Very Heavy Resisted Sprinting: A Better Way to Improve Acceleration?

Effects of a 4-Week Very Heavy Resisted Sprinting Intervention on Acceleration, Sprint and Jump Performance in Youth Soccer Players

Domen Bremec

GYMNASTIK- OCH IDROTTSHÖGSKOLAN
Självständigt arbete advanceradnivå (Masters’s Thesis): 38:2018
Masterprogrammet i Idrotssvetenskap (Sport Science Master) 2016-2018
Handledare: Niklas Psilander
Examinator: Örjan Ekblom
Abstract

Aim
Aim was to investigate the effects of heavy resisted and unresisted sprint training protocols and see its effects on sprint time, vertical and horizontal jumping and sprint mechanics.

Method
Youth male soccer players \( n = 27 \) participated in this study, they were all individually assessed for the horizontal force-velocity profile using two unresisted sprints and load-velocity profile using four progressively resisted sprints (25%, 50%, 75% and 100% body mass). For all sprints an isotonic braking device was used. They also performed vertical and horizontal jumps, counter-movement jump (CMJ) was used for the former and standing long jump (SLJ) for the latter. They were put in three groups (RST: resisted sprint training; UST: unresisted sprint training and TAU: control group – “training as usual”). Athletes performed a 4-week training intervention (5x20m resisted sprint group; 8x20m unresisted sprint group) and were tested 7 days after completing their final training session.

Results
Only RST improved all sprint times (T30, T20, T10, T5) substantially (-4.2% to -7.9% in split times) and provided trivial or small changes in sprint mechanics. The small changes were seen in sprint mechanical parameters of \( RF_{\text{max}}, P_{\text{max}} \) and \( F_{0} \). UST only showed trivial effects in those parameters, while TAU showed a small decrease in both \( P_{\text{max}} \) and \( V_{\text{max}} \). Regarding the jumps, RST and UST both showed a small increase in standing long jump and a trivial effect in counter-movement jump, while TAU decreased in both.

Conclusions
Main conclusion is that resisted sprinting has proven to be a worthwhile method to improve acceleration and sprint performance and can be used by practitioners across a wide array of sports. It also improved jumping performance and sprint mechanical outputs, which point toward an improvement in better application of force in a horizontal direction.
Table of Contents

0 Acknowledgements ............................................................................................................. 1
1 Introduction .......................................................................................................................... 2
2 Purpose ................................................................................................................................ 7
  2.1 Research Questions ........................................................................................................ 7
3. Methods ................................................................................................................................ 8
  3.1 Participants and Protocol ............................................................................................... 8
  3.2 Equipment ....................................................................................................................... 9
  3.2 Testing Procedure ........................................................................................................... 10
  3.3 Loading and Sprint Distance ......................................................................................... 11
  3.4 Data Analysis ................................................................................................................ 12
  3.5 Training Sessions .......................................................................................................... 14
  3.5 Statistical Analysis ........................................................................................................ 14
4. Results ................................................................................................................................... 15
5. Discussion ............................................................................................................................ 19
  5.1 Limitations ..................................................................................................................... 23
6 Practical Application ............................................................................................................. 23
7 Conclusion ............................................................................................................................. 24
8 Literature ............................................................................................................................... 25
9 Appendices ........................................................................................................................... 33
  Appendix 1: Informed Consent ............................................................................................. 33
  Appendix 2: FVP - Split Time ............................................................................................... 38

List of Tables

Table 1: Classification of resisted sled sprint sled loads expressed as percentage of body mass and velocity decrements proposed by Petakos et al. 2016: ................................................................. 6
Table 2: Study timeline ............................................................................................................ 14
Table 3: Descriptive characteristics of all the participants and subjects in each group, values are presented as mean and standard deviation (±SD) ........................................................................................................ 16
Table 4: Athlete body-mass, jump and sprint performance variables during pre- and post-testing for RST, UST and TAU groups ........................................................................................................ 17
Table 5: Athlete sprint mechanics variables during pre- and post-testing for RST, UST and TAU groups ...... 18
Table 6: Post – pre changes in athlete body-mass, jump, sprint and mechanical sprint variables between the RST, UST and TAU groups. ........................................................................................................ 19
0 Acknowledgements

Although there will be an order of appearance for people I would like to acknowledge, the importance of all is immeasurable. Without complicating it too much, I would like to thank my family – Marjan, Breda and Natalija, I feel your love and support anywhere I go on this world.

To my colleagues and dear friends Miha and Robi for all sport science talks and observations and ways on how to improve everything around us. Thanks to my brother in arm in this thesis, Micke, it was an honour and a pleasure. Special thanks to Johan, for all the talks and tips on the matter, the thesis would not have been as it is if it were not for your help. Maybe we collaborate on the next one.

Last, but not least, a special thanks to Damjana, for everything. I appreciate it. Whole masters would not have been as it was if it were not for your support, your visits and everything else. Thanks for being there and for being you.
1 Introduction

Being fast and being explosive, those have been two of the most attractive traits of athletes for as long as there were people on this Earth. First, it was mostly because of the biological needs, being fast often meant surviving. Sprinting is essential for success in many sports, and as such, it is a comprising part of sports and the more recent development of a broader sport science field. Team sports are among the most popular sporting events in the world and they are often the subject of improvement and advancements. Matches and plays are decided in brief moments, split seconds and instant actions of athletes involved. One capability that is highly important in popular team sports, such as football (soccer), handball, rugby, and basketball is the ability to accelerate, and sprint short distances of approximately 5-30 meters as fast as possible (Morin et al. 2016a; Seitz et al. 2014; Haugen et al. 2014; Manchado et al. 2013; Comfort et al. 2012; Stojanović et al. 2017). Short-sprinting performance may mirror actual game situations at high level and could be an important determinant of match-winning actions in soccer (Cometti et al. 2001). High-level soccer players perform a high amount of intense actions every game (Bangsbo et al. 2006; Haugen et al. 2014) and sprint faster in the first 10 meters (Stølen et al. 2005) than lower level players. Higher level or performance on the pitch is also largely influenced by sprint performance (Bentley et al. 2016; Brown et al. 2017; Comfort et al. 2012; Cross et al. 2017 cited in Seitz et al. 2014). Soccer performance depends on a combination of technical, tactical, physical, physiological, and psychological factors (Stølen et al. 2005). Important physiological determinants are maximal strength, anaerobic power and capacity comprised of abilities such as force, power and velocity. The latter are especially important for high intensity skills and movements such as tackling, dribbling, jumping, sprinting, accelerating or changing direction (Cometti et al. 2001; Cronin & Sleivert 2005; Cormie et al. 2010; Jimenez-Reyes et al. 2017; Reilly et al. 2000).

The relationship between jumping, both vertical and horizontal, and functional performance such as acceleration have been researched in many sports. There is a significant correlation between horizontal jump (HJ) and short acceleration distances (Loturco et al. 2015b) such as 10- and 30-m (Maćkala et al. 2015) and 60-, 100-, and 200-m sprint distances (Hudgins et al. 2013) for both time and peak speed. Yanci et al. (2014) found that correlation between sprint and vertical jumps (VJ) or HJs was highest for the 15-m sprint distance, although the most consistent correlations were between HJ and acceleration. HJs are likely not good indicators of sprint parameters at the distance reaching maximal velocity ($v_{max}$) (Kale et al. 2009).
Performance in HJ has been associated with the athletes’ ability to transfer the linear momentum of force directly from the ground to the peak horizontal acceleration of the body’s centre of mass. This is also critical to break the inertia (i.e. starting from a zero-velocity) and achieve high velocities over short distances (Brechue et al. 2010; Hudgins et al. 2013; Loturco et al. 2015b; Loturco et al. 2015a). Kugler and Janshen (2010) concluded that the horizontal forces are important for acceleration. However, maximizing the forward propulsion requires optimal, not maximal force application. That is in agreement with findings by Bucheit et al. 2014, who found out that improvement in horizontal force production capability may be efficient to enhance sprinting performance over short distances. Faccioni (1995) described significant correlations between countermovement jumps and the maximum speed reached by elite and sub-elite sprinters during specific speed testing. It appears that the competitive level of the athletes (sprinters) affects the relationship between VJ heights and sprint ability. Some studies indicate a relationship between sprint time and double- or single-leg VJs (Berthoind et al 2001; Bret et al. 2002; Hennessy et al. 2001; Coh & Tomažin 2003; Kukolj et al. 1999; Mero et al. 1981; Miguel & Reis 2004; Tourn et al. 2001; Young et al. 1995; Kale et al. 2009). Counter movement jump (CMJ) is being used to measure the improvement of the reactive strength under the stretch–shortening cycle (Benche et al. 2002 cited in Kale et al. 2009). Additionally, ballistic exercises are similar to the sprint movement patterns, since they allow both projection and lifting of the subject, and have acceleration and deceleration phases (Newton & Kraemer 1994; de Villarreal et al. 2013; Loturco et al. 2015b). On the other end of the spectrum, Loturco et al. (2015a) showed with elite U-20 soccer players that HJ improve the acceleration/velocity over short distances, whereas VJ produce greater improvements in longer sprints. These findings are in accordance with a number of previous studies that analysed the role of vertical and horizontal ground reaction forces in different phases of sprinting speed (i.e. acceleration and top-speed phases) (Buchheit et al. 2014; Clark, Ryan, & Weyand 2014; Cross et al. 2015; Weyand et al. 2000; Loturco et al. 2015a). Young et al. (2015) also concluded that training designed to improve acceleration and reactive strength may potentially transfer and enhance the change of direction (COD) speed performance, which is relevant to all sports that require COD speed.

In practice, the smallest worthwhile improvement could be as small as 1-3% in sprint and acceleration performance, but it could already have a decisive influence on the outcome of a play or a match. As such, those improvements are highly important and may be the deciding factor between winning and losing. Improving the maximal sprint performance has been one of
the main goals for all practitioners working with athletes in many different sports. Sprint acceleration is defined by the rate of change in running velocity (Petrakos et al. 2016). Improvements can come from an improvement in acceleration and/or maximal velocity phases. Key performance indicators (KPIs) of a sporting performance often comprise of abilities for acceleration and maximal velocity (Petrakos et al. 2016). Recent literature suggests that, the ability to generate large magnitudes of ground reaction force (GRF) in the horizontal direction is key in determining acceleration performance, especially regarding the mechanical efficiency of overall capacity (Morin et al. 2016a). Furthermore, success within sprinting events relies heavily on both the ability to accelerate rapidly and through achieving and maintaining high running velocities (Kawamori et al. 2014). Propulsive forces within acceleration are 46% greater than those observed within maximal velocity running (Morin et al. 2016b). Herein, the training programs should consider modalities that provide overload to the propulsive nature of GRF application within acceleration phase of sprint running (Morin et al. 2016b).

There are two common methods of improving sprint performance, (1) either to increase an athletes’ force and power output, or (2) improve efficiency and use of a given physical output (Petrakos et al. 2016). In the first method, we have seen various training methods positively transferring to sprint performance with increases in maximal strength, maximal power, reactive strength (i.e. plyometric training) and any combination of these methods (Petrakos et al. 2016). The second method usually involves sprint technique drills (Petrakos et al. 2016). The majority of training interventions and exercises focus on enhancing production of force (e.g. back squat), force velocity (e.g. Olympic lifts variations) or reactive strength (e.g. drop jumps) in the vertical direction of movement (Petrakos et al. 2016). Research has shown that untrained and low level sprinters reach maximum running speed around 30–40 m and cannot maintain this speed after the 40–50 m mark (Coh et al. 2001; Delecluse et al. 1995; Maćkala et al. 2015). Sprint and acceleration ability implies large forward acceleration, which has been related to the capacity to produce and apply high amounts of power output in the horizontal direction onto the ground. Practically, that means high amounts of horizontal external force at various velocities over sprint acceleration (Jaskolska et al. 1999; Morin et al. 2011a, 2011b, 2012; Rabita et al. 2015; Samozino et al. 2016).

Resisted sprinting (RS) is a method of training that may involve an athlete sprinting with an added load using a weighted sledge, a weighted vest, a speed parachute, or performing uphill or sand dune training (Harrison & Bourke 2009). A more recently developed method also
involves using a robotic resistance device using a servomotor to modulate resistance load (Mangine et al. 2017). Resisted sprinting provides mechanical overload to the horizontal component of GRF application and brings about a mechanically more efficient force orientation per stride (Morin et al. 2016a). Kinematically we can observe the following: increased stance time, shank angle (i.e. shin angle relative to the ground) and trunk angle (i.e. torso lean relative to the ground), and increased hip extension (Morin et al. 2016a). Kinetically we also observe the changes in the following parameters: force, rate of force development and power (Mangine et al. 2017). Focus of coaches training athletes is the actual transfer from training to performance, so the key is to outline the training regimen most likely to have the greatest transfer. Haugen et al. (2014) emphasize the importance of specificity for improving sprint performance in football players. Young (2006) notes that general resistance training is valuable in terms of reducing the sport injury risk and improving the force and power abilities of the muscles. However, in the case of movement velocity and movement patterns for experienced athletes, resistance training regimens should be as specific as possible in order to yield the greatest transfer to the actual performance. With these considerations in mind, resisted sprint training (RST) is a viable alternative.

Research that compared RST with unrestisted sprint training (UST) has shown that RST provides efficiency of output (i.e. kinetics) as well as the actual physical output (i.e. kinematics) itself. Both traditionally utilized methods provide practitioners with positive outcomes and enhance sprint performance. The classification of RST loads expressed as body mass and velocity decrement can be seen in Table 1. Using moderate to high loads (>30% body weight) produce more forward lean and increase the horizontal impulse more when compared to UST, likely allowing a greater horizontal force application. Even though there are likely many positive outcomes from resisted sprinting, it should also be mentioned that a greater whole body or trunk forward lean might be negative for some parts of the sprinting phase, such as the maximal velocity phase. However, RST in general might be used as a standalone method or, more likely, an ingredient in combination with, training regimens focusing on vertical force production since RST closely replicates the motor pattern of sprinting and might provide an increase in peak force, maximal strength and rate of force development (Petrakos et al. 2016). With RST, the traditionally recommended load is one that does not alter the sprint mechanics (technique) of the sprinter, usually between 10-13% of body weight, or a load that causes up to a 10% decrement in maximal velocity (%V_{dec}) of the athlete. This relative load may be insufficient for trained athletes, not providing enough overload to enhance their sprint
acceleration (Petrakos et al. 2016). Petrakos et al. (2016) showed in their meta-analysis, that there is no evidence of detrimental effects of high load RST on acceleration and maximal velocity in sprinting. Although RST with moderate to very heavy loads in team sports athletes is effective in improving sprint acceleration, research has not proven RST to be more effective than UST in regards to enhancing acceleration or maximal velocity. However, there is very little research done on very high load RST and that there is no study comparing heavy and/or very heavy RST with UST done on youth team sport athletes. An important notion is the specificity of the training load utilized, with higher loads seemingly more favourable (useful) in improving the acceleration phase (higher horizontal force output and lower velocity) whilst moderate- to low loads might favour improvements in high velocity phases of sprinting (e.g. maximal velocity phase). A recent study by Morin et al. (2016a) concluded that very heavy RST (load corresponding to 80% of body mass) compared to UST clearly increased the horizontal force production and mechanical effectiveness whilst also being effective in improving 5-m and 20-m sprint performance in team sport athletes. Furthermore, a study by Harrison and Bourke (2009) showed that it is beneficial to use resisted sprinting for increases in jump performance. They have seen significant increase in starting strength and in jump height using resisted sprints. This shows that resisted sprinting is beneficial in increasing the initial acceleration from a static start.

**Table 1:** Classification of resisted sled sprint sled loads expressed as percentage of body mass and velocity decrements proposed by Petrakos et al. 2016:

<table>
<thead>
<tr>
<th>Category</th>
<th>%BM</th>
<th>%V&lt;sub&gt;dec&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light (L)</td>
<td>&lt;10.0</td>
<td>&lt;10.0</td>
</tr>
<tr>
<td>Moderate (M)</td>
<td>10.0-19.9</td>
<td>10.0-14.9</td>
</tr>
<tr>
<td>Heavy (H)</td>
<td>20.0-29.9</td>
<td>15.0-29.9</td>
</tr>
<tr>
<td>Very Heavy (VH)</td>
<td>&gt;30.0</td>
<td>&gt;30.0</td>
</tr>
</tbody>
</table>

%BM sled load as a percentage of body mass, %V<sub>dec</sub> decrement in sprint velocity elicited by sled load compared with unresisted sprint velocity (Petrakos et al. 2016).

All the recent data suggests and encourages for this field to be more extensively researched, especially considering the sprint performance of team sport athletes, such as soccer, where sprinting is one of the detrimental capabilities that can potentially decide a match or a decisive play. Motives for the implementation of very heavy resisted sprint training in this population is clear, as most research is done with light resistance (>10% body weight) and focuses more on kinematics, while in the very heavy resistance training bigger importance is on the kinetics of the sprint performance. To our knowledge, this is the second study (Morin et al. 2016b) to
investigate the very heavy resistance sprint training and compare it to the unresisted sprint training, but it is the first one used in a youth team sport setting with individualized loads and also looking into the vertical and horizontal jumping performance. Results of this study investigating the individualized specific overload would be of great importance to all practitioners in the field, working in team sports, specifically in soccer, to determine the most appropriate method for improving sprint, acceleration and ballistic capabilities of the athletes. Furthermore, the training intervention is set into a realistic context of soccer season periodization and can provide a realistic gauge as to whether a 4-week training intervention is long enough for any significant changes to occur.

2 Purpose

The aim of this study in youth soccer players was to compare the effects on sprint performance and mechanical outputs of a heavy resisted sprint training program centred on the individual optimal loading (L_{opt}) for increasing the maximal power output (P_{max}) versus an unresisted sprinting group. Another aim was to compare the jump performance (VJ and HJ) between the two experimental groups and see if any changes occurred. The hypothesis is that resisted sprint training in the individualized condition (i.e. P_{max} condition of Force-velocity profile) would result in greater improvement of power capacity (i.e. early acceleration) than the more traditional, unresisted loading protocol aiming to develop the application of force at higher velocities. This thesis serves to provide novel experimental data on a specific population enhancing the scientific understanding of the very heavy resisted sprinting. It also serves as a practical pathway for practitioners, sport coaches and strength and conditioning coaches, to determine whether using outlined methods is sensible if the goal is to improve acceleration, sprinting and jumping performance.

2.1 Research Questions

This thesis aims to answer the following research questions:

- Does the heavy RST group improve the horizontal force application, mainly via more effective ground force application more than the UST group in the 4-week intervention?

- Does the heavy RST group improve early acceleration performance more than the UST group?

- Does the heavy RST group improve horizontal and vertical jump performance (length in HJ and height in VJ) more than the UST group?
Does the heavy RST group improves 30-meter sprint time more (i.e. better time) than the UST group?

3. Methods

3.1 Participants and Protocol

The collection of data occurred in Sweden, comprising of 27 male youth soccer players (N=27). Participants’ age (mean±SD) was 15.7±0.5 years, height was 175±9 centimetres and weight 62±9 kilograms. All subjects were active youth association football (soccer) players, recruited from the local football club. Subjects had no previous experience with resisted sprint training but they had some previous experience with counter-movement jumps and standing long jumps. The testing was completed during their late pre-season period. All of the subjects gave their written informed consent to participate in this study, which was approved by the Stockholm Regional Board of Ethics and performed in accordance with the Declaration of Helsinki. Athletes were also given a volunteer information sheet describing the study and outlining potential benefits and risks. After consideration, all subjects volunteered and provided informed consent. Soccer players were all part of the same club and competed at competitive youth level, playing in the Swedish U16 and U17 Division in the upcoming season. There were 20 (n=20) players from the U16 team and 7 players (n=7) from the U17 team. The requirements were that the athletes were devoid of lower limb injuries (<3 months pre-testing) and able to sprint and jump maximally. In total, 27 subjects were recruited before the study, but because of illness or injury, 24 subjects (6 control subjects, 18 intervention subjects) completed all parts of the testing and intervention program. The injuries or illnesses did not happen on any of the intervention training sessions. The results of this study are based on the data obtained from these 24 subjects. The players did not perform any additional or gym-based strength work for the duration of the intervention. The remaining team specific training included 4 soccer specific sessions, 2 of them of longer (75-90 minutes) and 2 shorter (45-60 minutes) duration and a competitive match once per week, once the season started (before the 7th session of the intervention).

Athletes were divided into two intervention groups – the resisted sprint training (RST: n=8) and the unresisted sprint training (UST: n=10) group. The control group (TAU: n=6) was matched with the experimental groups based on age and anthropometrics. The grouping of experimental groups was done based on their Force-velocity (F-v) profiles, more accurately their Force-velocity slope (S_{Fv}). Data was acquired from the 30-m unresisted sprints using 5-m split times
and inserted into the excel spreadsheet (Appendix FVP Split Time.xls) for calculation. As the study by Samozino et al. 2016 showed, this method is accurate, reliable and valid to evaluate mechanical properties of sprinting. Training groups (RST and UST) were matched for their F-v slopes, so both experimental groups had similar average F-v slope values (RST: -62.2%, UST: -63%). The slope of the F–v relationship determines the F–v mechanical profile (SFV), this is the individual ratio between force and velocity qualities (Samozino et al. 2016). This means that steeper the slope, the more negative its value, more “force-oriented” the F-v profile and vice versa (Morin et al. 2016a).

3.2 Equipment

For resisted sprint trials, the robotic resistance device called 1080Sprint (1080 Motion AB, Lidingö, Sweden) was used. The 1080 Sprint is a portable, cable resistance device that uses a servomotor (2000 RPM OMRON G5 Series, OMRON Corporation, Kyoto, Japan) to modulate resistance load. The device has a computer operated electrical engine, which is attached to a drum with a line, and is programmed so that resistance can be set independent of each other when the line is being pulled out and in on the drum. As the line is pulled out, the speed set will determine maximum speed allowed. In the other phase the set speed will determine at what rate the line is being pulled in. This system can independently control resistance and speed in both the concentric and eccentric phase of movement. The motor is connected to a composite fiber cord that is wrapped around a spool and can extend up to 90 meters. The cord was attached to the athlete via a hip belt or hip harness (Exxentric, Stockholm, Sweden). The resistance load was controlled by the Quantum computer software (1080 Motion AB, Lidingö, Sweden), where all sprinting kinetics data were stored. The unit was programmed to provide isotonic horizontal resistance to the athlete, in increments of 1-kg amount, between a minimum manufacturer set resistance of 1-kg, and a maximum of 30-kg. Instantaneous velocity time data were collected from the manufacturer software at a rate of 333-Hz. This device has been used in recently published resisted sprint studies by Mangine et al. (2017) and Cross et al. (2018). The manufacturer (Bergkvist et al. 2005) has previously reported the repeatability (± 0.7%) and accuracy of the 1080 Sprint for measuring position, velocity (± 0.5%) and force (± 4.8N). Pre- and post-training measurements were performed with the same protocol and equipment. Jump trials were collected using the OptoJump hardware and OptoJump Next software (MicroGate, Bolzano, Italy). Height and weight were recorded in all participants via a commercial scale and stadiometer (SECA, Hamburg, Germany).
3.2 Testing Procedure

Athletes were provided with three (3) familiarisation sessions, similar to that of primary testing procedures, >48 hours before pre-testing. Athletes were instructed to wear their typical footwear (football boots) for maximal sprinting and normal training (running) shoes for jumping. Before testing, athletes performed a standardized 20 min warm-up including jogging, dynamic stretching, technical drills, and four submaximal 30m stride outs (two at 70, 80 and 90% of maximal self-selected effort). All athletes followed a progressive habituation training to heavy resistance prior to the beginning of the study. This study was based on the assessment, and subsequent prescription, of resistance loads based on the operational procedures outlined in recent research by Cross et al. (2017b).

Athletes were individually assessed for horizontal Force-velocity and Load-velocity profiles by utilizing a battery of sprints against increasing resistance provided by the 1080Sprint. The testing protocol consisted of 6 sprints: 2 performed against a minimal resistance (considered “unloaded”) on the 1080Sprint (set at minimal resistance of 1kg) and 4 with increasing loading that equated to 25%, 50%, 75% and 100% (to the nearest 1 kg) of body mass. All sprints were conducted on an outdoor artificial (“astro”) turf soccer pitch. All sprint tests using the 1080Sprint were conducted in the “Isotonic” mode to provide the smoothest resistance during testing, as per manufacturer recommendations. The testing was directly preceded by a minimum of 5 min passive rest after the warm-up, and a minimum of 3 min passive rest was prescribed between each trial. Two parallel cones were positioned approximately 3-5 meters from the 1080 Sprint to denote the “starting line”. The athletes were instructed to begin each maximal trial whenever they were ready. Participants were verbally encouraged throughout each maximal sprint. The Quantum software of the 1080Sprint can detect the athlete’s position and then be set to initiate data collection on his first movement for a specified distance (i.e., 20 meters). The starting leg recorded during first pre-testing was made constant throughout all the training and post-testing. For each trial, the athlete would step up to a marked line on the pitch, take up all the tether (lean into the device), and sprint forward from a standing split stance without countermovement. All athletes performed the sprints on the same pitch during each training session with a marked start and finish with 2 parallel cones for each distance used. Athletes were also verbally encouraged to present maximal involvement from the outset, and sprint “through” each distance marker to ensure a full maximal collection devoid of any purposeful deceleration.
The vertical jumping (VJ) tests: the procedure for VJ consisted of 3 trials of counter-movement jumps (CMJ), done on an artificial grass (“astro turf”) football pitch using regular running shoes. The CMJs were tested using the Opto Jump (Microgate, Bolzano, Italy) hardware and software. They performed three (3) trials of the CMJ with the hands placed on their hips during the take-off, flight and landing phase for every trial. They were given >60s of rest between each trial. The participants were instructed to descend to a depth that would allow them to generate the highest possible jump and to “double” land to make sure the measurements were valid. The highest jump of the 3 trials was selected for analysis. Any jump that did not meet the considered requirements was excluded from calculations and repeated.

The horizontal jumping (HJ) tests: 3 trials of standing long jumps (SLJ) were performed after completing the CMJs, with at least 2 minutes of rest between performing the SLJs. From the erect position the subject executed the jump as far as possible (measurement accurate to 1.0 cm), landing on both feet without falling backward. The testing was done on an artificial grass (“astro turf”) football pitch using regular running shoes. At the moment of take-off the feet were in the parallel position. Distance was measured in centimeters and done by the same researcher on both the pre- and post- testing, to exclude the chance of the measurement bias. The rest set between trials was <60s for each athlete. The best trial of the 3 jumps was selected for analysis. Any jump that did not meet the considered requirements was excluded from calculations and repeated.

3.3 Loading and Sprint Distance

For resisted trials, 4 sprints with increasing loading protocol that equated to 25%, 50%, 75% and 100% (to the nearest 1 kg) of body mass, were prescribed. The conversion to the 1080Sprint loading was done by the conversion from the manufacturer, which is 0.35. So if an athlete required 40kg load (as 50% of BM), the resistance programmed into the machine would equal 14 kg. This span of loading parameters was selected to provide a wide array of data for each athlete, to enable the accurate plotting of load-velocity relationships. The distance sprinted was 30m for unloaded sprint trials and 20m for all of the resisted trials. Distances were selected from previous studies (Cross et al. 2017b; Maćkala et al. 2015) and pilot testing and set at 30m for unloaded and 20m for loaded sprints. Those distances were shown to be long enough to reach the maximal velocity or to be within <95% of their absolute unloaded velocity. For unloaded sprint the setting on the 1080Sprint device was at minimum (1kg) setting and the
obtained raw unfiltered data was later inserted into the modified Excel spreadsheets (see Appendix FVP Split Time.xls) to adjust for the resistance provided by the device.

### 3.4 Data Analysis

All the data has been collected using the 1080Sprint built-in software, which has been shown to be proven and valid (Bergkvist et al. 2005). From an unloaded 30-m sprint and each 5-m split time sprint mechanical outputs were computed (Figure 1) using the Excel spreadsheet (Appendix FVP Split Time.xls). The computation of individual loading parameters from multiple resisted sprints combined into a load-velocity relationship (Figure 2).

**Force-velocity profiling:** A Force-velocity profile measures athletes force-power-velocity characteristics during a sprint and gives information if an athlete is force- or velocity-deficient, as well as provides an optimal profile which to work towards (i.e. two athletes may display similar power outputs, their force and velocity capacities may be markedly different) (Jimenez-Reyes et al. 2017). In theory, all athletes are biased towards either strength (force) or speed (velocity) which may limit them in jumping and/or sprinting movement, so measuring force and velocity – independent from power output – is useful for identifying whether an athlete is force- or velocity-deficient (Jimenez-Reyes et al. 2017; Samozino et al. 2014).

For resisted trials, a validated method by Samozino et al. 2016 was used to model external horizontal force production from centre of mass movement. Methods outlined in the study by Cross et al. (2017a), allowed to get information about the maximal horizontal force ($F_0$), maximal running velocity ($v_0$) and maximal mechanical power output in the horizontal direction ($P_{\text{max}}$). It also provided information about maximal effectiveness of total force produced that is directed in the forward direction at sprint start ($RF_{\text{max}}\%$), rate of decrease in RF which describes the ability to limit the decrease in mechanical effectiveness with increasing speed ($D_{RF}$), actual maximal speed ($v_{\text{max}}$) and optimal velocity for developing horizontal power which is the speed at which the athlete should train (load in until that speed can be produced) ($v_{\text{opt}}$). For an extensive clarification of those parameters see a study by Morin et al. (2016a). The aim of profiling power over multiple-trials is to determine the metrics involved to present $P_{\text{max}}$ (Soriano et al. 2015).
The force-velocity relationship using multiple trials of resistive loads has been previously validated and shown to be linear (Cross et al. 2017b). Therefore, an associated linear load-velocity profile can be computed to represent the span of loading where mechanical conditions can be targeted. Peak velocities achieved during each resisted trial condition (25, 50, 75, 100% of BM) were taken and matched with the exact resistance protocol from each respective sprint.

In this data, the unloaded sprints were done against minimal possible resistance provided by

![Figure 1: Force-velocity (F-v) and power-velocity (P-v) relationships used to compute maximal theoretical force (\(F_0\)) and velocity (\(v_0\)), maximal power \(P_{max}\) and corresponding optimal velocity \(v_{opt}\). The slope of the F-v relationship (S_fv) indicates the force-velocity profile of the athlete. Data is for 1.74m, 59kg youth soccer player.](image1)

![Figure 2: Running velocity measured with the 1080Sprint device during resisted sprint acceleration, against loads corresponding to unloaded (minimum load of 1kg), and 25, 50, 75 and 100% BM for a 1.74 m, 59 kg youth soccer player.](image2)
the 1080Sprint machine (1kg). The calculation provided by the 1080 Quantum software allowed to calculate the optimal load (L_{opt}) value at which the P_{max} development is the greatest (Bergkvist et al. 2005). By combining the data calculated in the unresisted conditions and applying these parameters to the load-velocity (L-v) profile, each athlete in the RST group was provided with an individualised resisted sprint training load. *Load-velocity profiling* is done in order to decide the optimal training load for each athlete utilized in training.

### 3.5 Training Sessions

The overall training design followed the recent studies done on resisted sprinting (Morin et al. 2016b). There were 3 sessions of familiarisation to heavy and very heavy loads over 2 weeks and 1 week of testing sessions. After that, the subjects did the training intervention that lasted for 4 weeks. Resisted sprint sessions consisted of 5 20-meter sprints at L_{opt} calculated from the pre-testing. Each repetition was separated by at least a 3 minute rest. The unresisted sprint sessions were comprised of 8 20-meter sprints, with at least a 3 minute rest between each trial. This was done in an attempt to match the sprinting duration between the resisted and unresisted method, although there is no published data on the matter.

**Table 2:** Study timeline.

<table>
<thead>
<tr>
<th>Session</th>
<th>Force-velocity-power assessment for both experimental groups</th>
<th>Experimental Group</th>
<th>Control Group Training as Usual</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2 unloaded x 30m 4 loaded x 20m (25, 50, 75, 100% BM)</td>
<td>RST; 5x20m</td>
<td>UST; 8x20m</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>-</td>
<td>2 unloaded x 30m</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>10</td>
<td>2 unloaded x 30m</td>
<td>-</td>
<td>2 unloaded x 30m</td>
</tr>
</tbody>
</table>

BM: body mass; L_{opt}: optimal load used by the RST experimental group

### 3.5 Statistical Analysis

Data was analysed using IBM SPSS 22 statistical package for Windows (SPSS, Chicago, IL, USA). All numeric variables are displayed as means ± standard deviations (SD) within 95% confidence intervals. The normality of distribution and homogeneity of variances was checked with Shapiro-Wilk test and Levene’s test, respectively. Between group difference on the delta
was assessed with one-way analysis of variance (ANOVA) or with Kruskal-Wallis test in case of asymmetrically distributed variables. When a significant p-value was detected, POST-HOC test or independent samples T-test was used in order to obtain differences between the groups. Tukey’s test was used in case of equal variances between groups, otherwise Games-Howell test was applied. Pre- and post- training within group differences were determined using dependent samples T-test, and Wilcoxon singed-rank test was used for asymmetrically distributed variables and/or unequal variances between groups. Additionally, Cohen's d was used to compare effect size (ES) Cohen's effect sizes were interpreted as follows: d < 0.2 = trivial effect, d < 0.5 = small effect, d < 0.8 = medium effect, and d > 0.8 = large effects (Cohen 1988). Statistical significance was set at alpha equal to 0.05, with p ≤ 0.05. Statistical trend was set at p ≤ 0.10. Statistical power was determined to be > 0.90 at the 0.05 alpha levels.

4. Results

Pre-testing data analysis showed that there were no significant differences between groups except for $V_0$ and $V_{\text{max}}$ when comparing RST and TAU groups. The main result from the within group comparison showed significant differences in the RST group, variables that significantly changed pre- to post- were body mass ($p=0.010$), CMJ ($p=0.047$), SLJ ($p=0.010$), T30 ($p=0.037$), T20 ($p=0.036$), T10 ($p=0.038$), T5 ($p=0.038$) and $RF_{\text{max}}$ ($p=0.039$). For all of those variables of CMJ, SLJ and $RF_{\text{max}}$ increased, representing better performance, while the sprint times decreased in time, which also represents an improvement in performance. $F_0$ and $P_{\text{max}}$ variables were not significant, although they showed a trend with p values of 0.089 and 0.088 respectively, both increases represent a positive change. In other groups, UST showed a meaningful increase in CMJ ($p=0.007$) and SLJ ($p=0.001$) and a trend in body mass change ($p=0.09$). The control group (TAU) showed a significant increase in body mass ($p=0.046$) and a significant decrease in $V_{\text{max}}$ ($p=0.016$) and a decrease in $P_{\text{max}}$ ($p=0.075$) which is a trend. A detailed overview of all the results can be seen in Table 4 and 5. The characteristics of the participants are detailed in Table 3.

The main findings from between group comparison are meaningful changes in the RST group compared to the UST and TAU groups in the following variables: $T20$ ($p=0.043$ vs UST; $p=0.022$ vs TAU), $T10$ ($p=0.025$ vs UST; $p=0.012$ vs TAU), $T5$ ($p=0.017$ vs UST; $p=0.005$ vs TAU), $F_0$ ($p=0.015$ vs UST; $p=0.007$ vs TAU), $P_{\text{max}}$ ($p=0.034$ vs UST; $p=0.020$ vs TAU), $S_f$ ($p=0.022$ vs UST; $p=0.007$ vs TAU), $RF_{\text{max}}$ ($p=0.014$ vs UST; $p=0.006$ vs TAU) and $DRF$ ($p=0.021$ vs UST; $p=0.007$ vs TAU). Jump variable SLJ is significant when comparing RST vs
TAU (p=0.01) and UST vs TAU (p=0.001), while CMJ is only significant in UST vs TAU (p=0.017) and showing a trend when comparing RST vs TAU (p=0.053). Representation of between group changes can be viewed in Table 6.

**Table 3**: Descriptive characteristics of all the participants and subjects in each group, values are presented as mean and standard deviation (±SD).

<table>
<thead>
<tr>
<th></th>
<th>SAMPLE (N=27)</th>
<th>RST (n=8)</th>
<th>UST (n=10)</th>
<th>TAU (n=6)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Body mass (kg)</strong></td>
<td>62.0±8.9</td>
<td>62.2±9.6</td>
<td>63.7±10.3</td>
<td>61.0±7.8</td>
</tr>
<tr>
<td><strong>Stature (cm)</strong></td>
<td>175.2±9.1</td>
<td>178.2±8.6</td>
<td>174.6±12.0</td>
<td>174.0±6.2</td>
</tr>
<tr>
<td><strong>Age (yrs)</strong></td>
<td>15.7±0.5</td>
<td>15.6±0.4</td>
<td>15.6±0.5</td>
<td>15.9±0.4</td>
</tr>
</tbody>
</table>

*Kg = kilograms, cm = centimeters, yrs = years.*
### Table 4: Athlete body-mass, jump and sprint performance variables during pre- and post-testing for RST, UST and TAU groups.

<table>
<thead>
<tr>
<th></th>
<th>RST (n=8)</th>
<th>UST (n=10)</th>
<th>TAU (n=6)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Post-Pre</td>
<td></td>
<td>Post-Pre</td>
</tr>
<tr>
<td></td>
<td>µ ± SD</td>
<td>%Δ ± ΔSD</td>
<td>µ ± SD</td>
</tr>
<tr>
<td><strong>BM (kg)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>62.15±9.64</td>
<td>2.3±0.53</td>
<td>63.73±10.26</td>
</tr>
<tr>
<td>Post</td>
<td>63.58±9.11</td>
<td>0.5 (trivial)</td>
<td>64.48±10.16</td>
</tr>
<tr>
<td><strong>CMJ (cm)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>31.11±3.86</td>
<td>4.7±1.00</td>
<td>29.16±4.83</td>
</tr>
<tr>
<td>Post</td>
<td>32.56±4.86</td>
<td>0.14 (trivial)</td>
<td>31.01±4.90</td>
</tr>
<tr>
<td><strong>SLJ (cm)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>211.25±17.89</td>
<td>7.2±2.05</td>
<td>206.9±14.18</td>
</tr>
<tr>
<td>Post</td>
<td>226.38±19.94</td>
<td>-3.0 (small)</td>
<td>219.10±17.72</td>
</tr>
<tr>
<td><strong>T30 (s)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>5.34±0.24</td>
<td>-2.0±0.5</td>
<td>5.42±0.47</td>
</tr>
<tr>
<td>Post</td>
<td>5.15±0.20</td>
<td>-0.3 (small)</td>
<td>5.45±0.38</td>
</tr>
<tr>
<td><strong>T20 (s)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>3.96±0.22</td>
<td>-4.2±0.06</td>
<td>4.00±0.36</td>
</tr>
<tr>
<td>Post</td>
<td>3.79±0.17</td>
<td>-0.2 (small)</td>
<td>4.06±0.28</td>
</tr>
<tr>
<td><strong>T10 (s)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>2.50±0.20</td>
<td>-5.7±0.06</td>
<td>2.55±0.30</td>
</tr>
<tr>
<td>Post</td>
<td>2.36±0.15</td>
<td>-0.2 (small)</td>
<td>2.61±0.21</td>
</tr>
<tr>
<td><strong>T5 (s)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre</td>
<td>1.67±0.20</td>
<td>-7.9±0.06</td>
<td>1.71±0.26</td>
</tr>
<tr>
<td>Post</td>
<td>1.54±0.15</td>
<td>-0.2 (trivial)</td>
<td>1.77±0.18</td>
</tr>
</tbody>
</table>

Presenting the within group outcomes of the main anthropometric, jump, sprint and sprint mechanical variables. Abbreviations: n=sample size, BM=body mass, µ=mean, SD=standard deviation, %Δ=change between pre and post in percent, ΔSD=standard deviation of the change, d = Cohen’s d effect size; BM = body mass, CMJ = counter-movement jump, SLJ = standing long jump, T30 = 30-m sprint, T20 = 20-m sprint, T10 = 10-m sprint, T5 = 5-m sprint.

Triple asterix (**) is significance value (p < 0.001 vs Pre-test), double asterix (***) is significance value (p < 0.01 vs Pre-test), asterix (p < 0.05 vs Pre-test) and (§) is a trend (p < 0.10). Values are presented as mean ± standard deviation; percent change ± standard deviation and standardized effect size ± 95% confidence limits.
Table 5: Athlete sprint mechanics variables during pre- and post-testing for RST, UST and TAU groups

<table>
<thead>
<tr>
<th></th>
<th>RST (n=8)</th>
<th>UST (n=10)</th>
<th>TAU (n=6)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>µ ± SD</td>
<td>Post-Pre</td>
<td>µ ± SD</td>
</tr>
<tr>
<td></td>
<td>%Δ ± ΔSD</td>
<td>d (effect)</td>
<td>%Δ ± ΔSD</td>
</tr>
<tr>
<td>$F_0$ (N·kg⁻¹)</td>
<td>Pre</td>
<td>5.5±1.66</td>
<td>18.2±0.04</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>6.5±1.70§</td>
<td>4.66±0.80</td>
</tr>
<tr>
<td>$V_0$ (m·s⁻¹)</td>
<td>Pre</td>
<td>8.77±1.13</td>
<td>-4.0±0.20</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>8.42±0.93</td>
<td>9.24±1.23</td>
</tr>
<tr>
<td>$P_{max}$ (W·kg⁻¹)</td>
<td>Pre</td>
<td>11.74±2.44</td>
<td>14.4±0.08</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>13.43±2.53§</td>
<td>10.64±2.06</td>
</tr>
<tr>
<td>$S_{FV}$ (%)</td>
<td>Pre</td>
<td>-65.38±25.92</td>
<td>21.2±1.42</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>-79.25±27.35</td>
<td>-52.00±15.30</td>
</tr>
<tr>
<td>$R_{F_{max}}$ (%)</td>
<td>Pre</td>
<td>36.75±5.06</td>
<td>8.9±1.28</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>40.00±3.78*</td>
<td>34.20±4.24</td>
</tr>
<tr>
<td>$D_{RF}$</td>
<td>Pre</td>
<td>-6.13±2.41</td>
<td>21.2±0.11</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>-7.43±2.53</td>
<td>-4.89±1.41</td>
</tr>
<tr>
<td>$V_{max}$ (m·s⁻¹)</td>
<td>Pre</td>
<td>7.54±0.42</td>
<td>0.2±0.09</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>7.56±0.51</td>
<td>7.70±0.61</td>
</tr>
</tbody>
</table>

Presenting the within group outcomes of the sprint mechanical variables. Abbreviations: n=sample size, x̅=mean, SD=standard deviation, Δ%=change between pre and post in percent, ΔSD=standard deviation of the change, d = Cohen’s d effect size; $F_0$ = theoretical maximal horizontal force, $V_0$ = theoretical maximal running velocity, $P_{max}$ = maximal mechanical horizontal power output, $S_{FV}$ = slope of the linear $F$-$v$ relationship, $R_{F_{max}}$ = maximal value of ratio of force that is directed in a forward direction, $D_{RF}$ = rate of decrease in ratio of force, $V_{max}$ = actual maximal running velocity. Triple asterix (***) is significance value ($p < 0.001$ vs Pre-test), double asterix (**) is significance value ($p < 0.01$ vs Pre-test), asterix ($p < 0.05$ vs Pre-test) and ($) is a trend ($p < 0.10$). Values are presented as mean ± standard deviation; percent change ± standard deviation and standardized effect size ± 95% confidence limits.
Table 6: Post – pre changes in athlete body-mass, jump, sprint and mechanical sprint variables between the RST, UST and TAU groups.

<table>
<thead>
<tr>
<th>Variable</th>
<th>RST (n=8)</th>
<th>UST (n=10)</th>
<th>TAU (n=6)</th>
<th>RST vs UST</th>
<th>RST vs TAU</th>
<th>UST vs TAU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body mass (kg)</td>
<td>1.43±1.14</td>
<td>0.75±1.25</td>
<td>0.50±0.40</td>
<td>p=0.02</td>
<td>p=0.01</td>
<td>p=0.001</td>
</tr>
<tr>
<td>CMJ (cm)</td>
<td>1.45±1.71</td>
<td>1.85±1.68</td>
<td>-0.63±1.70</td>
<td>p=0.02</td>
<td>p=0.01</td>
<td>p=0.001</td>
</tr>
<tr>
<td>SLJ (cm)</td>
<td>15.13±12.21</td>
<td>12.2±8.42</td>
<td>-2.25±4.61</td>
<td>p=0.01</td>
<td>p=0.001</td>
<td>p=0.01</td>
</tr>
<tr>
<td>T30 (s)</td>
<td>-0.20±0.22</td>
<td>0.03±0.25</td>
<td>0.09±0.19</td>
<td>p=0.02</td>
<td>p=0.01</td>
<td>p=0.001</td>
</tr>
<tr>
<td>T20 (s)</td>
<td>-0.17±0.18</td>
<td>0.06±0.23</td>
<td>0.05±0.15</td>
<td>p=0.02</td>
<td>p=0.01</td>
<td>p=0.001</td>
</tr>
<tr>
<td>T10 (s)</td>
<td>-0.14±0.16</td>
<td>0.06±0.22</td>
<td>0.03±0.14</td>
<td>p=0.03</td>
<td>p=0.01</td>
<td>p=0.001</td>
</tr>
<tr>
<td>T5 (s)</td>
<td>-0.13±0.15</td>
<td>0.06±0.20</td>
<td>0.01±0.12</td>
<td>p=0.02</td>
<td>p=0.01</td>
<td>p=0.001</td>
</tr>
<tr>
<td>F₀ (N·kg⁻¹)</td>
<td>1±1.43</td>
<td>-0.66±1.70</td>
<td>0.05±0.50</td>
<td>p=0.02</td>
<td>p=0.01</td>
<td>p=0.001</td>
</tr>
<tr>
<td>V₀ (m·s⁻¹)</td>
<td>-0.4±0.58</td>
<td>0.32±1.29</td>
<td>-0.51±1.05</td>
<td>p=0.04</td>
<td>p=0.02</td>
<td>p=0.01</td>
</tr>
<tr>
<td>Pₘₐₓ (W·kg⁻¹)</td>
<td>1.69±2.41</td>
<td>-1.00±2.63</td>
<td>-0.47±0.67</td>
<td>p=0.03</td>
<td>p=0.02</td>
<td>p=0.001</td>
</tr>
<tr>
<td>RFₘₐₓ (%)</td>
<td>3.25±3.62</td>
<td>-1.45±5.27</td>
<td>-0.17±2.71</td>
<td>p=0.01</td>
<td>p=0.001</td>
<td>p=0.01</td>
</tr>
<tr>
<td>DRF</td>
<td>-1.30±1.94</td>
<td>0.87±2.36</td>
<td>-0.29±0.70</td>
<td>p=0.02</td>
<td>p=0.01</td>
<td>p=0.01</td>
</tr>
<tr>
<td>Vₘₐₓ (m·s⁻¹)</td>
<td>0.02±0.25</td>
<td>0.08±0.41</td>
<td>-0.24±0.17</td>
<td>p=0.02</td>
<td>p=0.01</td>
<td>p=0.001</td>
</tr>
</tbody>
</table>

Presenting the between group outcomes of the main anthropometric, acceleration and sprint variables. Abbreviations: n=sample size, Î±=mean, SD=standard deviation, p = significance level, depicted only for significant changes; BM = body mass, CMJ = counter-movement jump, SLJ = standing long jump, T₃₀ = 30-m sprint, T₂₀ = 20-m sprint, T₁₀ = 10-m sprint, T₅ = 5-m sprint. F₀ = theoretical maximal horizontal force, V₀ = theoretical maximal running velocity, Pₘₐₓ = maximal mechanical horizontal power output, Sₒ = slope of the linear F-V relationship, RFₘₐₓ = maximal value of ratio of force that is directed in a forward direction, DRF = rate of decrease in ratio of force, Vₘₐₓ = actual maximal running velocity.

5. Discussion

Overall, only the resisted sprint group (RST) made progress across all of the variables observed – sprint and acceleration times, sprint mechanics and jumps. The RST and TAU groups significantly increased their body mass and the UST group showed a trend. These findings could point toward that the improvements made are from the intervention itself, not the gain in body mass.

After 4 weeks of training, the participants in RST had no significant change in body height. RST in youth soccer population showed significant differences in body mass (increase 2.3%), T₃₀ (3.7% decrease in time), T₂₀ (4.2% decrease in time), T₁₀ (5.7% decrease in time), T₅ (7.9% decrease in time), CMJ (4.7% increase in height), SLJ (7.2% increase in length) and also RFₘₐₓ (8.8% increase) when comparing pre- and post- testing. There were also noticeable trends in F₀ and Pₘₐₓ parameters (p=0.089 and p=0.088 respectively). In the introduction, it was mentioned that a sprint or acceleration of 1-3% could have a meaningful impact on the outcome.
of a certain play or action, so the improvements here definitely show meaningful changes that affect the sport performance positively.

In the UST group changes that were significant are the two jumps, CMJ improved by 6.3% and SLJ by 5.9%. All of the other changes are statistically not significant, the body mass is showing a trend (p=0.09).

In the TAU group we have seen two significant changes, one is in the body mass and the other one is the $V_{\text{max}}$. $P_{\text{max}}$ is showing a trend (p=0.075). In percentages the changes are 0.8% for body mass and -3.0% for $V_{\text{max}}$.

The initial hypothesis was that the RST group experiencing high horizontal forces during training would transfer into an increase in a mechanical capacity (i.e. increased $F_0$), mainly via more effective ground force application because of the high horizontal force. That has been partially observed in pre- to post- results of RST, $F_0$ showing a trend with a p value of 0.089. One possible explanation of why this is showing only as a trend could be the duration of the training intervention (4 weeks) and an intervention with longer duration of resisted sprinting (i.e. 8 weeks) would be see a significant change. To back this observation is the finding that $P_{\text{max}}$ showed a trend with a p value of 0.088, so the maximal power output in the horizontal direction has improved, but still the duration of 4 weeks might not have been long enough to see a significant change. Another marker of improvement is $RF_{\text{max}}$, which is statistically significant in the RST group, and it represents the theoretical maximal effectiveness of force application (i.e. proportion of total force production directed in the forward direction of motion at sprint start). This shows that the RST group became more effective at directing their forces in forward direction to accelerate better. It also shows similar findings as Morin et al. (2016b) have found that very heavy resisted sprinting improves mechanical effectiveness and maximal horizontal force capabilities in amateur soccer players.

Another hypothesis was that the RST group would improve early acceleration time more than the UST, which proves to be true for split times of 5, 10 and 20 meters. They were all significantly better than UST and the control group (TAU). That is in agreement with Morin et al. 2016b, who also found that very heavy resisted sprinting (load corresponding to 80% of body mass) is clearly effective in improving 5- and 20-meter sprint performance when compared to UST in amateur soccer players. However, the present study produced even larger
performance gains in both the 5m (7.9% vs 5.7%) and the 10m (5.7% vs 3.5%) sprint times compared to Kawamori et al. (2014). This is both interesting and unexpected since the duration of this intervention was shorter. One possible explanation could be that the resistance (30% \(V_{\text{dec}}\)) used in Kawamori et al. (2014) is categorized as very heavy, but the resistance in the present study was even heavier, at 50% \(V_{\text{dec}}\). In the mentioned study by Kawamori et al. (2014) it has also been discussed that even greater external load could induce even larger sprint and acceleration improvements. Loading used in the present study was, on average, 103.5% of body mass, which is considered very heavy under the classification of Petrakos et al. (2016) and is even higher than what previous studies (Morin et al. 2016b; Cross et al. 2018) have used.

The third hypothesis was that the RST group would improve horizontal and vertical jump performance more than the UST group, but the findings have shown this not to be the case, since both RST and UST groups improved their jump performance similarly. One interesting observation is that the improvement in RST group for CMJ was 4.7% and 7.2% for SLJ, for the UST group the percentages are 6.3% for CMJ and 5.9% for SLJ. Those results are in agreement with some previous studies (Yanci et al. 2014; Loturco et al. 2015b; Maćkala et al. 2015; Kale et al. 2009). This could be because maximal velocity sprinting (i.e. unresisted) is more vertically oriented and therefore shows bigger improvement in vertical jumps, in contrast with resisted sprinting that improve the horizontal jumps more. This is also on point with the goal of resisted sprinting to direct the forces more horizontally (Morin et al. 2016b).

The last hypothesis was that the RST group would improve the 30-meter sprint time more (i.e. better time) than the UST group. This has shown not to be statistically significant, however looking at within group changes than we see that the RST group improved the 30-m sprint time 3.8% and the UST group actually performed a bit worse (0.5% worse time than at pre-testing) but that may be due to many different factors, which will be discussed next.

One big factor here is the motivation of the UST group to do their sprints maximally. This study used a youth population and the participants could feel that using the resisted sprints could be much more appealing than just doing regular sprints. Note that the placebo could be a factor for the RST group. They could have felt as if they were getting more attention and were subject to a new and exciting type of training compared to the UST group who could have felt that they were “just” doing regular sprinting. In that case, we have a situation where the RST group might train harder and is more focused and puts in a higher effort in each training compared to the
UST group. If athletes believe that they are getting a beneficial treatment, i.e. a placebo effect, there is evidence that they are able to perform better on physiological testing such as performance measurements (e.g. due to expectancy and motivation) (Beedie and Foad 2009; Bérdi et al 2011). Moreover findings from Beedie and Foad (2009) indicate that expectancy and motivation might also play a significant role in generating negative outcomes, i.e. a nocebo effect in sports performance. This study tried to reduce any eventual placebo or nocebo effect and to maximize the effort from both groups; athletes in the UST group were set up to compete head to head against each other during training. This measure intended to even out any possible placebo issues.

The improvement in sprint and acceleration for the RST group confirms previous findings (Kawamori et al 2014; Morin et al 2016b; Cross et al 2018). However, all those studies used both longer duration of the intervention periods and higher number of training sessions than the present study. Petrakos et al. (2016) also recommended that the minimal duration of resisted sprinting intervention should be 6 or more weeks. However, due to practical reasons, the present study was put in a realistic context of a team sport where we had a 4-week training block available to improve sprint and acceleration performance. Findings of the present study are very important to all practitioners in the real world of athletic development, since frequently, the time is an issue, so the minimal effective dose for maximal result is always the goal.

An attempt to match the sprint durations (UST: 8x20m - each sprint took around 4 seconds – total time 32s; RST: 5x20m each sprint took between 6 and 7 seconds – total time 30-35s) adds to the strength of this study. With that being said, the UST actually did more sprints (8) than RST (5), but the total sprinting duration has been very similar. However, it could be argued that it is more time efficient to only do 5 sprints than 8 if the rest time is the same (3 minutes) as it was in the case of the present intervention.

All athletes were tested 7 days after completing their last training session, that is similar to previous studies in the field (Cross et al. 2018; Morin et al. 2016b). One thing to note here is the fact that the season has already started a little over mid-way of the intervention, so the fatigue definitely has an effect on all the players. Possibly, that is why the results from UST and TAU are either more or less unchanged (UST) or became worse (TAU) and heavily resisted sprinting might have an effect in retaining the sprinting capabilities gained during training. As such, perhaps it would make sense to use it in small dosages even during the season, the so
called “micro-dosing”, just to retain the gains acquired in the off- and pre-season phases. Researching such use of the heavy resisted sprinting could be another interesting way to look into the matter of resisted sprinting.

The duration of the study itself (4 weeks) can be considered both a strength and a weakness, a strength in the sense that meaningful differences were found in such a short period. Studies in the field of resisted sprinting had longer durations – 8 weeks (Morin et al. 2016b) or even 12 weeks (Cross et al. 2018). Duration as a weakness is discussed under the limitations.

5.1 Limitations

There are a number of limitations that need to be considered in the interpretation of the results of this study. One of them is the factor of motivation of UST group during training which has been discussed previously. Also to be considered is the duration of the intervention. A 4-week period might be too short to elicit any substantial change for the UST group, so longer training duration interventions should be considered. Another limitation is the time of the study, since we started in late winter period when the temperatures were lower (4 degrees Celsius when pre-testing) and progressively they have been raising (11 degrees Celsius when post-testing), so that may have effected both the individual effort and quality of training. However, the surface conditions did not differ to cause any kind of negative effect during the whole intervention.

6 Practical Application

RS training may be used to specifically improve maximal horizontal force production in sprinting. It has proven to be useful in youth team sport population to improve the athletes’ horizontal force production and force application, improve their sprint mechanics (i.e. better forward lean, less “popping up” immediately after start) and work on their strength qualities as well. Clear improvements were seen even in such a short period – 4 weeks, so this is definitely a viable option to use, if improving sprint and acceleration performance is the goal. In addition, it could be used in smaller dosages during the season, to preserve the sprint qualities gained during the pre- and off-season. It also positively affects the jump performance in both vertical and horizontal directions. Important to note is that athletes must be assessed on their Force-velocity slope ($S_{FV}$) done with six 5-meter split times. It was observed that Force-deficient athletes tend to have larger gains with resisted sprinting across all the parameters, but it was also noticed that the curve is moving with their progress and in turn, their needs change so they should be re-assessed after a training block of a certain training protocol to work on the qualities
they are lacking. All in all, RS has proven to be a worthwhile method to improve acceleration performance and should be used by practitioners across a wide array of sports.

7 Conclusion

In the present study adolescent football players were subjected to a four-week training intervention based on either very heavy RST or UST, further a control group followed the normal team training with no additional training stimuli. The main conclusion is that resisted sprinting has proven to be a worthwhile method to improve acceleration performance and is a valid method to be used by practitioners across a wide array of sports. It also improved jumping performance and sprint mechanical outputs, which point toward an improvement in better application of force in a horizontal direction. It also showed to be a worthwhile method used for youth populations and showing performance increases in a relatively short period. As such, it is a viable option to use in off-, pre- and even in-season to either advance or preserve sprint and acceleration qualities. The present study showed that using loads in excess of one body mass or more (103.5% on average) can be used to produce sprint and acceleration gains in late pubertal adolescent population. The improvements shown in this study in short sprints of distances between 5- and 30-meters are definitely worth implementing heavy resisted sprinting into training regimes of teams with access to the equipment necessary. Future research should look further into using resisted sprinting with youth populations and it should also look into using the outlined methods with athletes that already have substantial experience with resisted sprinting and see if any differences are made there. Also, another interesting future research could be looking into using the resisted sprinting during the season as part of the “maintenance” training to preserve speed qualities gained or even further develop them using minimal effective dosage.
8 Literature


Appendices

Appendix 1: Informed Consent

Informed consent

Information till forskningspersoner:

Projekttitel:
Effekten av tungt belastade sprinter kontra obelastade sprinter på lagidrottare.

Ansvariga:
Forskningshuvudman: Gymnastik- och idrottshögskolan (GIH).
Kontaktperson: Domen Bremec, 076 2605389 domen.bremec@student.gih.se
Kontaktperson: Mikael Derakhti, 0704 526117, mikael.derakhti@student.gih.se
Försöksledare: Niklas Psilander, 0707 759495, nklas.psilander@gih.se
Personuppgiftsansvarig: Gymnastik- och idrottshögskolan

Plats för undersökningen: GIH, Lidingövägen 1, 114 86 Stockholm, Älvsjö IP, Älvsjö
Idrottsväg 2, 125 30 Älvsjö

Bakgrund/syfte:
Det finns flertalet viktiga fysiologiska och psykologiska kapaciteter när det kommer till idrottsprestation. En högst relevant kapacitet i lagidrotter som fotboll, rugby och basketboll är förmågan att accelerera och utföra kortare sprinter på mellan 5-30 meter så snabbt som möjligt. Således är förbättring av acceleration- och sprintförmåga en integral del av träningsprogram utformade för idrottare. Vidare har det visats att en högre prestationenivå samt startplats i vissa lagidrotter till stor del påverkas av sprintförmågan.

Nyligen publicerad forskning visar att tungt belastade sprinter, till skillnad från den tidigare vedertagna uppfattningen om användningen av enbart lätt belastade sprinter, kan förbättra både kraft- och effektutveckling samt sprintteknik, två av de modaliteter som är viktigast för acceleration- och sprintprestation. Däremot råder det oklarhet om tungt belastade sprinter ger en större effekt på acceleration-, sprint- samt hopprestation jämfört med samma volym obelastade sprinter på lagidrottare
Syftet med den här studien är att undersöka hur en intervention bestående av tungt belastade sprinter respektive en intervention bestående av obelastade sprinter påverkar acceleration- och sprintprestationen samt hopprestationen hos unga lagidrottare.

**Vetenskapliga frågeställningar:**
1. Förbättrar en träningsintervention bestående av tungt belastade sprinter acceleration-, 30-meter sprint- samt hopprestationen hos unga lagidrottare?

2. Är det någon skillnad mellan en intervention bestående av tungt belastade sprinter respektive obelastade sprinter sett till förbättringen av de beroende variablerna acceleration och sprintprestation samt hopprestation hos lagidrottare?

**Metod:**
Två gånger i veckan under fyra veckor ska lagidrottare från ett fotbollslag i Stockholm att utföra sprintträning under kontrollerade former på Älvsjö IP. Träningen kommer att bestå av en standardiserad uppvärmning som efterföljs av 5-8 tungt belastade sprinter alternativt obelastade sprinter. Dessa fyra träningsveckor föregavs av två veckors familjärisering samt förtester på Gymnastik & Idrottshögskolan, GIH. Efter träningsinterventionens fyra veckor utförs två eftertester, återigen på GIH. De tester som utförs är kraft- hastighetsprofilering, 30-m sprint (med splittider på intervallerna 0-5, 5-10, 10-15, 15-20, 20-25 samt 25-30-m), hopptester i form av counter movement jump (CMJ) och standing long jump (SLJ).

**Kunskapsvinster:**
Det är viktigt att generera förståelse för hur olika typer av träning påverkar sprint- och hopprestationen hos lagidrottare. Detta dels på grund av att dessa kapaciteter är så pass viktiga för idrottsprestation och dels för att belysa ett kunskapsfält i idrottsforskningen som till stora delar är outforskat. Praktisk användbarhet samt jakten på att maximera resultat med så liten insats som möjligt är av största betydelse för tränare och ledare inom idrotten, denna typ av träning skulle kunna erbjuda detta för många idrottslag då de innebär en mycket specifik träning med låg volym.

**Hur går studien till?**
Studien är uppdelad i flera delmoment:

1. Första steget innebär att du som forskningsperson tillfrågas om deltagande i studien. Via möte informerar vi dig kring projektet. Ni omedels sedan att genomföra en
hälsoenkät, anledningen till detta är att vi vill ha information angående din hälsa och
träningsbakgrund för att du skall kunna inkluderas i studien.

2. Andra steget är att du ger ditt skriftliga samtycke om frivilligt deltagande i studien,
alternativt att din vårdnadshavare ger sitt samtycke om du är yngre än 16 år om du själv
frivilligt vill delta i studien.

3. Vid nästa delmoment kommer vi att utföra en rad tester för att mäta din sprint- och
hoppförmåga samt styrkeförmåga i underkropp.

4. Efter dessa förberedande tester samt efter två pass då du fått bekanta dig med
utrustningen och träningsmetoden kommer du att två ggr/vecka att genomföra ett
belastat sprintträningsprogram alternativt ett obelastat sprintträningsprogram i
anslutning till din vanliga fotbollsträning. Passet tar ca 30 minuter att genomföra och
består utöver en given uppvärmning på ca 10-15 minuter av 5-8 sprinter med maximal
insats. Träningspassen kommer att utföras på måndagar respektive onsdagar.

5. Efter träningsperioden upprepas samtliga tester och prover som utfördes före
träningsperioden.

Översiktlig veckoplanering

Vecka 1.
Måndag & onsdag ⇒ Familjärisering med träning och tester,
Torsdag & fredag ⇒ Förtester.

Vecka 2-5.
Måndag & Onsdag ⇒ Träningsintervention

Vecka 5 & 6
Fredag & Onsdag ⇒ Eftertester

Träningen kommer att utföras under övervakande av Mikael Derakhti (MSc student GiH) och Domen Bremec (MSc student)
båda två med god erfarenhet inom området. Träningen kommer ta ca 30 minuter och utföras i anslutning till den vanliga
fotbollsträningen.

Vilka är riskerna?
Sammantaget bedöms riskerna med deltagande som mycket små. De risker som deltagande
can medföra är, om än relativt små, framförallt fysiska och är som följer;

- Smärta, obehag och skada vid testning av sprint, hopp och styrkekapaciteter
samt vid sprint träning. De åtgärder som kommer att vidtas för att minimera risken
för detta är;

1. Inom test- och träningssområdet erfarna testledare och provtagare, alla testledare har även
kunskaper om idrottsskador samt har genomgått hjärt- och lungräddnings utbildung.

2. Standardiserade protokoll för utförande av tester och träning.
Information om dina resultat:
Om så önskas kommer du som forskningsperson i studien att få ta del av dina testvärden efter fullt slutfört deltagande. Denna information skickas till dig per mail alternativt att du kan hämta informationen i pappersformat från forskarteamet. Eventuellt oförutsedda fynd vid tester som kan beröra din hälsa meddelas dig omgående. Resultat från studien i sin helhet kan om så önskas erhållas på samma vis som individuella resultaten.

Hantering av data samt sekretess:

Ändamålet med undersökningsresultaten är att kunna studera effekterna av träningsstudiens resultat och sedan för vidare publicering i vetenskaplig tidskrift. Undersökningsresultaten kommer att kodas så att endast försöksledare och medarbetare kan koppla provresultaten till namn på forskningsperson. Vid publicering av forskningsdata kommer dessa inte kunna kopplas till dig som individ.

All data kommer att behandlas i enlighet med den nya dataskyddsförordningen.

Deltagande:
Deltagande är helt frivilligt och du som forskningspersonen kan välja att avsluta ditt deltagande utan att några som helst efterföljande konsekvenser.

Försäkring/ersättning:
Personskadeskyddsförsäkring tecknad av GIH gäller under studien.
Projekt: Effekten av tungt belastade sprinter kontra obelastade sprinter på lagidrottare.

Jag har muntligen informerats och har fått tillfälle att ställa frågor. Jag har tagit del av ovanstående skriftliga information och samtycker till deltagande i studien. Jag är medveten om att mitt deltagande är helt frivilligt och att jag när som helst och utan närmare förklaringar kan avbryta mitt deltagande.

..........................................................
 datum Forskningsperson: namnteckning och namnfördlygande

..........................................................
 datum Vårdnadshavare: namnteckning och namnfördlygande

..........................................................
 datum Ansvarig: namnteckning och namnfördlygande

Denna blankett finns i två likalydande kopior varav forskningsperson och försöksledare har var sin kopia

Kontaktperson: Domen Bremec, 076 2605389 domen.bremec@student.gih.se
Kontaktperson: Mikael Derakhti, 0704 526117, mikael.derakhti@student.gih.se
Personuppgiftsansvarig: Gymnastik- och idrottshögskolan.
Appendix 2: FVP - Split Time

Spreadsheet available: [here](#)!

<table>
<thead>
<tr>
<th>F0 (N/kg)</th>
<th>V0 (m/s)</th>
<th>Pmax (W/kg)</th>
<th>FV Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.11</td>
<td>7.78</td>
<td>17.70</td>
<td>-1.17</td>
</tr>
<tr>
<td>RF max (%)</td>
<td>Drf (%)</td>
<td>Vopt (m/s)</td>
<td>Max Speed (m/s)</td>
</tr>
<tr>
<td>46%</td>
<td>-10.87%</td>
<td>3.89</td>
<td>7.40</td>
</tr>
</tbody>
</table>