the ventral root of the spinal cord (Enoka 2008). During the amortisation phase, the type Ia afferent nerves synapse with the alpha motor neurons in the ventral root of the spinal cord (Enoka 2008). The alpha motor neurons then transmit signals to the agonist muscle group (Enoka 2008). As in the mechanical model, if a concentric muscle action is not immediately followed by a stretch, or requires too great a motion about the given joint, the potentiating ability of the stretch reflex is negated (Cavagna et al. 1977). Kilani et al. (1989) state that the rate of musculotendinous stretch is vital to plyometric exercise as a high stretch rate results in greater muscle recruitment and activity during the concentric phase. Further research is required to clarify the degree to which model contributes to the increased force production during plyometric exercise.

The SSC can be further categorised into fast SSC and slow SSC. An example of a fast SSC action is a vertical jump of rebounding task that features a preceding flight phase, utilises short ground contact times (approximately 70-100ms), minimal displacement of centre of mass and small angular displacements at the hip, knee and ankle (Lloyd and Oliver 2014). A slow SSC such as a countermovement jump (CMJ) involves longer ground contact times (>250ms) during a vertical jump or rebounding task, and involves larger displacements of centre of mass and large angular displacements at the hip, knee and ankle joints and is characterised by a preparatory eccentric phase (Schmidtbleicher 1992; Lloyd and Oliver 2014).

Plyometric training is associated with structural adaptations to tendon structures. However, it appears that for this to occur, the duration of a plyometric intervention should be longitudinal. Foure et al. (2010) reported that tendon cross-sectional area was unchanged following a 14 week plyometric training intervention. Although Foure et al. (2010) reports there are likely to be mechanical adaptations to connective tissue, with alterations to tendons and including changes to both stiffness and energy dissipation. The

enhancement in SSC performance in short-term interventions is likely due to neurological adaptations. McBride et al. (2008) reported that one aspect of neural activation response to plyometric training is the pre-activation of agonist muscles during the preparatory and eccentric phases of both slow and fast SSC movements. This pre-activation of agonist muscles is important as it increases the active stiffness of the muscle-tendon complex (McBride et al. 2008). Activating the muscle prior to touchdown means that the tendon is placed under tension before contact with the ground (Gamble 2013). Consequently, there is minimal change in muscle fascicle length during ground contact so that the majority of change in length occurs at the tendon, which during the eccentric phase is further stretched and then rapidly shortens due to elastic recoil during the concentric phase before take-off (Gamble 2013). This can enhance the storage and return of elastic energy during eccentric and concentric phases (McBride et al. 2008). Taube et al. (2008) proposes that another effect of descending neural input is to modulate locally mediated inhibition of stretch reflex neural pathways, via the golgi tendon organ immediately prior to and end during the pre-stretch phase (Newton and Kraemer 1994).

3.1 The development of power in youth populations

Muscular power has been tested for many years in youth populations (Branta et al. 1984), but has been omitted from the popular long term athletic development model developed by Balyi and Hamilton (2004). There is a rapid development of muscular power between the ages of 5 and 10 years (Branta et al. 1984). Lloyd and Oliver (2014) state that this is due to age-related neuromuscular coordination. Beunen (2000) showed that during childhood a secondary spurt in muscular power exists between the ages of 9 and 12 in girls and 12 and 14 in boys. This secondary development phase occurs at the onset of puberty (Ford et al. 2011) and therefore can occur at varying rates due to maturational differences in children.

The adolescent spurt in muscular power is initiated approximately 1.5 years pre-peak height velocity (PHV), and peaks 0.5-1 year post-PHV (Beunen and Malina 1988). Lloyd and Oliver (2014) state that improvements in maximal muscular power coincide more closely with peak weight velocity (PWV). Potential morphological mechanical adaptations associated with the rapid secondary spurt in muscular power during PWV

include; increases in muscle cross-sectional area, alterations in fascicle length and changes in pennation angle (Lloyd and Oliver 2014). Both morphological and neural factors develop naturally from childhood to adulthood, which can enable a more effective neuromuscular regulation of human locomotion (Malina et al. 2004). Lambertz et al. (2003) states that children also display more inhibitory mechanisms to protect the musculotendon unit, such as increased co-contraction, greater antagonist activation (Croce et al. 2004), and reduced stretch reflex utilisation (Oliver and Smith 2000).

The majority of the research concerning plyometric training has been in short-term interventions <12 weeks (Markovic and Mikulic 2010; Saez de Villarreal et al. 2012; Asadi et al. 2016; Chelly et al. 2010; Diallo et al. 2001; Chaouachi et al. 2014; Matavulj et al. 2001). There is a large amount of evidence showing the positive effects of adhering to a plyometric training programme on several performance measures. For example, plyometric training can lead to increased lower-body maximal muscle strength, sprint velocity, agility (Saez de Villarreal et al. 2012). With increases in sprint performance from 5m to 30m in adolescents (Chaouachi et al. 2014) and 40m in youth soccer players (Chelly et al. 2010; Diallo et al. 2001) being reported.

Despite such improvements in sprinting speed, Booth and Orr (2016) state that plyometric training has not been shown to be a better form of training for sprint performance compared to sprint training alone. However, different phases of a sprint rely on slow and fast SSC properties to different degrees and depends on the duration of foot contact (Gamble 2013). During the acceleration phase, there is more reliance on slow SSC and when an athlete attains high velocities, fast SSC then predominates as the foot contacts become shorter (Gamble 2013). This therefore shows the importance of developing both fast and slow SSC capabilities which can be achieved by adhering to a plyometric training programme (Lloyd and Oliver 2013).

Thomas et al. (2009) investigated the effects of plyometric training on agility and muscular power in youth soccer players and found increased performance in countermovement jump height and agility. The authors speculate that such improvements were in part likely due to increased firing frequencies. This argument is supported by a study conducted by Matavulj et al. (2001) using junior basketball players reported increased maximal voluntary contraction and rate of force development of the knee extensors in addition to improvements in vertical jumping height. A recent meta-analysis

conducted has also examined the effects of plyometric training on change of direction performance and showed increased performance in this measure following short-term interventions (Asadi et al. 2016).

3.2 Plyometric training and reducing the risk of injuries

Although concern has been expressed by some researchers with regard to the injury risk during plyometric training (Potach and Chu 2008). When plyometric training interventions have been controlled, with adequate supervision and correct technique, no injuries have been reported. Plyometric training has been shown to reduce the risk of lower-extremity injuries in team sports (Mandelbaum et al. 2005; Myklebust et al. 2003) and has been advocated as a preventive injury strategy (Lephart et al. 2005). Plyometric training has been shown to reduce the recovery time of injuries (Zouita 2016) and has been used as a rehabilitation tool (Ramirez-Campillo et al. 2015). Furthermore, Ismail et al. (2010) states that plyometric exercise is more effective than strength training alone in improving functional performance of athletes after a lateral ankle sprain.

A protective effect of well-conditioned athletes is that they are more resistant to neuromuscular fatigue, which has been shown to cause injury (Hawkins et al. 2001; Verrall et al. 2005). This is further evidenced by an increased incidence of injuries in the latter stages of matches when players are fatigued (Best et al. 2005, Brooks et al. 2005). Resistance training can also serve as a general protective effect in making the musculoskeletal system stronger and as a result, more resistant to stresses incurred during training and games (Kraemer and Fleck 2005). Takarada (2003) supports this statement by declaring that trained muscle is more resistant to microtrauma caused by strenuous physical exertion and recovers faster.

When delivering plyometric training drills, it is recommended coaches pay close attention to the landing and jumping mechanics of the participants. With the importance of a triple extension of the ankles, knees and hips upon jumping and triple flexion upon landing, with a neutral lumbothoracic spine position, and coordination of upper and lower limbs demonstrated and emphasised regularly (Lloyd et al. 2011).

3.3 Volume of plyometric training

Regarding plyometric training, volume refers to the total number of foot contact times performed during a session (Gambetta 2007). In sports, including soccer, a youth athlete might experience a large number of ground contacts and Lloyd and Oliver (2014) suggest that strength and conditioning coaches should not overload youths with an excessive amount of ground contacts. Current guidelines throughout the literature state that the number of contact times should not be >250 (National Strength and Conditioning Association, 2009; Lloyd and Oliver, 2014; Fleck and Kraemer, 2014). While this number of contacts may be excessive, the figure is based on a case study (Clarkson 2006) where a 12 year old child developed exertional rhabdomyolysis. Research conducted by Ramirez-Campillo et al. (2015) and Diallo et al. (2001) demonstrated youth soccer players completed 260 jumps, even on consecutive days without the occurrence of injury. However, these two studies were short-term (6 and 8 weeks) and thus, it would be unwise to recommend a plyometric training intervention with training sessions occurring on consecutive days due to a possible increased risk of injury until research suggests otherwise. A major limitation to planning plyometric training based on contact times/volume is that the number ground contact times does not take into consideration the eccentric loading (e.g. height of jumps or whether the jump performed is unilateral).

Despite the extensive use of lower body plyometric training, there is a lack of systematic evidence to determine the optimal load for plyometric exercises (Vossen et al. 2000). This presently remains the case, particularly in youth athletes. With further research required examining the optimal dose-response. However, recent research has shown that reduced volume of plyometric training induced similar performances compared to higher volume in youth rugby players (Jeffreys et al. 2017).

3.4 Intensity of plyometric training

Intensity refers to the amount of eccentric strain (e.g. drop jump height), placed on the musculotendon unit during an exercise (Potach and Chu 2008). Lloyd and Oliver (2014) recommend that due to the high neural demands placed on the neuromuscular system during plyometric actions, young athletes should be gradually introduced to plyometric

training. Such an approach is also important to ensure that the training emphasis is placed on movement quality (alignment and stability), correct landing mechanics, short ground-contact time, recruitment of a large number of motor units, high stimulation of rate of force development and utilisation of the stretch reflex (Lloyd and Oliver 2014).

3.5 Plyometric training repetition velocity

The use of real-time feedback is important regarding the repetition velocity and to ensure the plyometric training drills are executed safely and to a high standard. Flanagan and Comyns (2008) state that this can not only educate the participant, but can increase motivation and enhance performance outcomes. Lloyd and Oliver (2014) state that strength and conditioning coaches should constantly emphasise the importance of fast and powerful interaction with the surface.

Faigenbaum (2006) recommends that that plyometric training should not be conducted on consecutive days in youth populations, although there is no experimental evidence that sustains such recommendations. However, there are several interventions in youth soccer that used >72 hours (Michailidis et al. 2013; Shalfawi et al. 2012), or >48 hours (Meylan and Malatesta 2009) of rest between plyometric training sessions to allow for adequate recovery. The recovery capacity of youths from plyometric exercises has been reported to be higher than adults, and <24 hours may be sufficient to recover from a previous explosive exercise stimulus (Marginson 2005). This is supported by Ramirez-Campillo et al. (2015) who reported similar explosive and endurance adaptations in young male soccer players when plyometric training was conducted twice weekly in season on consecutive and non-consecutive days.

3.6 Recovery intervals during plyometric training

The recovery intervals for children following various forms strength training are not as well established compared to adults (Murphy et al. 2014). Nonetheless, children have been shown to recover quicker than adults and therefore the same training guidelines may not apply (Falk and Dotan 2006; Ratel et al. 2006). Enhanced recovery is due to a lower

reliance on glycolysis, quicker phosphocreatine resynthesis (Lloyd and Oliver 2014), faster acid base regulation (Ratel et al. 2002), and increased fatigue resistance due to lower power output (Falk and Dotan 2006).

Although children have been shown to recover quicker than adults, no studies have used dynamic resistance exercise with different repetitions, with research currently limited to isometric resistance exercises. Prepubescent males have been also been shown to exhibit less neuromuscular fatigue compared to adults (Murphy et al. 2014).

3.7 Plyometric training intervention design recommendations

Plyometric training volume is recommended to be increased by 20% per week in in short term interventions (Ramirez-Campillo et al. 2015). Participants with no previous experience of plyometric training, are also recommended to perform exercises with minimal eccentric-loading (Lloyd and Oliver 2013). As participants enhance their technical competency, both the level of structure and intensity can be increased. With multiple hops, drop jumps and repeated jumps over mini hurdles and unilateral movements that have a greater loading often included (Lloyd and Oliver 2014).

Based on previous research (Ramirez-Campillo et al. 2015; Christou et al. 2006; Meylan and Malatesta 2009; Saez de Villarreal et al. 2012), it is suggested that plyometric training jumps should include a combination of multilateral and multidirectional movements. Jumps that include a horizontal propulsion phase are important as it appears this method can maximise gains in speed performance (Saez de Villarreal et al. 2012). From a specificity viewpoint, Young (2006) states that cyclic unilateral horizontal bounding and jumping plyometric exercises (in horizontal direction) are the most appropriate training mode to develop sprint capabilities. Bounding exercises in particular feature comparable horizontal propulsion forces, foot contact times, and muscle activation to those recorded in sprinting (Mero and Komi 1994). Single-leg sagittal plane hurdle hops can also be included as this exercise has been shown to produce the greatest gluteal and hamstring activity across both phases and may also be important as an ACL injury preventative method (Struminger et al. 2013).

Atkins et al. (2013) observed a bilateral deficit in ground reaction forces in young soccer players between the ages of 13-15, with the magnitude of imbalance increasing with age until late adolescence when such differences are reduced. Such an imbalance may predispose players to injury, and suggests a bias in activation and motor control relating to the lower limbs and subsequent force transfer through the kinetic chain (Atkins et al. 2013).

Atkins et al. (2013) states that correct attention to focused training, designed to reduce the level of imbalance through unilateral training, may confer protective benefits and reduce possible risk. Furthermore, hip imbalances can increase the risk of lower back injury (Nadler et al. 2002). This would suggest that both unilateral and bilateral plyometric training exercises should be incorporated into a plyometric training programme design.

When conducting a plyometric training programme it is recommended that coaches regularly monitor the training response (Fleck and Kraemer 2014). There are several methods used to measure plyometric training and SSC ability. The most widely researched performance measure of plyometric training is via vertical or horizontal jumping. With methods including; countermovement, vertical, squat, drop or broad jumps (Lloyd and Oliver 2013).

4. Combining repeated sprints and plyometric training

To the investigator's knowledge, only two studies have been conducted that investigated the effects of plyometric training on RSA in youth sports. Hermassi et al. (2014) reported enhanced leg power and increased CMJ, but reported no significant difference in RSA. Upon closer inspection of this study, there could possibly have been no improvement in RSA due to the plyometric training programme only incorporating bilateral hurdle and drop jumps. To enhance sprinting and acceleration performance, plyometric training is recommended to feature unilateral bounding exercises (Delecluse et al. 1995). This is supported by studies mentioned previously (Chaouachi et al. 2014; Chelly et al. 2010; Diallo et al. 2001; Meylan and Malatetsa 2009) who used a combination of bilateral and unilateral plyometric exercises to enhance acceleration and sprinting performance.

Buchheit et al. (2010) conducted a study that focused on the effects of explosive strength training on RSA. They reported increased performance in CMJ, 10m and 30m sprint times but no performance enhancement in the RSA in the group that performed explosive strength training. While RSA only increased in group that conducted sprint training only. It is possible to speculate that the group that conducted explosive strength did not improve in RSA due to methodological limitations in the training intervention design. The participants in Buchheit et al. (2010) study only performed explosive training once a week which may not be sufficient. Furthermore, the study did not include the training programme explaining what type of plyometric training exercises were conducted. It would be useful to check the programme to determine the progression, frequency, volume and intensity of each exercise included in the study.

Therefore, with only two studies having been conducted investigating the effects of plyometric training on RSA, with both studies appearing to hold a number of limitations, further research within this topic is required.

5. Purpose of the study and hypothesis

In light of current literature, it would suggest that that the inclusion of a more intense and non-soccer-specific training stimulus, such as plyometric training which is integrated into the normal soccer training program, has the potential to induce improvements in explosive power and sprinting performances that are greater than maturation or soccer specific training performance gains.

Previous research that has examined the effects of plyometric training on RSA that did not show improvements in RSA performance appear to hold methodological limitations. To the investigators knowledge, no other research has been conducted that has investigated the effects of a periodised plyometric training on RSA.

The aim of this study was to examine the effects of performing a short-term intervention combining repeated sprints and plyometric training with normal soccer training sessions on RSA and several other measures of physical performance in high-level youth soccer players. It was hypothesised that performing a combination of repeated sprints and plyometric training would enhance RSA and several other performance measures compared to performing sprint training alone.

6. METHODS

6.1 Subjects

Twenty male youth soccer players aged 14-15 were recruited for the study from one Finnish football club (JJK). To ensure there was no maturational bias, PHV was determined. A further three players were excluded from the study due to being late developers according to their estimated maturation stage. The groups were randomly split within the football club recruited (see table 2 for subject characteristics). All participants prior to starting the programme had a limited amount of strength and conditioning training history with no previous background of periodised plyometric training. Before giving their written informed consent to participate, the participants and parents/ guardians were informed of any possible risks to the experimental procedures. The study was approved by the local ethical committee.

TABLE 2. Subject characteristics

Group <i>n</i> = 20	Age	Mass (kg)	Height (cm)	PHV
RST <i>n</i> = 9	14.6 ± 0.31	54.9 ± 8.4	169 ± 9.72	0.53 ± 0.76
COM <i>n</i> = 11	14.7 ± 0.32	55.03 ± 5.8	168 ± 4.7	0.51 ± 0.5

6.2 Experimental design

The two experiment groups were a repeated sprint training group (RST) and a combination of repeated sprints and plyometric training (COM). Both groups also performed soccer specific training. The COM group performed a 50% reduction in repeated sprints compared to the RST and RST groups. Plyometric training was performed prior to the repeated sprints in the COM group. See figure 1 for the experimental design.

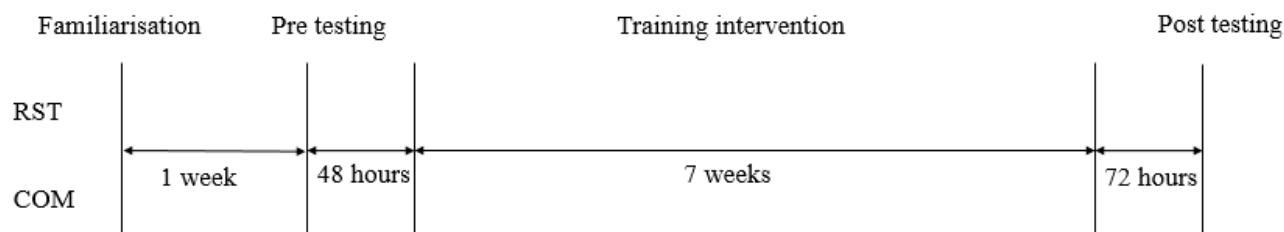


FIGURE 1. Experiment design

6.3 Measures

Prior to pre-testing, the participants completed a familiarisation training period to reduce the possible learning effects. Pre-testing was conducted over a one day period >48 hours after any other training or physical activity and 2-3 days before the initiation of the training intervention. During post-testing, the tests were performed in the same order as pre-testing, at the same time of day, in the same venue and by the same team of investigators. The post-tests were performed 2-3 days after the final training session of the intervention with no other forms of physical activity between this period. Participants were instructed to wear the same sport clothing, have a good night's sleep (>8 hours) before each testing day and avoid eating 2-3 hours before measurements.

During testing, all participants had their height, sitting height and weight recorded and then completed a dynamic warm-up for 10 minutes. They then completed the CMJ, RSI and isometric leg press MVC tests. After resting for 5 minutes, the participants then completed the 10m and 30m sprints. The participants completed the sprinting tests 3 times, with 3 minutes recovery in-between trials. The fastest time recorded was used for analysis. After a further 5 minutes' rest period, the participants then completed the RSA test. This was completed only once.

Height and body mass. Height was measured using a wall-mounted stadiometer and recorded to the nearest 0.5cm. Sitting height was measured by having the participants sit on a 40cm box against the same wall-mounted stadiometer and recorded to the nearest 0.5cm, with 40cm subtracted from the total sitting height recorded. Sitting height was

measured due to this value being required to estimate PHV. Body mass was measured to the nearest 0.1kg using a digital scale.

PHV. PHV is the period in which adolescents have their fastest upward growth in height (Lloyd and Oliver 2012). The age that a child is expected to achieve PHV can be calculated using a maturity offset value. PHV is a non-invasive method to estimate the prediction of physical maturity. To calculate the participants PHV, the following was recorded; gender, date of birth, date of measurement, standing height (cm), sitting height (cm) and weight (kg). This data was then inputted into the following tool: https://kinesiology.usask.ca/growthutility/phv_ui.php

Countermovement jump (CMJ). All jumps were performed in controlled laboratory conditions, using a force plate (Department of Biology Physical Activity, University of Jyväskylä, Finland) with arms placed on the hips. Take-off and landing was standardised to full knee and ankle flexion on the same spot. Three jumps were conducted with the highest recorded value being used for analysis. Data was analysed using Spike version.

Reactive strength index (RSI). Lloyd and Oliver (2014) suggest that the CMJ may not be able to elicit the stretch reflex. Therefore, a reactive strength index (RSI) ($\text{jump height} \div \text{contact time}$) was used in addition to the CMJ. Furthermore, the RSI of an individual is a measure of SSC ability that reflects the prerequisite of true SSC function (Komi, 2000). It demonstrates an athlete's ability to rapidly change from an eccentric motion into a concentric muscular contraction and is an expression of their dynamic explosive vertical jump capacity (Lloyd and Oliver, 2014). Participants were instructed to maximise jump height and minimise ground contact time after dropping down onto a force plate using a force plate (D of Biology Physical Activity, University of Jyväskylä, Finland) from a 30-cm drop box. Three trials were conducted with the highest recorded value being used for analysis. Within RSI, three further measures were analysed; drop jump height, ground reaction force (GRF) and RSI contact time. Data was analysed using Spike version.

Isometric leg press MVC. The isometric leg press MVC has been used previously to measure lower leg strength in plyometric training interventions (Saez de Villereal et al. 2010). It was performed by exerting force against a press-platform (Department of Biology Physical Activity, University of Jyväskylä, Finland). Three trials were conducted with the highest peak force value recorded value for analysis. Relative strength was also

calculated (absolute peak force \div participants body mass $\text{N}\cdot\text{kg}^{-1}$). Data was analysed using Spike version.

10m and 30m sprint test. Measured to the nearest 0.01 second using photoelectric cells (Department of Biology Physical Activity, University of Jyväskylä, Finland). Starting position was standardised to a still split standing position, with the leading toe of the preferred foot forward and behind 30cm behind the start line. Sprint start time was initiated when the participant moved through the first photocell at the start line. Three trials were conducted with the fastest time recorded being used for analysis. Previous plyometric training literature have incorporated 10m and 30m sprint times to test for improvements in sprinting speed (Chaouachi et al. 2014; Chelly et al. 2010; Diallo et al. 2001).

RSA. Measured to the nearest 0.01 second using photoelectric cells (Department of Biology Physical Activity, University of Jyväskylä, Finland). The starting position was standardised to an identical still split standing position to the 10m and 30m tests. The participants sprinted 20m, before changing direction 180° and then sprinting back 20m to the start line. This was completed 6 times in total, with the participants resting 20s between each repetition. The RSA test followed the same protocol as Impellizzeri (2008). The sum of the total sprint time of the 6 sprints was used for analysis.

6.4 Training intervention

The 7-week intervention was completed in 2016 (October-December) during pre-season. The duration of the intervention was 7 weeks, a one-week reduction to what was originally planned and designed. The post testing was brought forward by one week to ensure the COM and RST groups could attend post testing due to a fixture change. This time-frame has been shown to be effective for enhancing a wide range of performance measures in other plyometric training interventions (Meylan and Malatesta 2009; Chelly et al. 2010; Chelly et al. 2014; De Hoyo et al. 2016) and this duration is common practice for a pre-season timeframe in youth soccer.

Subjects in both the RST and COM groups performed two training intervention specific training sessions per week (Monday evenings and Saturday afternoons). The two groups performed an additional identical soccer specific training session on Tuesday evening (see table 3). The two groups performed an identical warm-up prior to their respective intervention training sessions. See tables 4-6 for the detailed training programmes. Figure 2 shows the repeated sprint training drill. After the completion of the two groups respective intervention training exercises, the subjects were instructed to rest passively for 5-10 minutes before technical soccer specific training. Due to the participants in the COM group having no experience of formal plyometric training, they were closely monitored and supervised by the investigators throughout the investigation. With landing mechanics demonstrated and appropriate coaching cues given when required.

TABLE 3. Schedule of training for intervention

Mon	Tue	Wed	Thu	Fri	Sat	Sun
Intervention training - Evening	Soccer training - Evening				Intervention training - Afternoon	

TABLE 4. RST training programme

Weeks 1-3				
Sets	Repetitions	Distance	Rest between sets	Rest between repetitions
3	6	40m (every 10m change of direction 180°)	4 minutes (passive)	20 seconds
Weeks 4-7				
Sets	Repetitions	Distance	Rest between sets	Rest between repetitions
3	6	40m (every 20m change of direction 180°)	4 minutes (passive)	20 seconds

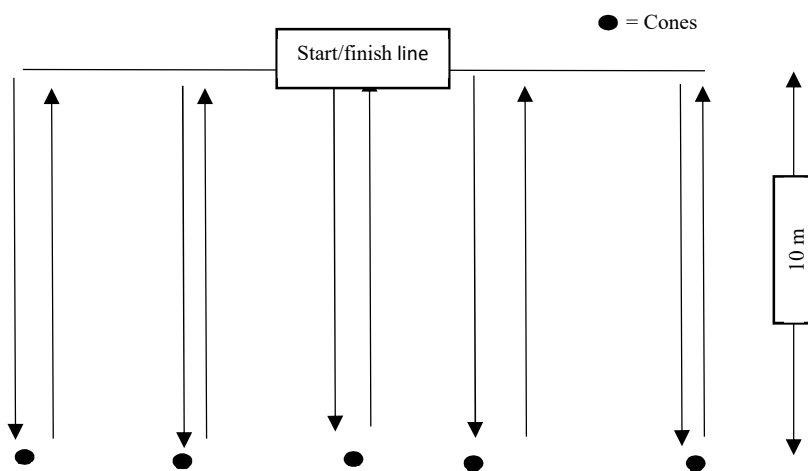


FIGURE 2. Repeat sprint training exercise drill.

TABLE 5. COM training programme

Exercise	Week1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
sets x reps 'rest between reps (rest between sets)							
Tuck jump	6x1	6x1	4x2(60s)	6x2 (60s)	7x2 (60s)	5x3 (60s)	8x2 (60s)
Lateral tuck jump	6x1	6x1	4x2(60s)	6x2 (60s)	7x2 (60s)	5x3 (60s)	8x2 (60s)
Drop jump 30cm (bilateral)	5x1' 10	6x1' 10	5x2'10 (60s)	6x2'10 (60s)	7x2' 10 (60s)	5x3' 10 (60s)	8x2' 10 (60s)
Drop jump 10cm (unilateral)					3x1' 10	4x1' 10	6x1' 10
Vertical hop (unilateral)	4x1	5x1	5x1	6x1	4x2 (60s)	5x2 (60s)	6x2 (60s)
horizontal hop (unilateral)	4x1	5x1	5x1	6x1	4x2 (60s)	5x2 (60s)	6x2 (60s)
Hop, hop, hold (unilateral)		4x1	5x1	6x1			
Lateral bounds					5x1	7x1	5x2 (60s)
Total jumps/contacts	33	46	56	66	85	100	136

TABLE 6. COM training programme (repeated sprint training drills).

Weeks 1-3				
Repetitions	Sets	Distance	Rest between sets	Rest between repetitions
3	3	40m (every 10m change of direction 180°)	4 minutes (passive)	20 seconds
Weeks 4-7				
Repetitions	Sets	Distance	Rest between sets	Rest between repetitions
3	3	40m (change of direction 180° after 20m)	4 minutes (passive)	20 seconds

6.5 Statistical analysis

The data for the study was analysed using IBM SPSS Statistics version 22. All data was checked for normality using a Shapiro-Wilk test and presented as mean and SD. Statistical significance was determined using the p - value of ≤ 0.05 and. The changes in both pre and post measurement values of the intervention were analysed using a paired-samples t test. Cohen's d was calculated to determine the effect size with the following criteria, $d = \leq 0.20$ (small effect), $d = 0.5$ (medium), $d = \geq 0.8$ (large effect). Two-way repeated measures mixed ANOVA were conducted to determine interaction effect between the groups.

7. RESULTS

CMJ. There was no statistically significant improvement in CMJ height in the RST group ($p > 0.05$). However, there was a statistically significant improvement in CMJ height in the COM ($p < 0.05$). An increase of 8% with a medium effect size $d = 0.58$. See figure 3. Despite this increase, there was no statistically significant interaction effect between groups ($p > 0.05$).

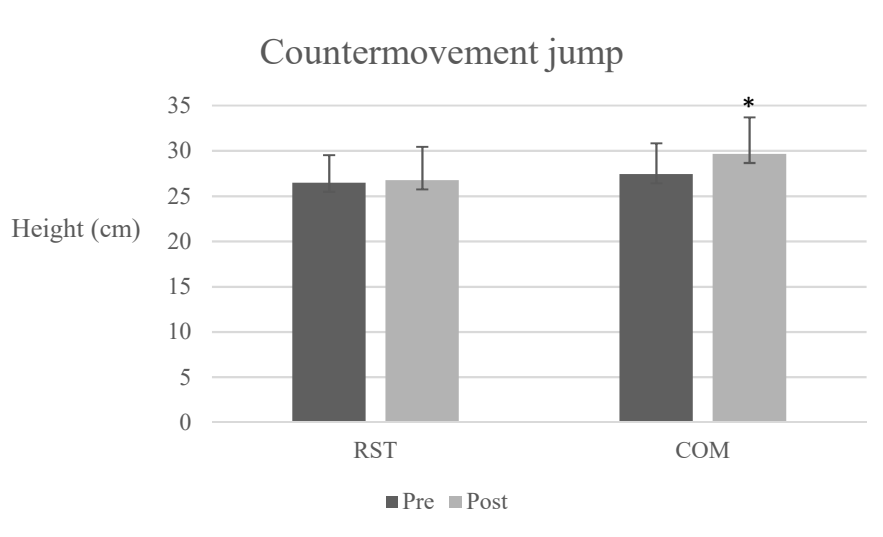


FIGURE 3. CMJ pre and post. *Denotes significant difference with the corresponding pre-value ($p < 0.05$).

RSI. There was a statistically significant improvement in RSI in the RST group following the intervention ($p < 0.05$). An increase of 9%. With a medium effect size $d = 0.64$. There was also a statistically significant improvement in RSI in the COM group ($p < 0.05$). An increase of 21%. With a large effect size $d = 1.2$. See figure 4. Despite this increase, there was no statistically significant interaction effect between groups ($p > 0.05$).

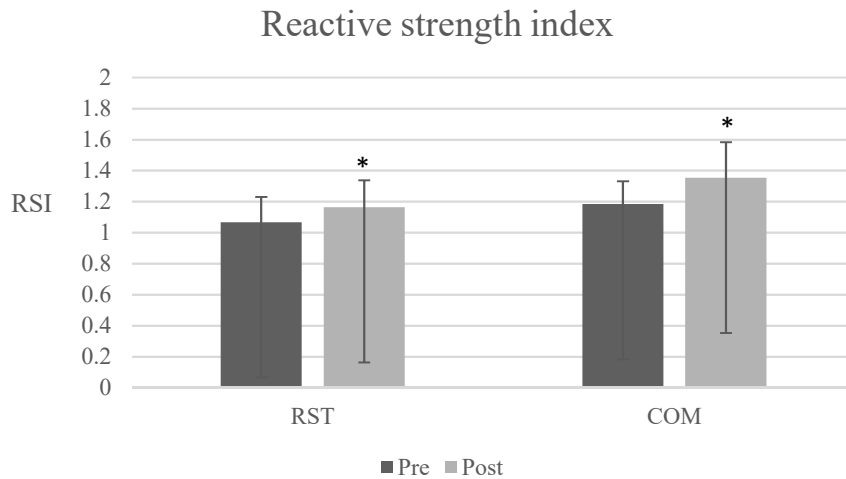


FIGURE 4. RSI pre and post. *Denotes significant difference with the corresponding pre-value ($p < 0.05$).

RSI drop jump height. The RST group significantly increased ($p < 0.05$). With an increase of 2% and a small effect size $d = 0.13$. There was also a statistically significant improvement in RSI jump height in the COM group ($p < 0.05$). An increase of 5% with a small effect size $d = 0.35$. See figure 5. There was no statistically significant interaction effect between groups ($p > 0.05$).

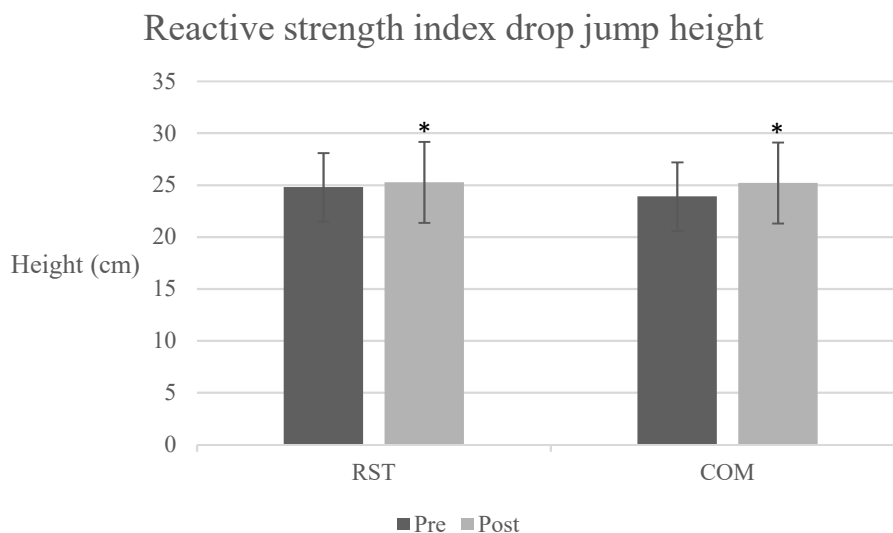


FIGURE 5. RSI drop jump height. *Denotes significant difference with the corresponding pre-value ($p < 0.05$).

GRF. There was no statistically significant improvement in GRF in the RST group ($p > 0.05$). There was a statistically significant improvement in GRF in the COM group ($p < 0.05$). An increase of 20% and a large effect size $d = 1.05$. See figure 6. There was no statistically significant interaction effect between groups ($p > 0.05$).

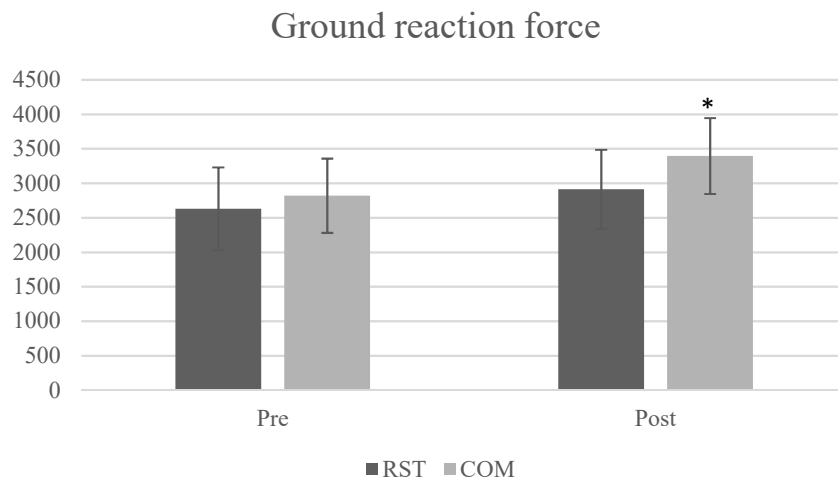


FIGURE 6. GRF pre and post. *Denotes significant difference with the corresponding pre-value ($p < 0.05$).

RSI contact time. There was no statistically significant improvement in RSI contact time in the RST group following the intervention ($p > 0.05$). However, there was a statistically significant improvement in RSI contact time in the COM group ($p < 0.05$). A decrease in contact time of 20% with a large effect size of $d = 1.8$. See figure 7. Despite this increase, there was no statistically significant interaction effect between groups ($p > 0.05$).

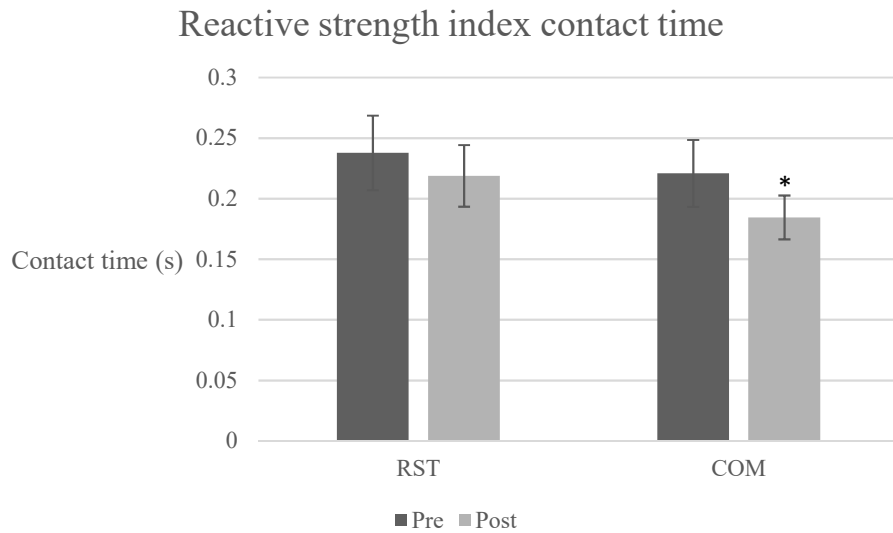


FIGURE 7. RSI contact time. *Denotes significant difference with the corresponding pre-value ($p < 0.05$).

Leg press MVC. There was no statistically significant improvement in leg press MVC in both groups following the intervention ($p > 0.05$). See figure 8. Table 7 displays the leg press MVC relative to body mass ($\text{n} \cdot \text{kg}^{-1}$) pre and post values for both groups.

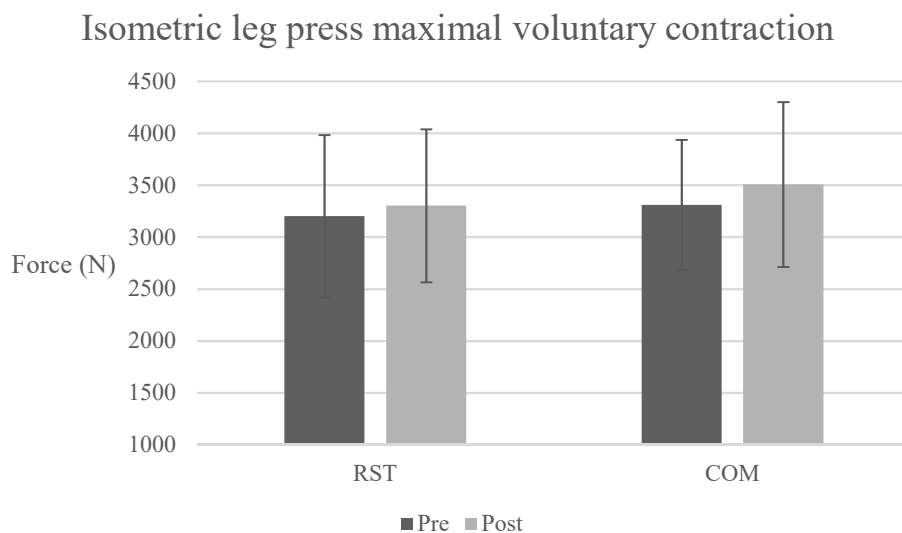


FIGURE 8. Leg press MVC pre and post.

TABLE 7. RST relative to body mass leg press MVC pre and post results.

RST group			
Pre			
Min	Max	Mean	SD
$\text{N}\cdot\text{kg}^{-1}$	$\text{N}\cdot\text{kg}^{-1}$	$\text{N}\cdot\text{kg}^{-1}$	
40.3	72.80	55.4	9.65
Post			
Min	Max	Mean	SD
$\text{N}\cdot\text{kg}^{-1}$	$\text{N}\cdot\text{kg}^{-1}$	$\text{N}\cdot\text{kg}^{-1}$	
50.8	67.1	60.3	7.9
COM group			
Pre			
Min	Max	Mean	SD
$\text{N}\cdot\text{kg}^{-1}$	$\text{N}\cdot\text{kg}^{-1}$	$\text{N}\cdot\text{kg}^{-1}$	
Post			
Min	Max	Mean	SD
$\text{N}\cdot\text{kg}^{-1}$	$\text{N}\cdot\text{kg}^{-1}$	$\text{N}\cdot\text{kg}^{-1}$	
37.9	72.4	60.2	10.7

10m sprint. There was no statistically significant improvement in 10m sprint time in both groups ($p > 0.05$). See figure 9.

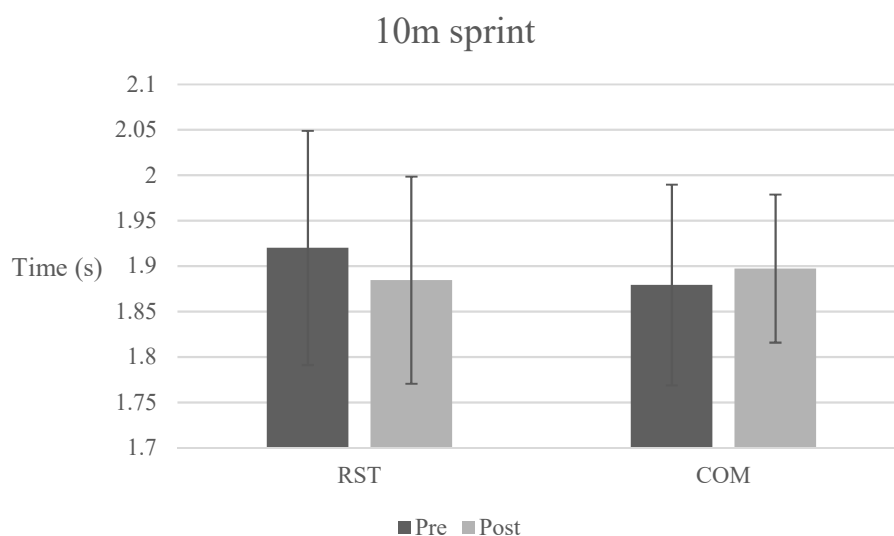


FIGURE 9. 10m sprint times pre and post.

30m sprint. There was no statistically significant improvement in 10m sprint time in both groups ($p > 0.05$). See figure 10.

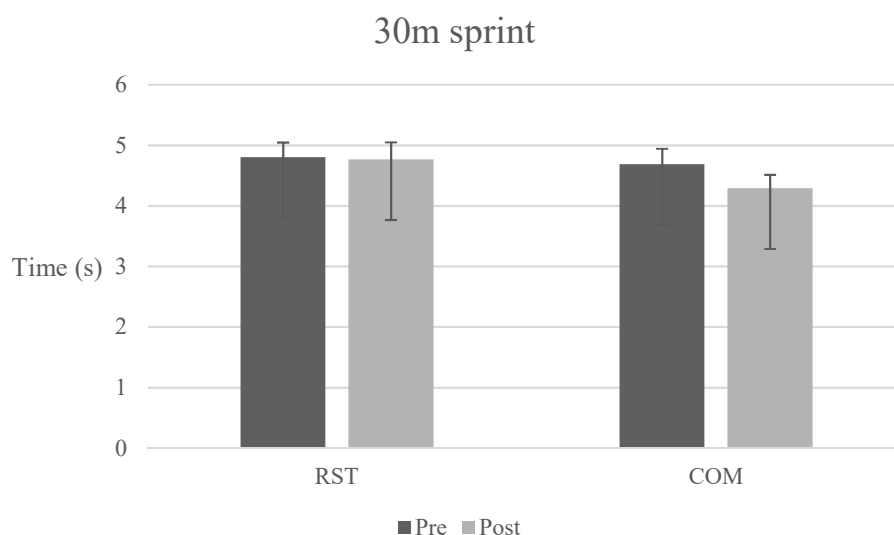


FIGURE 10. 30m sprint times pre and post.

RSA. There was a statistically significant improvement in RSA in the RST group following the intervention ($p < 0.05$). An improvement of 4% and a large effect size $d = 1.6$. There was also a statistically significant improvement in RSA in the COM group ($p < 0.05$). An improvement of 2% and a medium effect size $d = 0.67$. See figure 11. There was no statistically significant interaction effect between groups ($p > 0.05$).

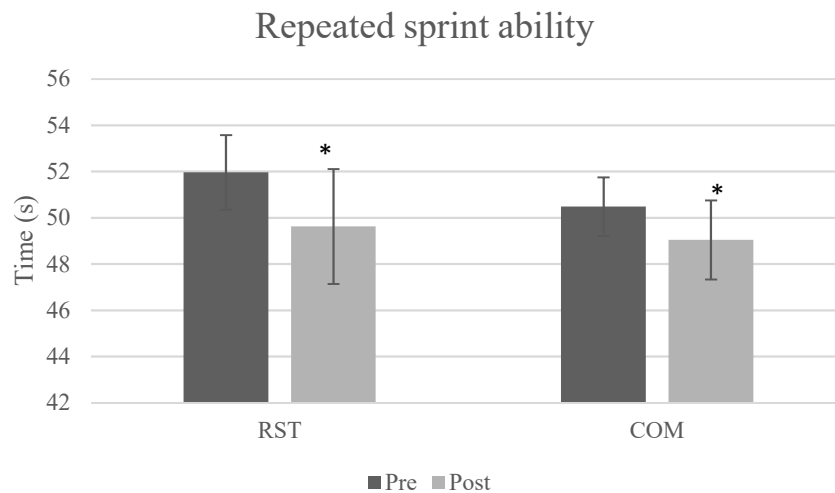


FIGURE 11. RSA pre and post. *Denotes significant difference with the corresponding pre-value ($p < 0.05$).

8. DISCUSSION

The purpose of the study was to examine whether combining repeated sprints and plyometric training enhanced RSA and several other physical performance variables.

The main findings of the study were:

1. Combining repeated sprints with plyometric training and repeated sprint training alone can significantly improve the RSA of youth soccer players.
2. Combining repeated sprints with plyometric training can significantly enhance several other physical performance measures including; CMJ, RSI, GRF, RSI contact time in addition to RSA compared to repeated sprint training alone.
3. RSA can be significantly enhanced without a significant improvement in 10m or 30m sprint times.

Repeated sprint and plyometric physical training programs are often implemented during preseason to bring players to an appropriate initial level of fitness prior to starting the season. Participating in a preseason regimen involving plyometric training may also serve to reduce injuries and improve the athletic performance of adolescents, both by strengthening ligaments, tendons, and bones and by enhancing muscular strength, endurance, and power (Gamble 2013).

In the present study, RSA performance was significantly enhanced in both groups. The RST group significantly improved, reducing their RSA time by 4% and the COM group also experienced a significant improvement in RSA by 2%. Despite this difference increase, there was no statistically significant interaction effect between groups. Although there was no statistically significant interaction effect between groups, there were differences in effect sizes between groups, suggesting the two modes of training could have different magnitudes of effect on the performance of RSA. To the authors knowledge, this is the first study to show enhanced RSA after an intervention involving plyometric training. The RST group improved their RSA to a greater degree compared to the COM group (4% vs. 2%) which was possibly due to specificity of training for inducing positive changes in ion homeostasis and buffering capacity and promoting an oxidative phenotype in skeletal muscle (Bishop et al. 2011).

Further possible mechanisms and adapting factors for improving RSA and tolerance to repeated maximal sprint efforts could be increases in; oxygen delivery to muscle tissue, concentration of aerobic enzymes, mitochondrial size and number, and capillary density can improve maximal aerobic (Iaia et al. 2017; Bishop et al. 2011; Spencer et al. 2004). Additionally, there can be an increased anaerobic capacity, with enhanced phosphocreatine resynthesis, the upregulation of key glycolytic enzymes, increased lactate clearance and inorganic phosphate removal as well as increased muscle buffering capacity (Bishop et al. 2011; Spencer et al. 2004). Iaia et al. (2017) also reported a lower lactate response and an increase in the content of monocarboxylate transporters in response to an 8-week intermittent-sprint training intervention.

The volume of repeated sprints in the RST group was also 50% greater compared to the COM group which add further weight to specificity of training influencing greater improvements in RSA. A further explanation to how both groups enhanced their RSA without significantly improving their 10m and 30m sprint times could possibly be due to neuromuscular factors.

During the RSA test, there is a rapid 180° change of direction after 20m in the same manner that both groups had trained during the intervention. With participants possibly applying more force with a faster contact time during the change of direction contact time. It would be interesting to see if this was in fact the case by using a force plate at the site of change of direction during the RSA test. Furthermore, to change direction efficiently, the acceleration phase and first steps are important (Young et al. 2001; Cronin and Hansen 2005). It would therefore have been beneficial to have included a 5m acceleration sprint time within the testing measures. The absence of such a measure therefore provides a limitation to the study.

To measure SSC performance in this intervention, both CMJ and RSI measures were included. As hypothesised, the RST group did not significantly improve their CMJ. However, the COM group did significantly improve their CMJ by 8% supporting previous research (Saez de Villarreal et al. 2015; Buchheit et al. 2010; Diallo et al. 2001; Michailidis et al. 2013; Rubley et al. 2011). There was no significant interaction effect between groups for the CMJ measure. Regarding RSI, both groups significantly improved, supporting previous research (Lloyd et al. 2012; Ebben et al. 2014). Despite

the RST group performing no plyometric training during the intervention, a significant difference was found, with an improvement of 9%. The COM group also significantly improved their RSI but to a larger degree, with an increase of 21%. There was no statistically significant interaction effect between groups. Despite no statistically significant interaction effect between groups, there differences in effect sizes between the groups suggests that the two modes of training could have different magnitudes of effect on the RSI adaptation. Due to the short-term intervention period of 7 weeks, the enhancement in SSC performance in this study is likely due to neurological adaptations (Foure et al. 2010). The results from this study would support the literature that youth athletes who are between 14-15 years of age and 0.5-1 years' post PHV and can experience an adaptation to plyometric training (Viru et al. 1999; Lloyd and Oliver 2014).

The results from this investigation show that after a short-term 7-week training intervention that by combining repeated sprints and plyometric type exercises reactive strength and fast SSC performance can improve to a greater extent than slower SSC (21% vs. 9%). Both experiment groups also significantly improved their RSI drop jump height performance. The RST group increased by 2%. This is an interesting finding as there was no significant improvement for the RST group for the CMJ measure. The COM group also increased their RSI drop jump height, improving by 5%. Despite a significant increase, the magnitude of change was lower compared to the CMJ height (5% vs. 8%). There was also no statistically significant interaction effect between both experiment groups despite different effect sizes.

The GRF within the drop jump and RSI contact time were also examined during analysis. Despite no statistically significant difference reported the RST group improved their GRF by 10%. The COM group did however significantly improve their GRF by 20% supporting Ebben et al. (2014). The RST group did not significantly reduce their contact time. The COM group did significantly reduce their contact time by 22%. There was no significant interaction effect between groups.

A possible argument for an improved RSI experienced by the RST group could be due to the repeated sprint training programme. The sprints performed were fast SSC type exercises which could explain improved RSI. Another contributing factor could be that there were rapid 180° change of directions after every 10m during the 40m sprint repetitions during the first 3 weeks of training and after every 20m for the remaining 4

weeks of the intervention. To efficiently decelerate an athletes' inertia and rapidly change direction requires application of lateral horizontal force (Goodwin and Cleather 2016). Furthermore, Goodwin and Cleather (2016) state that athletes who have a better ability to aggressively cut and change direction quickly can produce more force on impact at higher speeds with shorter contact times. Additionally, RSI has been shown to have a strong relationship with both change of direction speed and acceleration speed (Young et al. 2015). This is supported by number of other studies that have shown plyometric training programme can also improve biomechanical technique and neuromuscular control during high-impact activities such as cutting and landing (Myer et al. 2005; Myer et al. 2006; Chappell et al. 2008). Therefore, despite not performing any plyometric type of exercise during the intervention, the design of the repeated sprint training drills due to the rapid deceleration could have contributed to enhanced RSI.

It is important for soccer players to develop their reactive strength as it can affect performance in scenarios where there is a limited time to generate force such as jumping and sprinting which require a relatively short eccentric and concentric phase, and an effective transition between the two (Young et al. 1999). A key principle in neuromuscular training is individualisation, whereby the training load is related to an individual's neuromuscular capacity (e.g. determining optimal drop jump height). This can lead to optimised adaptation, however, if the drop height is too low, the neuromuscular system may fail to be overloaded sufficiently (Byrne et al. 2010). In contrast, if the drop height is too high the athlete performing the jump may not be able to control the eccentric and transition phases and will not be able to maintain their reactive strength qualities (Beattie et al. 2017). Consequently, the method of testing for RSI and training intervention prescribed for the drop jumps provides a limitation.

All subjects performed a drop jump from the same height (30cm) when a 20cm height may have been more suitable for some subjects. The range of contact time within the subjects were 0.17s to 0.30s. Beattie et al. (2017) found that RSI can be enhanced with drop jumps at 60cm height compared to 30cm. However, the subjects in that study were collegiate athletes and therefore cannot be compared to the participants in this study. It does none the less indicate it would be wise to determine the optimal drop jump height to measure an athletes true RSI and to assist with the optimisation of a neuromuscular training adaptation. Although all subjects increased the RSI and drop jump height, there

could possibly have been larger improvements if the drop jump height was set to an optimal height for each subject.

Contrasting with previous research (Chaouachi et al. 2014; Chelly et al. 2010; Diallo et al. 2001) there was no significant reduction in 10m and 30m sprint times. This was not expected as previous research has found that combining repeated sprint and acceleration drills with plyometric training enhanced 20m sprint times (Buchheit et al. 2010). Additionally, there is research demonstrating enhanced 10m and 30m sprint times following a plyometric training intervention (Diallo et al. 2001; Michailidis et al. 2013). The findings from this investigation would support Booth and Orr (2016) who state that plyometric training has not been shown to be a better form of training for sprint performance compared to sprint training alone.

There were no significant differences found in either experimental group for the isometric leg press MVC. This was expected as a review by Wilson and Murphy (1996) concluded that the relationship between maximal isometric strength and dynamic performance is questionable and is often not sensitive to training adaptations induced by dynamic activity. However, isometric tests can be included following a dynamic training intervention to measure RFD (Matavulj et al. 2001).

Including both a plyometric training only group and a control group would improve the study's quality. Including a plyometric only training group would show the true impact of plyometric training on RSA in this investigation. Further studies should also investigate training across the entire force-velocity curve and combine free weight training with a variety of intensities in addition to plyometric training in youth athletes. The plyometric training performed in this training intervention only included body weight exercises and was therefore to the right of the force-velocity spectrum. Another method to improve the training programme would be to determine the optimal drop jump height.

8.1 Conclusion

The findings from this study showed that youth soccer players can significantly enhance their RSA by completing both repeated sprint training and a combination of repeated sprints with plyometric training during a short-term 7-week training programme. To the

investigators knowledge, this is the first study to demonstrate that plyometric training can significantly enhance RSA.

Furthermore, the addition of plyometric drills to repeated sprint training can also significantly enhance SSC ability in addition to RSA. RSA was also significantly enhanced despite no improvements in 10m and 30m sprint times. The results also show some interesting findings relating to the adaptation rate of slow and fast SSC.

Furthermore, although the subjects are high level players in Finland and regularly completed 3-5 training sessions a week. In terms of strength and plyometric training history they are untrained. Therefore, the current findings could possibly not have the same impact if conducted with a group of footballers of the same age and maturation with a greater amount of strength or plyometric training history. However, many teams have limited access to strength training facilities or a periodised strength and plyometric training programme.

8.2 Practical Applications

When implementing a short duration pre-season training programme for youth soccer players, it appears to be worthwhile that coaches include a range of fast and slow SSC type activities in addition to repeated sprints and normal soccer specific training. This is likely to induce greater adaptation compared to performing repeated sprints alone. When designing a plyometric training programme, coaches should also establish the correct drop jump height for each athlete. Doing so is likely to optimise SSC adaptation.

8.3 Study strength and weaknesses

This study has both several strength and weaknesses. This investigation provided novel findings in that RSA was shown to improve following a training intervention including plyometric exercises. Additionally, the subjects recruited were high level soccer players with a similar training status to other junior athletes. Therefore, the findings from this

study can be applicable to other populations of youth athletes with the same training and maturation status. Furthermore, the practical applications can be useful to coaches, can be easy to implement and require limited equipment or funds. There is also currently a lack of evidence concerning the optimal plyometric training prescription, especially in youth athletes. The findings from this study can assist with determining the volume, intensity and duration of a training programme that can induce increases in SSC ability in youth athletes.

This study also holds limitations. The major limitation in this study was the absence of a plyometric only training group. This would have demonstrated the true impact of plyometric training on RSA within this group of youth athletes. A control group would also have been beneficial but this was not possible due to a small sample size and unfavourable to the club recruited.

Although the subjects recruited were high level, their strength training status was low and such a training intervention may not provide an adequate stimulus to youth athletes with a greater strength training status. Furthermore, there were only 20 subjects recruited and the sample size is therefore low. This could also possibly have affected the statistical power of some of the results.

There are also several weaknesses in the methodology of testing and training intervention. Additional measures including; rate of force development, unilateral reactive strength and countermovement jumps would have increased the quality of the study. Especially, as a large proportion of the plyometric exercises performed during the intervention were unilateral. However, due to pre and post testing time constraints these additional measures were not feasible.

Additional measures to improve the quality of the study would be to include a force plate at the site of the change of direction in the RSA test. As stated previously, the method of testing RSI could have been improved. With individual drop jump height determined and a more individualised training programme for each participant. However, this would have been difficult to implement, especially in a team sport environment. Furthermore, direct measurement of $\text{VO}_{2\text{max}}$ and blood lactate testing during the RSA would improve the quality of the study.

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