Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Medicine and Health Sciences
Department of Neuromedicine and Movement Science

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Relationships Between Maximal Back half-squat- and Hip-thrust strength, and Acceleration quality, Sprint time, Jump height, and Change of direction-speed in male youth soccer players

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Supervisor: Ulrik Wisløff
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Abstract

Background: Goals scored in soccer is accompanied by at least one powerful action (acceleration- sprint- jumps- and change of direction performance) of either the assisting or the scoring player. Maximal strength training (MST) using heavy loads with few repetitions is considered an effective method for improving these skillsets. The ergogenic ability of the back half-squat (BHS) exercise in soccer players is well established. Recently, prominent findings for the hip-thrust (HT) exercise upon powerful actions have been observed in amateur female soccer- and male rugby players. **Purpose:** We compared the effect of a 9-weeks MST program using the back half-squat (BHS) and hip-thrust (HT) exercise upon powerful actions in male youth soccer players.

Method: Twenty-three male youth soccer players (15.3 ± 1.3 yr, 65.7 ± 11.3 kg, 177.4 ± 10.3 cm) volunteered to participate in a randomized control trial. Players were randomized to either a HT- (n = 11) or a BHS group (n = 12). Another age-matched male youth team, playing in the same league was used as a control group (CG) (n = 12). All players were tested for 0-5 m, 0-10 m, 0-20 m, 0-30 m, and 0-40 m sprint, countermovement jump (CMJ), change of direction-speed (COD-speed), and one repetition maximum (1RM) in their respective regime (BHS or HT). Strength training with maximum loads using four series of four repetitions was performed concurrently two times per week for 9-weeks from pre- to post-testing. **COVID-19:** COVID-19 pandemic breakout March 12th in Norway forced us to cancel post-testing. Therefore, the present study presents the relationship between 1RM and powerful action at baseline.

Results: 1RM (kg · kg bw$^{-0.67}$) in BHS was stronger correlated with all powerful actions than that observed with HT. On average, we observed 32% stronger correlation between 1RM BHS (kg · kg bw$^{-0.67}$) and sprint performance compared to HT ($r = 0.87$, $p = 0.009$ vs $r = 0.59$, $p = 0.067$). Both 1RM (kg · kg bw$^{-0.67}$) in BHS and HT correlated significantly with CMJ and COD-speed.

Conclusion: 1RM scaled to body mass in BHS is a stronger determinant than HT for performance in powerful actions in male youth soccer players.

Keywords: Powerful actions, hip-thrust, back half-squat, acceleration, sprint, one repetition maximum

Acknowledgment

I want to thank Professor Ulrik Wisløff for supervising the present study, which is much appreciated. His expertise and advice in the field of exercise physiology, training, testing, and academic writing helped to lay the foundation of this study. I would also thank Vetle Veierød, a fellow student and co-worker in this project, who have contributed to a great deal of work during the period of testing and training to make it possible to complete the study. Vetle's ability to solve problems and to discuss issues that have arisen during this period has been invaluable and made this study time a great experience. I would also like to express my gratitude to Stein Olaf Olsen, Espen Alexander Eriksen, Thea Hirth, and Jan Magnus Brattebo, fellow students in our faculty, for helping us make it possible to carry out this project to its potential. Finally, thanks to all the subjects who have put a lot of their time and effort into this project.

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Abbreviations

1RM: One repetition maximum

1RM (kg · kg $bw^{-0.67}$): One repetition maximum, L:1, L^2:1, L^3:1, bw raised to the power of 0.67

1RM (kg): one repetition maximum absolute value

BHS: Back half-squat

bw: Bodyweight

CG: Control group

CMJ: Countermovement jump

COD: Change of direction

COD-speed: Change of direction-speed

CON: Conventional strength training

HJ: Horizontal jump

HT: Hip-thrust

Kg-0.67: Kilogram bodyweight raised to the power of 0.67 (kg · kg $bw^{-0.67}$).

L:1: Muscle ratio of the arms and legs

L^2:1: Cross-section area

L^3:1: Volume Ratio

m: Meter

$m \cdot s^{-1}$: Meter per second

$m \cdot s^{-2}$: Meter per second squared

n = Number of participants

MIV: Maximal intentional velocity

MST: Maximal strength training

p-value: Statistical significance value

PT: Power training

r value: Pearson Correlation Coefficient

RFD: Rate of force development

RGC: Running gait cycle

s: Seconds

SSC: Stretch shortening cycle

Introduction

Key actions related to game-decisive moments in soccer includes *powerful actions* of maximum neuromuscular activity such as acceleration, sprints, jumps, and change of directions (COD) (Stolen et al, 2005; Bravo et al, 2008; Di Salvo et al, 2010; Helgerud et al, 2011; Barnes et al, 2014; Silva, 2019). In the last decades, elite soccer players are experiencing a substantial increase in powerful actions during match play (Di Salvo et al, 2009; Barnes et al, 2014; Chmura et al, 2018; Silva, 2019). Between 2006 and 2013, the English Premier League players increased the number of powerful actions ($p < 0.001$) during a game, while the total distance covered did not change (Barnes et al., 2014). The frequency of sprints increased by ~85% (31 ± 14 to 57 ± 20 number of sprints) ($p < 0.001$), and absolute total sprint distance by ~35% (232 ± 114 to 350 ± 139 m) ($p < 0.001$) per game. Faude *et al.* (2012) observed that 83% of goals scored is accompanied by at least one powerful action of either the assisting or the scoring player, and that straight sprinting is the most dominant powerful action prior to scoring. A sprint is commonly divided into two predominant phases; 1) acceleration phase and 2) sprint phase (Morin et al, 2015; Howard et al, 2018). Acceleration is defined as the rate of change in velocity (defined as >2 $m \cdot s^{-2}$), which demands a player to reach maximum velocity in the shortest amount of time (Little et al, 2005; Ingebrigtsen et al, 2015). Sprints during soccer matches are usually defined as running > 2 seconds at speed > 25.2 $km \cdot h^{-1}$ (Helgerud et al, 2001; Impellizerri et al, 2006; Little et al, 2005; Rampinini et al, 2007; Di Salvo et al, 2007; Bradley et al, 2009; Di Salvo et al, 2010; Chmura et al, 2018). Elite players need to sprint a total distance ranging from 152 to 446 m (Di Salvo et al, 2007; Bradley et al, 2009; Bradley et al, 2010; Barnes et al, 2014; Chmura et al, 2018). These sprints are distributed between 8-35 sprints per game, depending on the level of play, fitness level and playing position (Di Salvo et al, 2007; Bloomfield et al, 2007; Di Salvo et al, 2009; Bradley et al, 2009; Bradley et al, 2010; Di Salvo et al, 2010; Varley & Aughey, 2013; Varley et al, 2018). Sprints regularly reach distances up to 30 m (Stolen et al, 2005), although specific playing positions such as wide defenders, wide wingers, and attackers may need to perform sprints greater than 30 m. These positions require the highest sprinting demand, usually reaching sprint distances over 20 m (Di Salvo et al, 2007). This is probably because the tactical roles are highly relevant for performing sprints in both defensive and offensive phases, especially counterattacks (Di Salvo et al, 2010; Andrzejewski et al, 2015).

Stolen *et al.* (2005) states that 50% of all sprints are less than 10 m during soccer matches. This distance is referred to as the acceleration phase (Little, et al, 2005; Ingebrigtsen et al, 2015). Elite male Norwegian players need to execute ~91 accelerations each game (Ingebrigtsen et al, 2015; Dalen et al, 2019). However, during a competitive season, it seems that the frequency of acceleration decreases (Dalen et al, 2019), while total distances tend to be unaffected (Rampinini et al, 2007). These observations could occur due to a tactical training approach to be more prepared for the upcoming opponent. This leads to lower training intensity in the competitive season compared to pre-season training, which makes it challenging to maintain the players' physical level throughout the season, leading to more accumulating fatigue (Malone et al, 2014; Babtista et al, 2019).

Over the last decade, the average sprint distance has increased. These findings combined with the above-mentioned observations, suggest that the frequency of powerful actions rather than total distance covered in matches, have a more substantial impact on physical performance in a soccer match (Barnes et al, 2015; Ingebrigtsen et al, 2015; Dalen et al, 2019). Therefore, to be successful in game-decisive moments, players need to produce more powerful neuromuscular activity than the opponent and maintain a high frequency of acceleration and sprint (Chelly et al, 2009; Dalen et al, 2019). Because of these physical demands, it is essential to find an optimal training modality to enhance powerful actions on soccer players. Strength training in the lower limb has proved to be efficient for improving these skillsets (Seitz et al, 2014).

Physiological determinations of powerful actions

Maximal strength and rate of force development in the lower limb

A player's capacity in terms of powerful actions of maximum neuromuscular activity seems to be determined by the individual's maximum strength and power potential in the lower limb (Ronnestad et al, 2008; Keiner et al, 2014; Silva, 2019). Maximal strength represents the highest force elicited by the neuromuscular system, regardless of time, in a maximum voluntary contraction (one repetition maximum (1RM)) (Hoff & Helgerud, 2004; Stolen et al, 2005). Power could be defined as the rate of force development (RFD) and is a measure of how fast an athlete can develop maximum force after a voluntary contraction (Aagaard et al, 2002; Hoff & Helgerud, 2004; Stolen et al, 2005; McLellan et al, 2011; Maffiuletti et al, 2016). Soccer play is highly dependent upon acceleration, thereby Newton's second law of motion (Force = mass · acceleration). That is, for a given mass of a player's bodyweight, the acceleration is proportional to force magnitude (Helgerud et al, 2011). Thus, an increase in 1RM and RFD in the given muscle, without a change in bodyweight, could improve powerful actions.

Effect of maximal- conventional- and explosive plyometric strength training on 1RM and RFD

There is a fundamental relationship between maximal strength and power, which means that soccer players need to be relatively strong to possess a high level of power (Cormie et al, 2011). For improving 1RM and RFD, a wide variety of strength training protocols have been used. Prominent results are found in strength training interventions ranging from maximal strength training (MST) with high loads (85-90% of 1RM), conventional strength training (CON) with moderate loads (70% of 1RM) and power training (PT) with low loads (0-30% of 1RM). Eight weeks of MST two times per week in lower limbs was shown to improve 1RM and RFD by 15% ($p = 0.002$) and 73% ($p = 0.044$) more than CON in untrained and moderately trained men (Heggelund et al, 2013). Further, ten weeks of MST three times per week was demonstrated to increase 1RM 18% ($p = 0.05$) more than PT in moderately trained men (Cormie et al, 2010). However, both groups enhanced their RFD to the same extent ($p = 0.05$). In male elite soccer players, MST plus PT group did not increase 1RM nor sprint performance more than the MST group alone (Ronnestad et al. 2008). Based on these findings, it seems that PT influences RFD, but not 1RM, to the same degree as MST. Thus, MST is more efficient for altering both the 1RM and RFD. Therefore, strength training programs with the purpose of enhancing 1RM and RFD should involve MST (Bird et al, 2005; Cormie et al, 2011; Heggelund et al, 2013). MST is performed with high-intensity loads (85 – 90% of 1RM), < 5 repetitions, 3 - 5 sets, and 3 min recovery between sets (Storen et al, 2008; Ronnestad et al, 2011; Heggelund et al, 2013). In contrast, CON consists of 8-12 repetitions and an intentional slow execution, which leads to more significant muscle hypertrophy and lower recruitment of high threshold motor units than MST (Wang et al, 2017). Behm & Sale (1993) suggest that it is intentional velocity rather than the actual velocity that is important for improving RFD. Thus, soccer players should focus on maximal intentional mobilization (MIV) in the concentric phase (Helgerud et al, 2011). This protocol is to ensure optimal neural adaptations and to stress all motor units, especially the high threshold motor units, to achieve maximal muscle activation (Behm, 1995). These neural adaptations occur due to enhanced neural drive to the muscles, which leads to an improved magnitude of efferent motor output, thus augmented motoneuron recruitment (Aagaard et al, 2010; Toien et al, 2018).

Biomechanical determinations of sprint performance

To ensure optimal strength training programs, it is crucial to know which muscles are the most vital for improving acceleration and sprint abilities in soccer players (Chelly et al, 2009; Silva et al, 2015; Suchomel et al, 2016). This can be assessed through the running gait cycle (RGC) (Figure 1). First, the knee-extension musculature (e.g. vastus lateralis and rectus femoris) and hip-extension musculature (e.g. gluteus maximus and hamstrings (e.g. biceps femoris)) are prime movers in sprinting (Howard et al, 2018). Secondly, the activation and interplay between these muscles alter throughout the acceleration- and the sprint phase (Figure 2) (Morin et al, 2015). The change in step frequency and length may affect this interplay. Also, the difference in orientation of truncus during these phases (i.e., forward-leaning in the acceleration phase, upright posture in the sprint phase (Nagahara et al, 2018)) regulates the relationship between the effectiveness of vertical and horizontal force production (Loturco et al, 2018). Further,

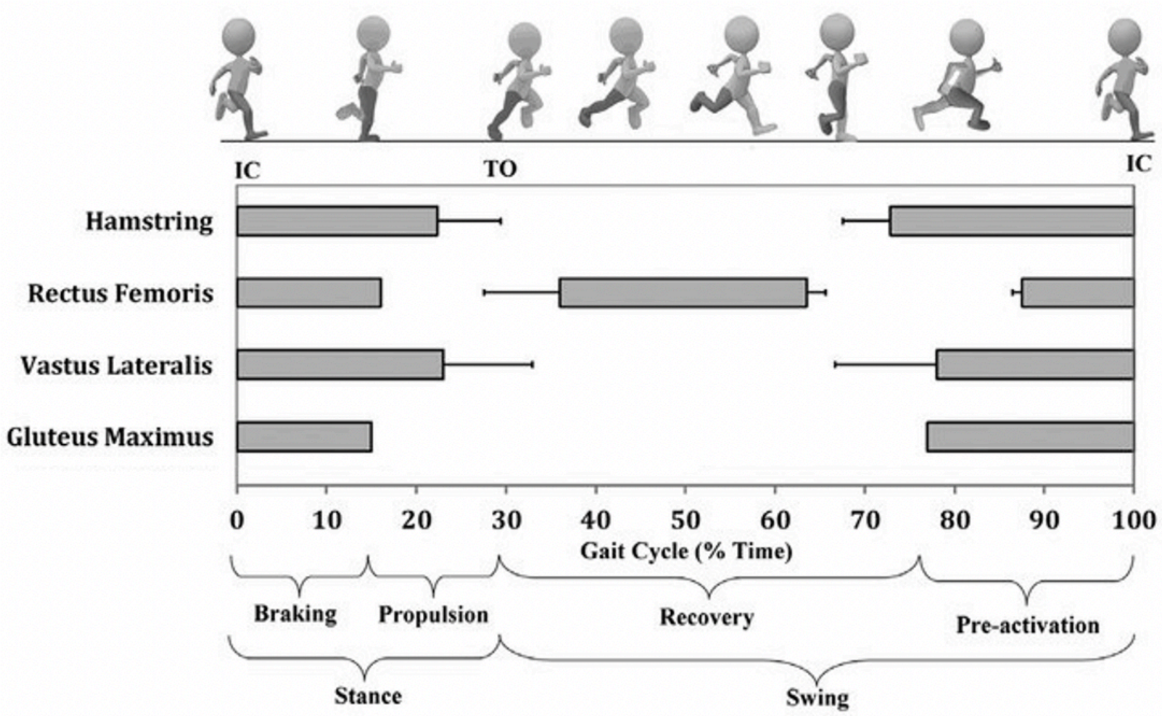

Figure 1 | IC, initial contact; TO, toe off. Demonstrating the muscle activation timings of the sprint specific lower limbs muscles across the running gait cycle as a percentage of time. Grey areas represent time and phase were muscle activation is present. The error bars represent the standard deviation of the mean onset and time in the termination phase. Adapted figure from Howard *et al.* (2018). Results were gathered from, Mero and Komi (1987), Novacheck (1998), Pinniger *et al.* (2000), Kuitunen *et al.* (2002), Kyröläinen *et al.* (2005), Thelen *et al.* (2005), Chumanov *et al.* (2007), Higashihara *et al.* (2010), and Yu *et al.* (2008).

these muscle groups are continuously active in sprinting to generate high ground reaction force (GRF). Enhanced GRF is measured through the stretch-shortening cycle (SSC) at ground contact (stance phase) at maximum sprint speed (Komi, 1986). This is usually achieved after 20 m (Morin et al, 2015). Research has proven a significant relationship between maximum GRF and maximal sprint performance (r = 0.78) (Hunter et al, 2005; Morin et al, 2015). To produce high GRF, there needs to be a rapid transfer of elastic energy from the eccentric- (pre-activation phase at TO) to the concentric (breaking phase at IC) phase (Nagahara et al, 2018). As the sprint speed increases, there is less time to generate maximal force when the foot hits the ground. Therefore, it is paramount that these muscles generate as much force as possible in the shortest amount of time (i.e., measured as RFD). Consequently, it is essential to find a strength exercise that targets these muscles effectively in a vertical- and horizontal sprint specific way.

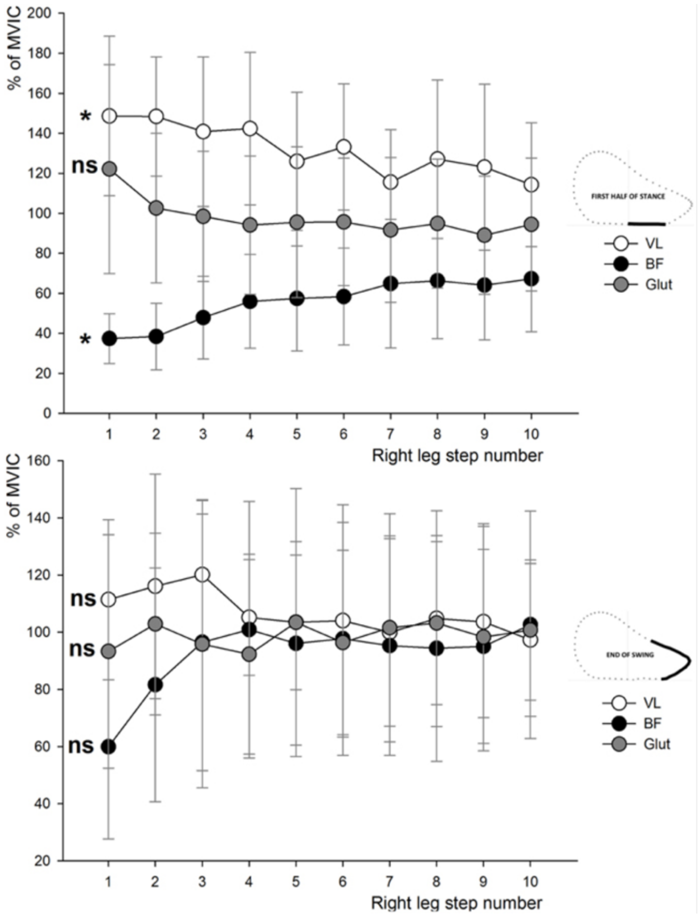

Figure 2 | Average EMG activity (±SD) (%MVIC) of the vastus lateralis (VL), biceps femoris (BF), and gluteus maximus (GM) during the first half of the stance (ground contact) and the end-of-swing phase (before the foot hits the ground) for all the right leg moves during the 10 first step in acceleration phase. Retrieved from Morin et al.

Back half-squat

Research have demonstrated a strong correlation between 1RM in BHS and sprint performance; first step ($m \cdot s^{-1}$) (r = 0.58, p = 0.01), 5 m (r = 0.60, p < 0.001), 10 m (r = 0.94, p < 0.001) and 30 m sprint time (r = 0.71, p = 0.01), countermovement jump (CMJ) (r = 0.78, p = 0.02) and COD-speed (r = 0.68, p = 0.02) in male junior and adult elite soccer players (Wisloff et al, 2004; Chelly et al, 2010, Comfort et al, 2013). These findings are the main reasons why the BHS has been the most investigated and commonly used exercise in strength programs in soccer players (Silva, 2015). However, no significant correlation between changes in 1RM and power-related measurements in soccer players after conducting MST interventions has been reported (Ronnestad et al, 2008). The BHS is a vertically loaded exercise performed to a 90° knee angel, which effectively targets the knee-extension muscles (e.g. vastus lateralis, rectus femoris) (Figure 3) (Schoenfeld, 2010; Garcia et al, 2019). The knee-extension musculature is paramount in sprinting, especially the acceleration phase (first 10 steps) during both the stance- and swing phase in the RGC (Figures 1 & 2) (Morin et al, 2015; Howard et al, 2018). Since it is crucial to produce high vertical force in the acceleration phase, due to the forward-leaning posture (Nagahara et al, 2018), the BHS is a relevant exercise for improving this phase. Therefore, the primary goal for the BHS exercise is to increase strength in these muscles and concomitantly improve powerful actions in soccer players (Hoff & Helgerud, 2004; Brughelli et al, 2008; Contreras et al, 2017).

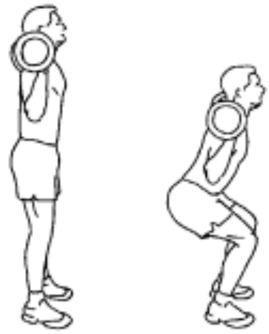

Figure 3 | Illustration of the BHS exercise. (1) Start posture (left picture), (2) feet position around shoulder width, go down eccentrically to (3) a 90° angle stop (right picture), (4) go up using maximal concentric movement until reaching start posture.

Hip-thrust

As of today, no significant correlation has been reported between 1RM in hip-thrust (HT) and powerful actions. HT is a horizontally loaded hip-extension exercise that effectively activates both gluteus maximus and biceps femoris (Figure 4) (Garcia et al, 2019). The gluteus maximus and biceps femoris are less activated in the acceleration phase (first 10 steps) and the braking and pre-activation in the RGC compared to vastus lateralis (Figure 1) (Morin et al, 2015) (Dorn et al, 2012; Bartlett et al, 2014). However, these muscles tend to be equally activated in the sprint phase (e.g. > 20 m). Also, it is crucial to generate high horizontal force in the sprint phase due to the influence of hip-extensors and upright posture (Beardsley & Contreras, 2014; Nagahara et al, 2018). Thus, HT may be a more specific exercise for improving this phase, compared to BHS.

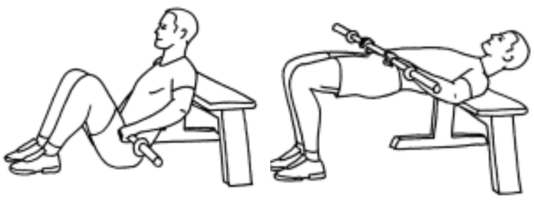

Figure 4 | Illustration of the HT exercise. (1) Start posture (left picture), feet around shoulder width, (2) perform a hip extension activating gluteus maximum until the hip is horizontally in line with upper body and quadriceps (right picture), (3) eccentrically move down to start posture.

The HT exercise has recently received considerable attention after Contreras and his colleagues (2015) demonstrated significantly greater mean and peak electromyographic (EMG) activity of the gluteus maximus ($p = 0.004$, $p = 0.038$) and biceps femoris ($p = 0.004$, $p = 0.004$) compared to BHS for the same relative load (10RM). Also, the BHS failed to elicit significantly greater mean and peak EMG activity of vastus lateralis ($p = 0.531$, $p = 0.400$). However, this study did not compare the beneficial effects between the HT- and BHS exercise upon powerful action.

Back half-squat- and Hip-thrust induced adaptations on sprint performance

Several studies have reported BHS training in the format of MST and MIV to improve the acceleration phase and sprint phase in male junior and adult elite soccer players (Ronnestad et al, 2008; Chelly et al, 2009; Helgerud et al, 2011; Ronnestad et al, 2011). Acceleration is usually measured in a 10 m- and 20 m sprint, while the sprint phase is measured in a 30 m- or 40 m sprint. Helgerud *et al.* (2011) trained BHS two times per week for eight weeks to demonstrate a 3.2% improvement in 10 m- ($p < 0.001$) and 20 m sprint ($p = 0.01$) in male elite soccer players. One limitation was that the study could not implement any control group (CG), mainly because a team at that level would not risk half of the players improving distinctively to the other half. Therefore, it is difficult to conclude whether the improvements were caused by seasonal changes in the soccer training, or by the strength training per se. Similarly, with no CG, Ronnestad *et al.* (2011) performed two BHS sessions each week for ten weeks and managed to improve 40 m sprint by 1.8% ($p = 0.05$) in male professional soccer players. Further, Ronnestad *et al.* (2008) got a 1.7% ($p = 0.02$) and 0.8% ($p = 0.02$) change in 10- and 40 m sprint within the group after seven weeks of BHS. However, there was no significant change compared to CG. Finally, Chelly *et al.* (2009) performed BHS with two sessions each week for eight weeks. They increased their running speed ($m \cdot s^{-1}$) in the first- and first five steps (22% and 7%, $p = 0.05$) and max velocity (12%, $p = 0.01$) through 40 m sprint in male junior elite soccer players. These changes were significantly greater compared to CG.

Regarding the HT, prominent findings in powerful actions have been reported. Contreras *et al.* (2017) demonstrated 1.05% and 1.7% improvement in 10- and 20 m sprint on male youth rugby players after six weeks of HT two times per week. Further, Garcia *et al.* (2019) performed HT two times per week for seven weeks. They improved 10- and 20 m sprint by 1.52% and 2.6%

on female amateur soccer players. Further, Contreras *et al.* (2017) compared the HT group with a front squat (FS) group, which have similar muscle activation at maximal weight as BHS (Gullet et al, 2008). This group improved their 10 m sprint by 0.66 %, with no change in 20 m sprint. Garcia *et al.* (2019) compared the HT group with a BHS group and a CG. Surprisingly, the BHS group decreased their 10 m sprint time by 1.52% with no change in 20 m sprint. In contrast, the CG increased their 10- and 20 m sprint with 2.5% and 1.19%, respectively. These findings may also announce the limitations of this study. In addition, these two studies where performed with CON first four weeks and MST in the remaining 2 – 3 weeks. This protocol may decrement the beneficial effects in sprint performance, mainly because CON do not influence 1RM and RFD at the same level as MST. This means that these subjects had less overall training stimuli in the format of MST and MIV compared to the BHS studies. Another reason is probably because of the low numbers of subjects participating in Garcia *et al.* 2019 (n = 17). Thus, a higher potential risk for outliers influencing the results.

Jumping

Elite soccer players perform 12-26 jumps per game, depending on playing position, whereas 4.6-9.9% of these jumps are directly related to scoring a goal (Faude et al, 2012; Nedelec et al, 2014). Jumping performance is often measured through countermovement jump (CMJ) (Silva et al, 2015). CMJ represent the highest jump a player can utilize with a maximum voluntary effort from a standing position, performed on a force plate (FP 4; HUR Labs Oy) (Ronnestad et al, 2011) or a contact mat (ErgojumpP apparatus) (Chelly et al, 2009).

Back half-squat- and hip-thrust induced adaptations on jumping performance

Since the BHS is a vertically loaded exercise, the movement is specially designed for performing a CMJ. At the same time, the HT is a horizontal specific exercise and is more relevant for improving horizontal jumps (HJ). Therefore, horizontal specific exercises are supposed to enhance horizontal movement more than vertical exercise and vice versa. Recent research contradicts this principle. First, the BHS group in Ronnestad *et al.* (2008) improved four consecutively max HJ by 4% ($p = 0.01$), with no change in CG in male elite soccer players. Also, there was no significant change in CMJ compared to CG. Second, Garcia *et al.* (2019) increased CMJ by 9.9% in the HT group and 10.4% in the BHS group in female amateur soccer players. Thirdly, Fitzpatrick *et al.* (2019) performed 14 weeks of HT training resulting in 6% ($p = 0.004$) increase in both the CMJ and HJ in female colligate athletes (Fitzpatrick et al, 2019). In contrast, Contreras *et al.* (2017) increased CMJ and HJ by 3.42% and 2.38% in the HT group, while the FS group improved 7.3% and 1.71%, respectively. There was no significant change within or between groups. These contradicting findings of movement specificity of the exercise may have a logical explanation; The knee-extensors are highly active at the start of the jump, while the hip-extensors are more active at the end (Garcia et al, 2019). This movement is present in both vertical- and horizontal jumps. Hence, it should be questioned the reliability of the exercise specificity principle in terms of improving jumping performance in different athletes. It may seem that the HT- and BHS exercise may be as equal efficient for improving vertical- and horizontal jumps in soccer players.

Change of direction-speed

A potentially underexamined determinant regarding physical match performance in soccer is COD (Keiner et al, 2014). Mainly because acceleration and sprints are often combined with COD and that players perform approximately 1.100 COD during a soccer match (Bangsbo et al, 2006; Andrzejewski et al, 2015). COD-speed in this thesis is referred to as the speed and efficiency of the COD. COD-speed can be defined as the ability to dynamically 1) reduce the tempo, 2) change movement direction, and 3) start accelerating and sprinting again (Jones et al, 2008). However, this skillset is rarely measured when conducting strength training interventions in soccer players (Sheppard & Young, 2006), probably due to a lack of standardization in the COD-speed tests.

Back half-squat and hip-thrust-induced adaptations on COD-speed

To date, Wisloff *et al.* (2004) is the only study to show a significant correlation between 1RM in BHS and COD-speed in male elite soccer players using a shuttle running test ($r = 0.68$, $p = 0.02$). Despite this strong relationship, other research has failed to document a significant-change and correlation between COD-speed and maximal strength in lower-limb, especially after MST interventions (Young et al, 2002; Brughelli et al, 2008; Jones et al, 2009; Chaouachi et al, 2012). However, it seems that it is mainly eccentric hamstring strength that generates force when the players reduce tempo after sprints and start accelerating again (Chaouachi et al. 2012). This means that BHS may not by adequately relevant due to the lower influence on hamstrings (Contreras et al, 2015). Since HT exercise targets the hamstrings (e.g. biceps femoris) significantly more than the BHS exercise (Contreras et al, 2015), HT could increase COD-speed more than BHS. For example, Garcia *et al.* (2019) demonstrated a tendency of greater improvement in COD-speed in a shuttle running t-test for the HT group compared to the BHS group. Another suggestion is that COD-speed is influenced by body composition, and soccer players should decrease their body fat to more rapidly change direction (Chaouachi et al, 2012). An increase in strength per kg bodyweight, which is related to Newton's second law of motion, could explain some of the significant correlations found between 1RM in BHS and COD-speed. Even so, the current gained information regarding COD-speed seems to mainly depend on the specificity of COD movement in soccer matches (Chaouachi et al, 2012). Based on current studies, it appears that COD-speed depends more on the eccentric strength and training specificity of COD movements rather than maximal muscle strength in lower limbs (Young et al, 2002; Brughelli et al, 2008; Jones et al, 2008). Therefore, research should try to develop drills that replicate the most pertinent COD angles during matches (Stolen et al, 2005). However, there is a fundamental factor missing to see improvement in COD-speed after strength training, which seems to be the standardization and specificity of the COD-speed test. This means that instead of duplicate COD-tests from other studies, researchers tend to develop their own COD tracks to see a possible beneficial improvement in soccer player's COD-speed.

Back half-squat vs. Hip-thrust

As reviewed above, few studies have compared the effect of the HT- and BHS exercise on 5 m, 10 m, 20 m, 30 m, 40 m sprint, and the findings seem to be equivocal. There are currently no existing strength training interventions comparing HT and BHS in the format of MST and MIV in male youth soccer players.

Aim and hypothesis

This study aimed to implement a 9-weeks MST program during the pre-season period to study if male youth soccer players achieved different beneficial adaptations between the HT exercise and BHS exercise in powerful actions. We hypothesized that; 1) HT will have more effect upon the later sprint phases than BHS (i.e. after 10 m), 2) BHS will have more effect in the acceleration phase compared to HT (i.e. up to 10 m), 3) HT and BHS will have a similar magnitude of improvement in jumping performance, and that 4) HT will have more effect on COD-speed performance than BHS.

Therefore, the purpose was to see if the BHS group had more significant improvement in the acceleration phase compared to the HT group and if the HT group improved more in the sprint phase compared to the BHS group.

COVID-19

Because of the COVID-19 pandemic break out in Norway one week before the post-test, we were not able to conduct any of the post-tests. Instead we hypothesized that; 1) 1RM in HT will demonstrate s stronger correlation with the later sprint phases compared to 1RM in BHS (i.e. after 10 m), 2) 1RM in BHS will demonstrate stronger correlation in the acceleration phase compared to 1RM in HT (i.e. up to 10 m), 3) 1RM in HT and BHS will demonstrate similar correlation in jumping performance, and that 4) 1RM in HT will show a stronger correlation with COD-speed performance compared to 1RM in BHS. Therefore, the present thesis presents the relation between maximal strength and powerful actions at baseline.

Method

Experimental Approach to the Problem

This study was designed to investigate one main question: Is there a difference between maximal strength in back half-squat (BHS) and hip-thrust (HT) in relation to acceleration quality, sprint speed, jump height, and COD-speed performance? For investigations, a male youth Norwegian soccer team from a 1stDivision Team was chosen and randomly divided into either a BHS group or HT group. A male youth soccer team in the same league was used as a control group (CG). Because of the COVID-19 pandemic breakout, the data obtained from CG (n = 12) could not be analysed in this study. All players had no previous lifting experience and were instructed to avoid any additional strength training outside of the experimental protocol. Changes in maximal strength and powerful actions were tested before the 9-week intervention. Post-testing could not be conducted due to COVID-19 pandemic breakout 1-week prior to post-test. This study took place at the beginning of the players' pre-season preparations, where they conducted three soccer sessions each week. These sessions lasted about 1.5 hours, involving 60 min of various technical and tactical drills, and 30 min of continuous play.

Subjects

Nineteen Norwegian male youth soccer players (15.3 ± 1.3 yr, 65.72 ± 11.29 kg, 177.4 ± 10.25 cm) volunteered to participate in this study (BHS n = 8, HT n = 11) (Table 1). Group BHS (n

= 8) performed the back half-squat exercise, while group HT (n = 11) used the barbell hip-thrust exercise. Coaches were informed about the study design and written informed consent was signed and confirmed from all subjects and their legal guardians.

Table 1 Player`s physical characteristics at baseline

Groups	Age (year)	Weight (kg)	Height (cm)
HT (n = 11)	15.5 ± 1.2	68.55 ± 10.78	178.1 ± 9.7
BHS (n = 8)	15.0 ± 1.4	62.90 ± 11.80	176.7 ± 10.8

Data are presented as mean ± standard deviation (SD). BHS, back half-squat; HT, hip-thrust; BHS, back half-squat

Testing and Training Procedures

Both training groups completed three familiarization sessions (4 x 12 RM) to ensure optimal technic and safety of all subjects, thus be prepared for the 1RM test. All tests were conducted over two days separated by 48 h of rest. Sprint measurements were performed indoors at artificial grass suited for soccer play (Flatåsen Hall, Trondheim). The 1RM and CMJ tests were performed in an athletics hall (Ranheim, Trondheim). Individuals were asked to abstain from physical activity 24 h before testing and avoid caffeinated supplements at test days. Players were instructed to use artificial soccer shoes, training t-shirt and shorts for the sprint measurements, and futsal shoes for the maximal strength and jumping assessments.

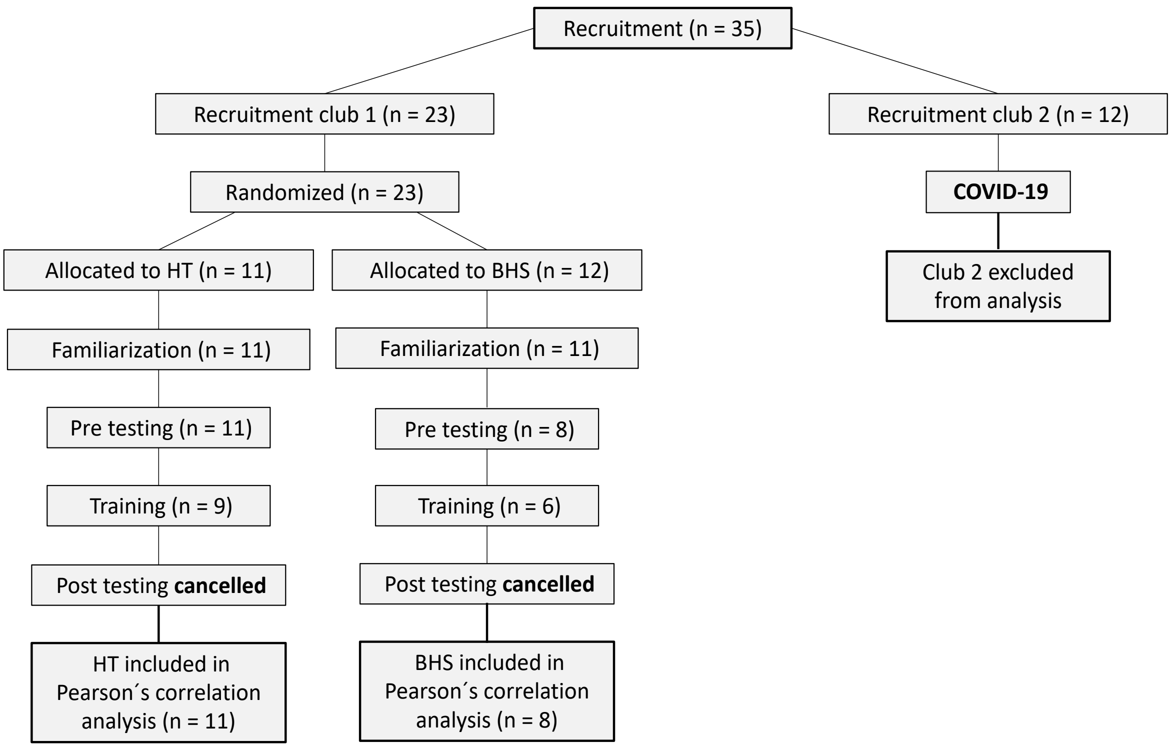

Figure 5 | Flow diagram of the study design. HT, hip-thrust; BHS, back half-squat

Test day 1

40 m straight-line sprint test

After conducting a 20 min thorough warm-up, involving a steady progression in effort from 0 -100% in general and explosive sprint specific assignment, the 40 m sprint test was performed. Time was recorded by photocells (Bower Timing systems) placed at 5 m, 10 m, 20 m, 30 m, and 40 m to investigate acceleration- and sprint phase. Each subject ran three sprint trials, separated by > 3 min rest, to ensure full recovery. Players started from a static from a "ready-set-go" signal and were informed to perform the sprint with maximal effort. The time recorded started when the subject intercepted the first photocell beam, placed at 0 m (30 cm in front of the foot). The best results for each split time independent of the trial were analysed. The magnitude of pre- post-test validity for 10 m sprinting has been reported as 0.02 s (< 1%) (Duthie et al, 2006).

Change of direction-speed test

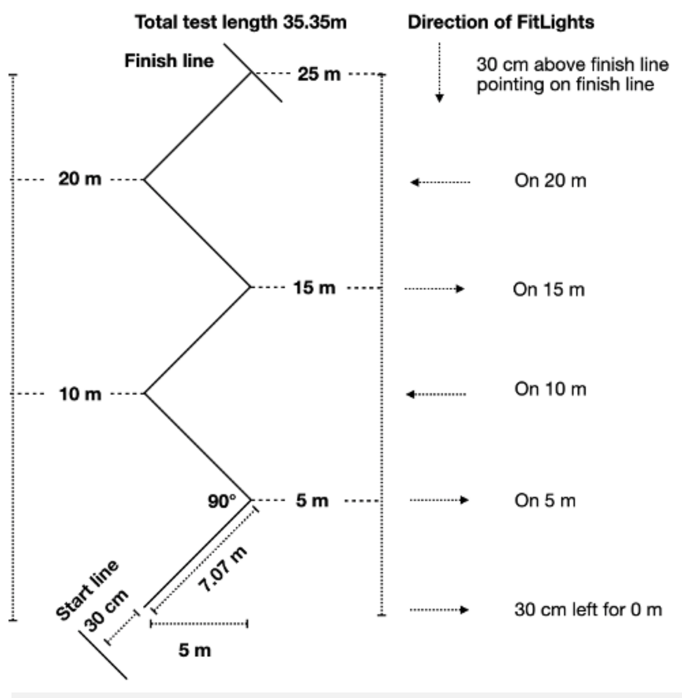

Figure 6 | Illustration of the change of direction-speed test

After performing the 40 m sprint test, subjects had 10 min active recovery before commencing the COD-speed test. The COD-speed test consists of six cones involving four COD angles of 90°, with 7.07 m between each cone with a total length of 35.35 m (see Figure 6). These angels were used because 84% of turn in FA Premier League soccer match is performed up to 90°, while 16% occur > 90° (Bloomfield et al, 2007). Time was recorded by Fit Light reflex lacers (Trainer, Sport corp. Ontario, Canada) placed on each cone 1 m above the ground. The same starting protocol as in the 40 m sprint test was used. Time started to record when the player intercepted the first lacer. Subjects ran three trials with > 3 min recovery. The best time at the last cone (25 m) was collected for statistical analysis.

Test day 2

Countermovement jump (CMJ)

After 48 h of rest, test day 2 was conducted. CMJ was performed before the 1RM test to avoid post-activation potential (Lacano & Setiz, 2018). The subjects started with a ten min warm-up, running on a track field followed by a five-minute inductive jumping warm-up. Jumping height was measured using a contact mat (Fusion Sport, SmartJump Australia). Players were instructed to place their hands on their hips during each attempt. Players had two min recovery between each jump. The best jump of three attempts was taken for statistical analysis. The repeatability of the CMJ has been calculated with a coefficient of variation of 1.6% (Coffey et al. 2009)

One repetition maximum (1RM)

After five min of rest, maximal strength in the lower limb was measured as 1RM in the BHS and HT group. BHS was performed to a 90° joint angle in the knee while the HT was performed with approximately the same angels (see Figure 3 & 4). The same movement was used in the training procedure. Before the 1RM test, subjects performed a standardized specific warm-up, starting with 10 repetitions at 50% of estimated 1RM, 5 reps at 60%, 3 reps with 70%, and 2 reps at 80%. The first 1RM attempt was performed with a load of roughly 5% below the estimated 1RM. After each successful lift, the weight was increased by 5 kg until the maximal level and/or failure were achieved. Each attempt was followed by a 3-5 min rest period to ensure optimal recovery. They performed 3-5 maximal lifts, were the highest successful lift was recorded.

Training procedure

Strength training was performed before or after soccer practice. The two training groups conducted the MST regime with MIV twice a week for 9-weeks for a total of 18 sessions. Players were given a minimum of 48 h rest between sessions. During the training period, subjects used an initial load corresponding to 85% of the 1RM pretest level. When two successful sets with the optimal technique were mastered, a load of 5 kg was added. After 9-week of training, players were given a 1-week break before performing the post-test. The minimum number of sessions to complete the intervention was set as one completing 85% (15/18 sessions) of the training.

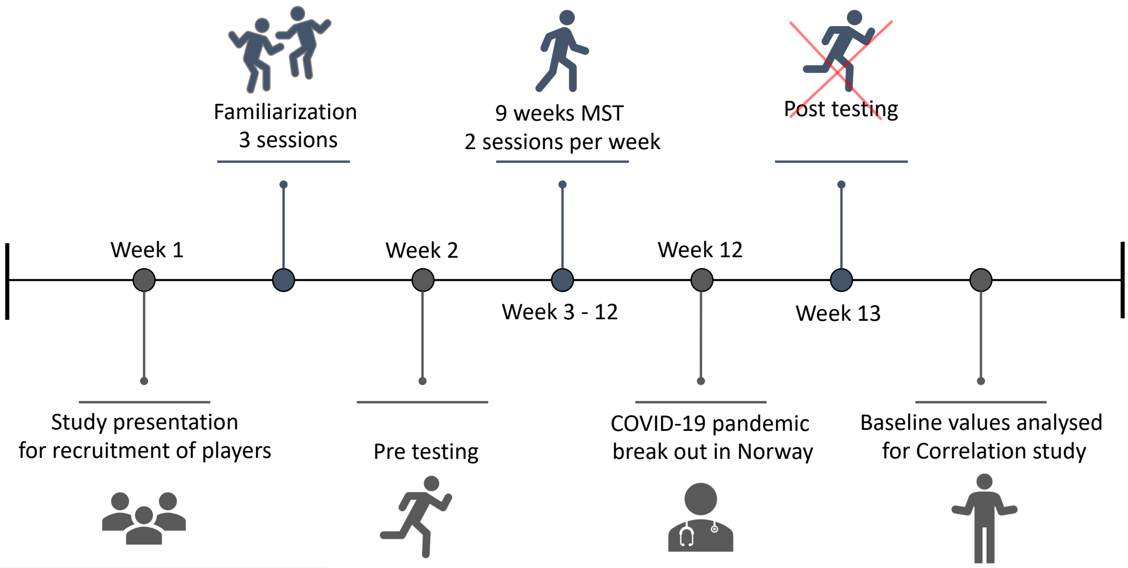

Figure 7 | Timeline of the study

Allometric scaling

Absolute strength is essential when a player need to move with the ball or make physical contact with an opponent. 1RM relative to bodyweight (kg · kg bw^{-1}) is relevant when using the body through accelerations. However, changes in maximal strength is not in direct proportion to bodyweight (bw). It should, therefore, be analysed using dimensional (L) scaling. The players` muscle ratio of arms and legs represent ratio L:1, the cross-section area L^2:1, and the volume ratio L^3:1. Since muscular strength is proportional to L^2:1, and bw varies directly with body volume, maximal strength will vary in proportion to $bw^{-0.67}$ (Wisloff et al, 1998). This compares a small and a bigger player by kg bw raised to the power of 0.67 (kg · kg $bw^{-0.67}$). This is crucial in young players because bw and size differ significantly at the same age (Wisloff et al, 1998). Excluding dimensional scaling will overestimate the small athletes and underestimate the big athletes (Hoff & Helgerud 2004; Helgerud et al, 2011).

Statistical Analysis

The software program IBM SPSS, version 25.0 (Statistical Package for Social Science, Chicago, IL) was used for the statistical analysis, and Microsoft Excel version 16.0 was used for data collection. The Pearson product-moment correlation was used to determine the relationship between selected variables. Thresholds of 0.50 and 0.70 for moderate and strong correlation coefficients suggested by Hopkins *et al.* (18) were used, $p < 0.05$ was considered 2-tailed significant. The results are presented as r value and p-value. Tables are presented for a summarized overview. All 1RM levels will be presented and discussed using dimensional scaling values (kg · kg bw$^{-0.67}$) to enhance the reliability of the relation between strength in the two exercises and powerful actions. 1RM (kg · kg bw$^{-0.67}$) is in this study is further stated as 1RM unless otherwise expressed as 1RM (kg) for absolute values.

Results

The relationship between 1RM and 1RM (kg) in the HT and BHS exercise and powerful actions are presented in Table 2. The range from strongest to weakest correlation in 1RM is shown in Table 3. The relation between 1RM and powerful actions is illustrated in Figure 8-13.

Table 2 Statistical correlation between hip-thrust (HT) and back half-squat (BHS) in powerful actions

Measurements	1RM (kg · kg bw$^{-0.67}$)				1RM (kg)			
	HT		BHS		HT		BHS	
	r value	*p-value*	*r value*	*p-value*	*r value*	*p-value*	*r value*	*p-value*
0 -5 m sprint	0.38	0.251	0.69	0.060	0.48	0.140	0.81	0.016*
0-10 m sprint	0.55	0.080	0.77	0.026*	0.58	0.060	0.84	0.009**
0-20 m sprint	0.57	0.070	0.86	0.006**	0.69	0.019*	0.91	0.001**
0-30 m sprint	0.56	0.074	0.89	0.003**	0.57	0.022*	0.93	0.001**
0-40 m sprint	0.61	0.050*	0.90	0.003**	0.71	0.015*	0.93	0.001**
Vertical jump	0.63	0.040*	0.85	0.008**	0.46	0.160	0.71	0.047*
COD-speed	0.60	0.050*	0.88	0.004**	0.51	0.100	0.86	0.007**
5-10 m sprint	0.70	0.016*	0.75	0.033*	0.66	0.028*	0.74	0.044*
5-20 m sprint	0.63	0.037*	0.93	0.001***	0.76	0.006**	0.94	0.001**
5-30 m sprint	0.60	0.054	0.93	0.001***	0.72	0.013*	0.93	0.001**
5-40 m sprint	0.65	0.031*	0.92	0.001**	0.74	0.009**	0.79	0.011*
10-20 m sprint	0.53	0.091	0.92	0.001**	0.77	0.060	0.95	0.001***
10-30 m sprint	0.55	0.082	0.93	0.001***	0.72	0.013*	0.94	0.001***
10-40 m sprint	0.63	0.039*	0.93	0.001**	0.75	0.008**	0.95	0.000***
20-30 m sprint	0.53	0.091	0.93	0.001***	0.64	0.032*	0.92	0.001**
20-40 m sprint	0.65	0.029*	0.91	0.002**	0.72	0.012*	0.83	0.006**
30-40 m sprint	0.74	0.009**	0.86	0.006**	0.77	0.006**	0.90	0.001**

1RM, one repetition maximum; kg · kg bw$^{-0.67}$, scaled to body mass; r value, Pearson correlation coefficient; p-value, level of significant; *, significance < 0.05; **, significance < 0.01; ***, significance < 0.001

Sprint performance

1RM in HT showed only strong correlation with 30-40 m ($r = 0.74$, $p = 0.009$), and 5-10 m ($r = 0.70$, $p = 0.016$) sprint time. 1RM in BHS correlated strongly in all sprint distances except 0-5 m sprint time ($r = 0.69$, $p = 0.060$). The relation between 1RM in HT and all sprint distances showed an average of moderate correlation at 0.59 (r = 0.38-0.74), explaining 34% (R^2 = 0.34) of the observed differences in sprint performance (Table 3). The relationship between 1RM in BHS and all sprint distances showed an average of strong correlation at 0.87 (r = 0.69-0.93), explaining 77% (R^2 = 0.77) of the observed differences in sprint performance (Table 3). Specific sprint distances from the acceleration- and sprint phase are illustrated in Figure 8-11.

One repetition maximum (kg)

The relation between 1RM (kg) in HT and all sprint distances showed an average of moderate correlation at 0.69 (r = 0.46-0.77). 1RM (kg) in BHS correlated strongly with all sprint distances. The relationship between 1RM (kg) in BHS and all sprint distances showed an average of strong correlation at 0.89 (r = 0.71-0.95).

Table 3 Sprint performance sorted by the Pearson correlation coefficient in HT and BHS

One repetition maximum (kg · kg $bw^{-0.67}$)									
Hip-thrust					Back half-squat				
Place(nr)	***Sprint distances***	***r value***	***p-value***	***R^2***	***Place (nr)***	***Sprint distances***	***r value***	***p-value***	***R^2***
1.	30-40 m	0.74	0.009**	0.55	2.	5-30 m	0.93	0.001***	0.87
2.	5-10 m	0.70	0.016*	0.51	3.	5-20 m	0.93	0.001***	0.86
3.	20-40 m	0.65	0.029*	0.42	5.	5-40 m	0.92	0.001**	0.85
4.	5-40 m	0.65	0.031*	0.41	4.	20-30 m	0.93	0.001***	0.86
5.	5-20 m	0.63	0.037*	0.40	1.	10-30 m	0.93	0.001***	0.87
6.	10-40 m	0.63	0.039*	0.39	6.	10-20 m	0.92	0.001**	0.85
7.	0-40 m	0.61	0.050*	0.37	7.	10-40 m	0.92	0.001**	0.84
8.	5-30 m	0.60	0.054	0.35	8.	20-40 m	0.91	0.002**	0.83
9	0-20 m	0.56	0.069	0.31	9.	0-30 m	0.89	0.003**	0.79
9.	0-30 m	0.56	0.074	0.31	10.	0-40 m	0.90	0.003**	0.80
11.	0-10 m	0.55	0.080	0.30	11.	30-40 m	0.88	0.006**	0.74
12.	10-30 m	0.55	0.082	0.30	12.	0-20 m	0.86	0.006**	0.74
13.	10-20 m	0.53	0.091	0.28	13.	0-10 m	0.77	0.026*	0.59
13.	20-30 m	0.53	0.091	0.28	14.	5-10 m	0.75	0.033*	0.56
15.	0-5 m	0.38	0.251	0.14	15.	0-5 m	0.69	0.060	0.47

1RM, one repetition maximum; kg · kg $bw^{-0.67}$, scaled to body mass; r value, Pearson correlation coefficient; p-value, level of significant; *, significance < 0.05; **, significance < 0.01; ***, significance < 0.001

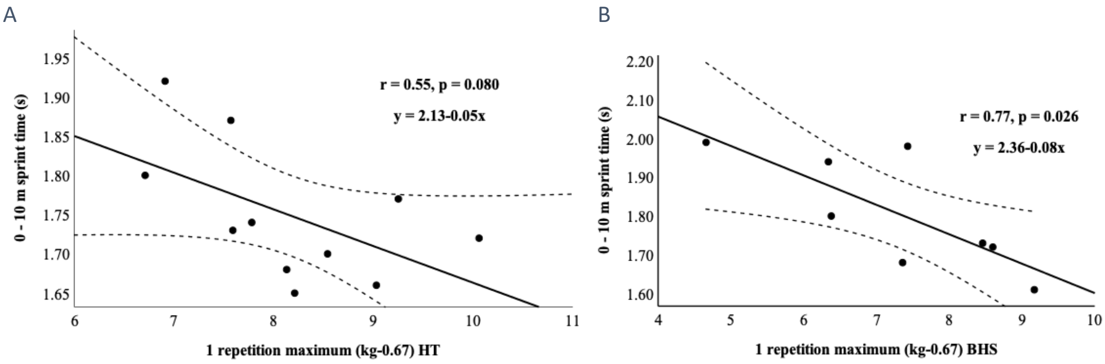

Figure 8 | Relation between maximal strength kg-0.67 (kg · kg bw$^{-0.67}$) and 0 – 10 m sprint time for the hip-thrust (HT) (A) and back half-squat (B)

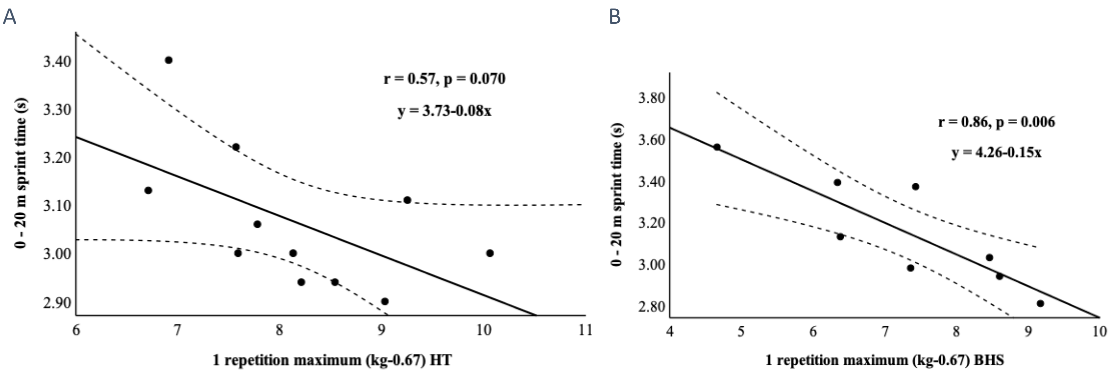

Figure 9 | Relation between maximal strength kg-0.67 (kg · kg bw$^{-0.67}$) and 0 – 20 m sprint time for the hip-thrust (HT) (A) and back half-squat (B)

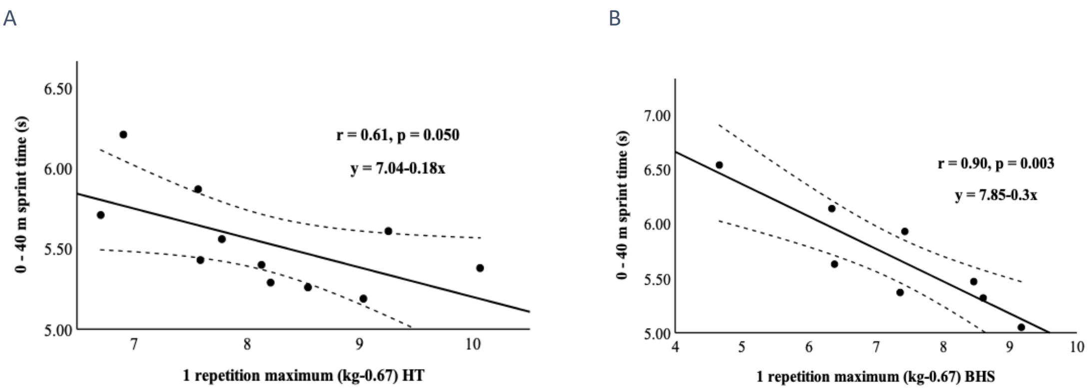

Figure 10 | Relation between maximal strength kg-0.67 (kg · kg bw$^{-0.67}$) and 0 – 40 m sprint time for the hip-thrust (HT) (A) and back half-squat (B)

A B

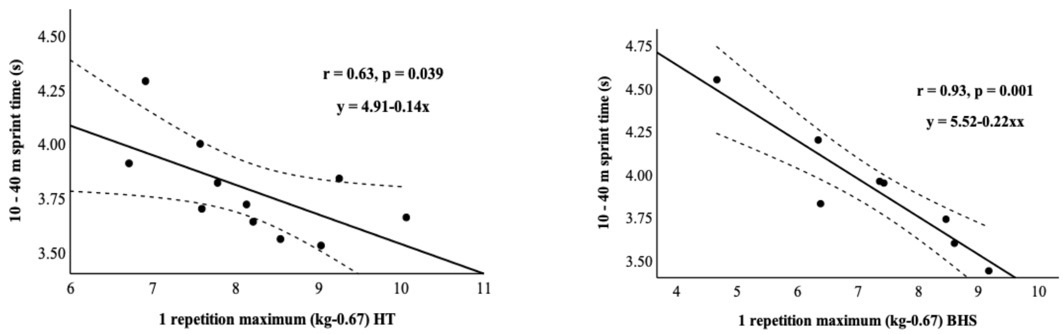

Figure 11 | Relation between maximal strength kg-0.67 (kg · kg bw$^{-0.67}$) and 10 – 40 m split time for the hip-thrust (HT) (A) and back half-squat (BHS) (B)

CMJ and COD-speed performance

1RM in HT showed moderate correlation with CMJ (r = 0.63, p = 0.04) and COD-speed (r = 0.60, p = 0.05) (Table 2). 1RM in BHS elicited strong correlation with CMJ (r = 0.86, p = 0.007) and COD-speed performance (r = 0.88, p = 0004). 1RM (kg) in HT shower border significant correlation with CMJ (r = 0.46, p =s 0.160) and COD-speed (r = 0.51, p = 0.100). 1RM (kg) in BHS correlated strongly with CMJ (r = 0.71, p = 0.047) and COD-speed (r = 0.86, p = 0.004). Relation between 1RM in HT and BHS with CMJ and COD-speed are illustrated in Figure 12 and 13.

A B

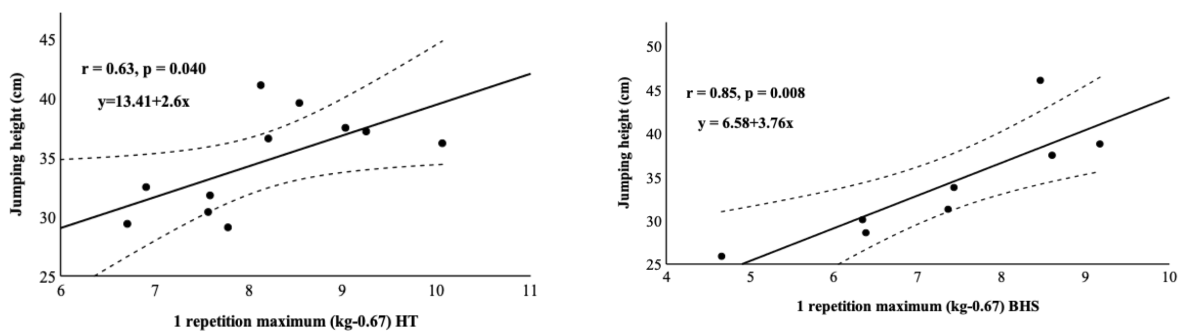

Figure 12 | Relation between maximal strength kg-0.67 (kg · kg bw$^{-0.67}$) and jumping height for the hip-thrust (HT) (A) and back half-squat (BHS) (B)

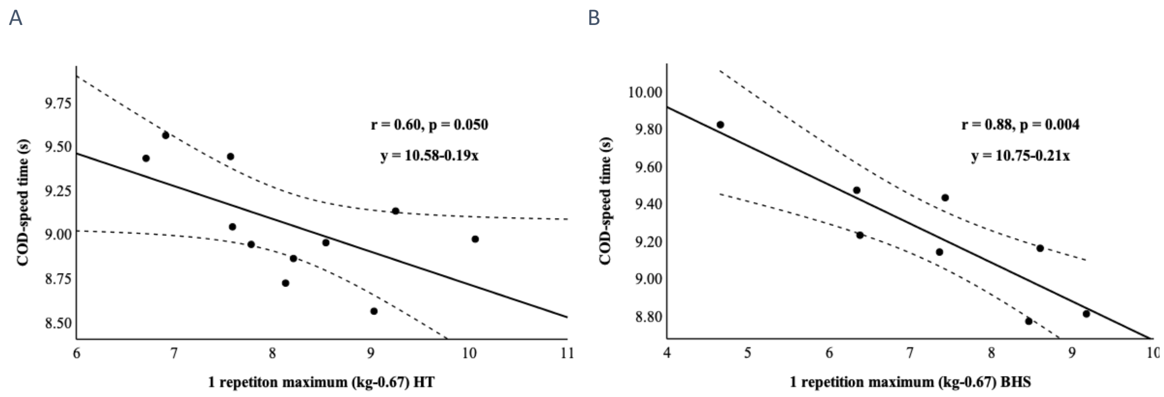

Figure 13 | Relation between maximal strength kg-0.67 (kg · kg bw$^{-0.67}$) and COD-speed time for the hip-thrust (HT) (A) and back half-squat (BHS) (B)

Applying all players (n = 19), strong correlation was found between CMJ and all sprint distances except 0-5 m (r = 0.44, p = 0.58) and 20-40 m sprint time (r = 0.39, p = 0.101). The relation between CMJ and all sprint distances, included COD-speed, showed an average of moderate correlation at 0.62 (r = 0.44-0.72). COD-speed showed strong correlation with all sprint distances, with an average of strong correlation at 0.86 (r = 0.78-0.90).

Table 4 Relation between jumping height, COD-speed and sprint performance implementing all players

The relation between CMJ and sprint time				**Relation between COD-speed and sprint time**			
(n)	***Sprint distances***	***r value***	***p-value***	***(n)***	***Sprint distances***	***r value***	***p value***
19	0 -5 m sprint	0.44	0.058	19	0 -5 m sprint	0.78	0.001***
19	0-10 m sprint	0.58	0.009**	19	0-10 m sprint	0.87	0.001***
19	0-20 m sprint	0.59	0.007**	19	0-20 m sprint	0.88	0.001***
19	0-30 m sprint	0.64	0.003**	19	0-30 m sprint	0.90	0.001***
19	0-40 m sprint	0.62	0.004**	19	0-40 m sprint	0.90	0.001***
19	5-10 m sprint	0.70	0.001**	19	5-10 m sprint	0.89	0.001***
19	5-20 m sprint	0.65	0.002**	19	5-20 m sprint	0.89	0.001***
19	5-30 m sprint	0.65	0.001**	19	5-30 m sprint	0.89	0.001***
19	5-40 m sprint	0.65	0.003**	19	5-40 m sprint	0.89	0.001***
19	10-20 m sprint	0.57	0.011*	19	10-20 m sprint	0.80	0.001***
19	10-30 m sprint	0.65	0.002**	19	10-30 m sprint	0.86	0.001***
19	10-40 m sprint	0.71	0.001**	19	10-40 m sprint	0.87	0.001***
19	20-30 m sprint	0.64	0.003**	19	20-30 m sprint	0.89	0.001***
19	20-40 m sprint	0.39	0.101	19	20-40 m sprint	0.88	0.001***
19	30-40 m sprint	0.66	0.002**	19	30-40 m sprint	0.68	0.001**
19	COD-speed	0.72	0.001***				

n, number of players; r value, Pearson correlation coefficient; p-value, level of significant; *, significance < 0.05; **, significance < 0.01; ***, significance < 0.001

Sprint time

The players' acceleration was highest after 5 m (3.2 m·s^{-2}), with a gradual decrease up to 10- (1.9 m·s^{-2}) and 20 m (0.9 m·s^{-2}) (Table 5). The speed at were players stop accelerate (reached maximum speed) occurred between 30-40 m (0.3-0.0 m·s^{-2}) (Figure 14A). The maximum speed given in m·s^{-1} and km·h^{-1} was reached at 20 m (8.0 m·s^{-1}, 28.8 km·h^{-1}) and were maintained throughout the 30-40 m (8.0 m·s^{-1}, 28.8 km·h^{-1}) (Figure 14B). The time used from 20-30 m (1.25 ± 0.10) and 30-40 m (1.25 ± 0.10) was identical (Table 5).

Table 5 Mean sprint time, meter per second and kilometer per hour for all sprint- and split distances

(n)	*Sprint distances*	*Mean ± SD*	*m · s^{-1}*	*km·h^{-1}*
19	0-5 m sprint	0.99 ± 0.08	5.1	18.2
19	0-10 m sprint	1.77 ± 0.11	5.6	20.3
19	0-20 m sprint	3.10 ± 0.20	6.5	23.2
19	0 -30 m sprint	4.34 ± 0.30	6.9	24.9
19	0 -40 m sprint	5.59 ± 0.39	7.2	25.8
19	5-10 m sprint	0.79 ± 0.05	6.3	22.8
19	5-20 m sprint	2.10 ± 0.13	7.1	25.7
19	5-30 m sprint	3.34 ± 0.23	7.5	26.9
19	5-40 m sprint	4.60 ± 0.31	7.6	27.4
19	10-20 m sprint	1.32 ± 0.09	7.6	27.3
19	10-30 m sprint	2.57 ± 0.19	7.8	28.0
19	10-40 m sprint	3.83 ± 0.28	7.8	28.2
19	20-30 m sprint	1.25 ± 0.10	8.0	28.8
19	20-40 m sprint	2.49 ± 0.19	8.0	28.9
19	30-40 m sprint	1.25 ± 0.09	8.0	28.8

s, seconds; n, number of players; ± SD, standard deviation of the mean; *m·s^{-1}*, meter per second; km·h^{-1}, mean kilometer per hour

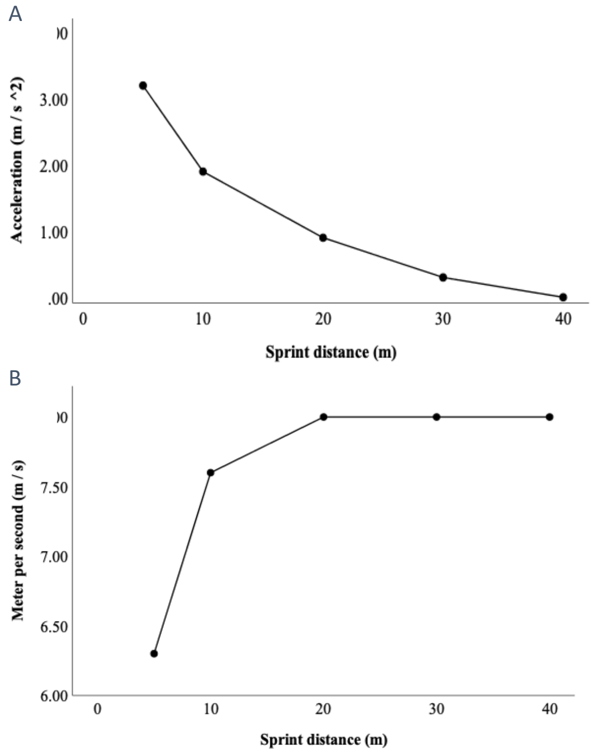

Figure 14 | The magnitude of change in acceleration of the players through a 40 m sprint. B) showing where players reach the maximum speed

Discussion

As far as the author is aware, this is the first study to compare maximal strength performance between HT and BHS and the relation to powerful action in male youth soccer players. In line with previous studies (Wisloff et al, 2004; Comfort et al, 2010), this study confirms a strong relationship between 1RM in BHS and 0-10 m, 0-20 m, 0-30 m, and 0-40 m sprint time, CMJ and COD-speed in male youth, junior and adult elite soccer players. As hypothesized, 1RM in BHS showed stronger relationships in the acceleration phase compared to 1RM in HT. Contrary to our hypothesis, 1RM in BHS showed a stronger correlation in sprint phases compared to HT. Also, opposite to our hypothesis, 1RM in BHS showed a stronger correlation with CMJ and COD-speed than HT. Hence, maximal strength in BHS seems to be a better estimation of the performance level in powerful actions compared to HT.

There are several reasons why the BHS showed a higher correlation to powerful actions than HT. Firstly, compared to hip-extensors, knee-extensors are more active in BHS and also more crucial in the acceleration phase. Secondly, knee-extensors are active in almost 100 percent of the time in the RGC, while hip-extensors seems to be active only 50 percent of the time. Thirdly, based on the body position and truncus, the standing movement of the BHS exercise may be a more specific design for the acceleration- and sprint phase compared to HT.

Acceleration phase

Newton´s second law of motion

Interestingly, 1RM in BHS and HT showed a nonsignificant- and the weakest correlation in the initial part of acceleration (0-5 m). Based on Newton´s second law of motion, this phase should rely mostly on the level of maximal strength, mainly due to the importance of neural activation of lower limbs. As the BHS is specifically designed for the position and activation of the muscles used when accelerating from a standing position, it is surprising that the 1RM level only showed a trend towards a significant correlation in 0-5 m. Similarly, McBride *et al.* (2009) found a nonsignificant relationship between 1RM in BHS and 0-5-yard (4.1 m) sprint time in colligate football players. In contrast, Comfort *et al.* (2013) found a strong correlation between 1RM and 0-5 m sprint time in male youth elite soccer players. Also, Chelly *et al.* (2010) demonstrated a significant relationship between 1RM (kg) and sprint velocity ($m \cdot s^{-1}$) in 0-5 m in male youth elite players. However, Comfort *et al.* (2013) had players with two strength-training sessions implemented in their weekly training routine. Chelly *et al.* (2010)

performed eight technical sessions before testing, which could lead to higher muscle fibers recruitment, thus greater RFD ability from 0-5 m. Since players of the present study had no previous lifting experience, the firing frequency of neural activation may, in general, be more limited compared to the players in these two studies. These findings could indicate that RFD is superior to 1RM in the initial part of acceleration. However, this study did not test RFD. Therefore, future correlations studies need to measure RFD and see if this factor shows a stronger relationship with the initial start of the acceleration compared to 1RM for the given exercises.

Further, in line with our hypothesis, 1RM in BHS and 0-10 m sprint showed stronger correlation compared to HT. The relationship between 1RM in BHS and 0-10 m is in line with other research in youth and adult elite soccer players (Wisloff et al, 2004; McBride et al, 2009; Helgerud et al, 2011). The weak correlation between 1RM in HT and 0-10 m sprint was expected due to the lower influence of hip-extensor in the initial start of the acceleration compared to knee-extensors. These findings indicate that the impact of 1RM in BHS have a stronger influence on sprint ability in the initial part of the acceleration phase compared to HT. However, both McBride *et al.* (2009) and Comfort *et al.* (2012) analysed the players' 1RM in BHS as relative to body mass (kg · kg bw^{-1}), which makes it difficult to compare our results with these findings as we used another form of scaling 1RM (kg · kg $bw^{-0.67}$) in BHS.

Possible interplay between lower limb muscles from the initial start of the acceleration- to the beginning of the sprint phase

Regarding 1RM and sprint- and split times from 0-20 m, the BHS correlated stronger with all measurements compared to HT. This is, to some extent, in line with our hypothesis as 0-20 m sprint performance depends mainly on the players ability to accelerate (e.g. 0-10 m). 1RM in HT showed moderate and strong correlation with 5-10 m and 5-20 m sprint time, with no significant correlation in 0-20 m. These findings could be explained by the dominant force of knee-extensors compared to hip-extensors in the late swing- (pre-activation) and in the first half of the stance phase (braking, IC) throughout the acceleration- and the start of sprint phase (first 10 steps (e.g. 0-10-20 m)) (Morin et al, 2015; Howard et al, 2018; Loturco et al, 2018; Nagahara et al, 2018). Also, in the late swing phase, vastus lateralis seems to be more active in the first 3 to 4 steps, compared gluteus maximus and biceps femoris. However, it appears that the interplay between these muscles reaches an equilibrium from the 4^{th} to the 10^{th} step, with a tendency for the gluteus maximus and biceps femoris to be more dominant at the end of the acceleration phase (Figure 2). This may explain the strong relationship between maximal strength in HT and split times from 5 m and not from 0 m. Importantly, the late swing phase is only a small percentage of the RGC and vastus lateralis still seems to be, in general, the most dominant muscle up to 20 m. This may explain why the relationships between 1RM in BHS and this phase, shows a stronger relationship than 1RM in HT.

Sprint phase

Muscle activity and force-generating capacity at maximum sprint speed

Contrary to our hypothesis, 1RM in BHS showed a stronger relationship with later sprint phases compared to 1RM in HT. However, the moderate and strong relationship between 1RM in HT and 5-40 m, 10-40 m, 20-40 m, and 30-40 m sprint time is the only phase where HT, to some degree, matches the BHS values in terms of the correlation value. Both knee- and hip-extensors are pertinent at maximal sprint speed (20-40 m), and maximal force production is an integral component at maximum sprint speed (Morin et al, 2015). Since GRF can determine maximal sprint speed performance (Nagahara et al, 2018), it is crucial to use an exercise that can enhance maximal force production in the stance phase at maximum speed. Vertical GRF correlates significantly with maximal sprint speed, while horizontal GRF correlates significantly with mean- and maximal sprint speed (Seitz et al, 2014). Based on the movement specificity of the two exercises, it is common to state that BHS represents vertical force, while HT represents horizontal force production. However, research suggests that both horizontally and vertically exercises should be used when developing maximal strength for improving sprint performance (Loturco et al, 2018). This is supported by the strong correlations for both 1RM in BHS and HT and the relation to distances from 20-40 m in this study. However, it seems that the BHS activates the sprint specific muscles to a greater extent than HT. This makes it plausible that 1RM in BHS is a better indicator than HT for the performance in the sprint phase. Despite both having strong relationships in the sprint phase, 1RM in BHS shows a stronger correlation with all sprint phases. Therefore, it appears overall that knee-extensors are the supreme muscles that need a high level of maximal strength and RFD to run faster.

The strong relationships between 1RM in BHS and sprint- and split time from 0-40 m strengthen the importance of possessing high levels of strength and RFD in male youth soccer players. It is, therefore, logical to provoke adaptations in these muscles to improve acceleration and sprint performance. Strong correlation may not be representative for causation; however, researchers have found that increase in 1RM and RFD through BHS after eight weeks of MST significant improve the 0-5 m, 0-10 m, 0-20 m, 0-30 m, and 0-40 m sprint performance in male youth and adult elite soccer players (Ronnestad et al, 2008; Chelly et al, 2009; Helgerud et al, 2011; Ronnestad et al, 2011). Still, there are prominent findings found for the HT after training interventions (Contreras et al, 2017; Garcia et al, 2019).

It is demonstrated that players who increased their 1RM in BHS by 17-52% after an MST intervention (Ronnestad et al, 2008; Chelly et al, 2009; Helgerud et al, 2011; Ronnestad et al, 2011), improved their sprint performance in specific distances (e.g. 0-10 m, 0-20 m, 0-30 m) that correlates strongly with 1RM in BHS. Therefore, it would be interesting to see if the same improvement (> 17%) of 1RM in HT after MST will give a similar improvement in respective sprint distances that correlate strongly with 1RM in HT (e.g. 5-10 m and 30-40). Still, the BHS exercise seems to be superior to the HT exercise on sprint performance in male youth soccer players, although adequately powered RCTs between the two exercises are lacking and warrened in this population.

Sprint speed;

Increasing maximum sprint speed after strengthening lower limb parameters, is traditionally explicated by greater GRF and RFD. This phase depends more on generating as much force as possible when the foot is in contact with the ground compared to the acceleration phase. Time spend at ground contact (stance phase) seems too short to be affected by the athletes´ maximal strength (Weyand et al, 2000; Sascha & Muller, 2013). Therefore, it is essential to possess a high level of RFD to generate more force per time unit. Since 1RM in BHS shows a stronger correlation in the sprint phase compared to HT, it could indicate that BHS is more relevant for increasing RFD, thus more pertinent for improving the sprint phase.

Jumping

In contrast to our hypothesis, 1RM in BHS showed a stronger relationship with CMJ compared to 1RM in HT ($r = 0.85$, $p = 0.008$ vs. $r = 0.63$, $p = 0.040$). The relationship between 1RM in BHS and CMJ is in line with previous research (Wisloff et al, 2004; Comfort et al, 2013). Despite a stronger correlation for the BHS group, both exercises were significantly correlated to CMJ. These findings may explain why research has demonstrated the same magnitude of improvement in CMJ between strength training interventions using BHS and HT in male recreational rugby players (Contreras et al, 2017), female colligate basketball players (Fitzpatrick et al, 2019), and female amateur players (Garcia et al, 2019). 1RM in these two exercises could, therefore, predict jumping performance. However, due to the stronger relationship between 1RM in BHS and CMJ, the result obtained in this study suggests that the BHS tends to be more pertinent for CMJ than HT.

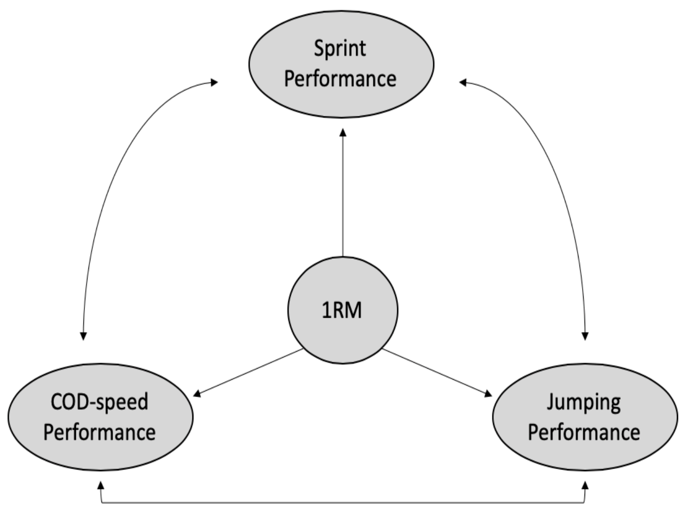

Figure 15 | Illustrations of the significant correlation found between powerful actions and 1RM

The close and moderate relationship between CMJ and sprint times was expected as both are accompanied by maximal strength (Cormie et al, 2011). Meaning that players with greater jumping height will have greater acceleration- and sprint performance compared to players with lower jumping height. These findings can be predicted by higher maximal strength. In line with the relationship between 1RM in BHS and HT and 0-5 m, CMJ showed border to significant with this sprint time. These findings amplify the weak correlation between 1RM and 0-5 m. Since this triangle gives logical data, it may support the fact that 1RM does not predict 0-5 m sprint ability in these players.

COD-speed

Contrary to our hypothesis, the 1RM in BHS showed a stronger correlation with COD-speed performance compared to 1RM in HT ($r = 0.88$ $p = 0.004$ vs. $r = 0.60$, $p = 0.050$). However, both exercises showed a significant correlation. For example, there has been one study demonstrating the tendency of greater improvement in HT compared to BHS after seven weeks of training in female amateur soccer players (Garcia et al, 2019). Hamstring strength is crucial when reducing tempo. Since HT targets this muscle more than BHS, the HT exercise could give a greater improvement in COD-speed after conducting MST. At the same time, the knee-extensors is more active during the acceleration phase than the hip-extensors. The stronger relation for 1RM in BHS indicates that possessing a high level of strength in the knee-extensors when accelerate again seems to be more important than have a high level of hamstring strength when reducing the tempo.

Further, COD-speed showed a strong correlation with all sprint distances. In contrast, no studies have found significant improvement in COD-speed after MST. This may be due to the problem of having standardized COD-speed tests, thus difficult to compare among studies. However, our adapted COD-speed test was based on frequent COD angles performed in matches. Therefore, future studies should consider the present test in future training interventions. Mainly because there is currently no gained information regarding the BHS independent influence in COD-speed after an MST intervention in this population.

Summary

The results of this study illustrate the importance of developing high levels of lower-body strength to enhance straight line sprint- jump- and COD-speed performance in male youth soccer players. All these measurements of powerful actions except 0-5 m, show a strong correlation with 1RM in BHS. 1RM in HT represents mainly moderate correlations in all powerful actions with a tendency of significant correlation with the acceleration phase. Importantly, all these physiological and biomechanical parameters seem to determine each other's performance level. To illustrate (Figure 15); 1) Maximal strength in lower limb determine sprint- jumping- and COD-speed performance. 2) Sprint performance is further strongly related to jumping performance, except the 0-5 m sprint time, which is also in line with the nonsignificant correlation between 0-5 m and 1RM in BHS and HT. 3) Jumping performance and COD-speed represent a strong relationship, and 4) COD-speed is strongly correlated with all sprint distances. This means that all these measurements seem to relate to each other and may predict that stronger players will demonstrate a higher level in terms of powerful actions. These physical actions are paramount to be successful in soccer matches.

As shown in other studies (Wisloff et al, 2004; Ronnestad et al, 2008; Chelly et al, 2009; McBride et al, 2009; Helgerud et al, 2011; Ronnestad et al, 2011; Comfort et al, 2013; Garcia et al 2019), results of this study enhance the importance of increasing maximal strength in BHS to improve acceleration- and sprint time, CMJ and COD-speed in male youth and elite soccer players. Further, this is the first study to find a moderate to a strong relationship between 1RM in HT and later sprint phase, CMJ, and COD-speed in this population.

Limitation

It is important to note that the HT group was represented by 11 players, while the BHS group had 8. As the number of subjects increases, the correlation value decreases while the level of significance is enhanced. However, the level of significance tends to not improve despite having lower correlation values compared to BHS.

Since these players had no lifting experience, another limitation may be that the movement of BHS is more adapted in humans, while HT requires more introduction and time to see neural adaptations. Therefore, the relation of 1RM and powerful actions between HT may be stronger after an MST intervention.

Conclusion

As our hypothesis, the critical ability to accelerate from 0-10 m showed a stronger correlation with 1RM in BHS than 1RM in HT. Contrary to our hypothesis, three surprising observations were found; First, the ability to sustain a high maximal sprint speed over 10-40 m, shows stronger relationships with 1RM in BHS than 1RM in HT. Second, 1RM in BHS correlates stronger with CMJ than 1RM in HT. Third, 1RM in BHS showed a stronger correlation with COD-speed compared to 1RM in HT. These results indicate that 1RM ($kg \cdot kg\ bw^{-0.67}$) in BHS, is more pertinent to determine all powerful actions than 1RM ($kg \cdot kg\ bw^{-0.67}$) in HT in male youth soccer players. Finally, as HT shows prominent relation with later sprint phases, CMJ and COD-speed, future research still needs to investigate fully MST intervention comparing BHS and HT in male youth soccer players.

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