TITLE PAGE

Title of the article:

Four weeks of power optimized sprint training improves sprint performance in adolescent soccer players.

Submission type:

Original investigation

Full names of the authors and institutional/corporate affiliations:

Mikael Derakhti [1,*], Domen Bremec [1,2,*], Tim Kambič [3,4], Lasse ten Siethoff [1], Niklas Psilander [1]

[1] The Swedish School of Sport and Health Sciences, Stockholm, Sweden

[2] SuperTrening Sport Performance Centre, Celje, Slovenia

[3] Faculty of Sport, University of Ljubljana, Ljubljana, Slovenia

[4] General Hospital Murska Sobota, Murska Sobota. Slovenia

[*]Equal author contribution/joint first authorship

Contact details for the corresponding author:

Niklas Psilander

The Swedish School of Sport and Health Sciences, Stockholm, Sweden

niklas.psilander@gih.se

+46 707 75 94 95

Preferred running head:
Resisted sprint training in youth soccer

ABSTRACT

Purpose: This study compared the effects of heavy resisted sprint training (RST) versus unresisted sprint training (UST) on sprint performance among adolescent soccer players. ***Methods:*** Twenty-four male soccer players (age: 15.7 ± 0.5 years; body height: 175.7 ± 9.4 cm; body mass: 62.5 ± 9.2 kg) were randomly assigned to the RST group (n = 8), the UST group (n = 10), or the control (CON) group (n = 6). The UST group performed 8 × 20 m unresisted sprints twice weekly for four weeks whereas the RST group performed 5 × 20 m heavy resisted sprints with a resistance set to maximize horizontal power output. The CON group performed only ordinary soccer training and match play. Magnitude-based decision and linear regression were used to analyse the data. ***Results:*** The RST group improved sprint performances with moderate to large effect sizes (0.76–1.41) across all distances, both within and between groups (>92% beneficial effect likelihood). Conversely, there were no clear improvements in the UST and CON groups. RST evoked the largest improvements over short distances (6%–8%) and was strongly associated with increased maximum horizontal force capacities (r = 0.9). Players with a pre-intervention deficit in force capacity appeared to benefit the most from RST. ***Conclusions:*** Four weeks of heavy RST led to superior improvements in short-sprint performance compared with UST among adolescent soccer players. Heavy RST, using a load individually selected to maximize horizontal power, is therefore highly recommended as a method to improve sprint acceleration in youth athletes.

Keywords: team sport, resistance training, force–velocity profiling, youth athletes, 50%v_{dec}

INTRODUCTION

The ability to accelerate over short distances is essential in field-based team sports such as soccer.[1, 2] Since 90% of sprints performed during a soccer match are shorter than 20 m, maximal sprinting speed is likely less important than acceleration.[3] Short-sprint performance mirrors actual game situations and is an important determinant of match-winning actions. For example, straight-line sprinting is the most frequent action during goal situations in professional soccer.[4, 5] Top-level players perform numerous intense actions every match and are significantly faster in the first 10–15 m than are lower-level players.[6-8] Thus, the fastest players will be approximately 1 m ahead of slower players after only 10 m of sprinting, which could be a decisive advantage in a match.[8]

Short-sprint performance is primarily determined by two abilities: the generation of large ground reaction forces, and the technical ability to apply a proportion in the direction of the sprint (i.e., horizontally).[9, 10] Researchers have investigated various means of training these physical and technical qualities with the aim of targeting the development of sprinting performance parameters. Notably, resisted sprint training (RST) is a popular method of providing resistance in a specific "horizontal" manner. In this method, where the resistance usually is created by towing a sled, the user can target the development of various sprint phases by increasing or decreasing the load.[11] This loading represents a continuum, with heavy loads roughly corresponding to horizontal force at low speeds, early sprint phases, and short distances, and lighter loads corresponding to horizontal force at high speeds, late acceleration (or perhaps maximum velocity), and long distances.[12]

RST with light loads [~10% body mass (BM) or ~10% reduction of maximal speed (v_{dec})] has traditionally been studied and recommended for improving sprint acceleration.[13, 14] However, RST using low resistance has been criticized because it only targets one part of the loading continuum (high speed and late acceleration) and often results in similar performance outcomes as non-resisted sprinting, particularly in well-trained individuals.[15] This likely occurs because RST with light loads does not acutely deviate much from unresisted sprinting and therefore results in a training outcome that is not substantially different. Accordingly, recent studies show that heavier loads (>30% BM and >30% v_{dec}) during RST are necessary to improve short-distance sprint performance among team sport athletes.[16-18]

RST based on %BM reduces the maximal velocity to different degrees depending on the athlete's level of development, and the actual resistance determined via friction.[19] The amount of velocity reduction, and not the absolute load, determines the training-induced stress and the type and magnitude of the adaptations.[20, 21] Individual–force velocity (F-v) profiling and load–velocity (L-v) profiling can be used to identify whether an athlete is proficient or deficient and to prescribe the suitable load for a specific velocity reduction.[12, 22] Values extracted from the latter profile characterize the neuromuscular limits of the system for force production. Notably, the maximal horizontal force (F_0), maximal running velocity (v_0), and maximal horizontal power (P_{max}). Additionally, individual profiling also enable analysis of the ratio of force produced in the horizontal direction (RF%) and a theoretical maximal value of RF% (RF_{max}), which is a measure of the maximal mechanical effectiveness of force application in the forward direction at the sprint start.[23] Currently, individual F-v and L-v profiling can be more easily achieved using a robotic system because the actual resistance is programmable and standardized across environments.[24]

Recent studies examining RST in elite athletes show a relationship between pre-training F-v profiles and how these profiles are affected by training.[25, 26] For example, athletes with low initial F_0 values show larger improvements in F_0 and short sprint performance compared with F_0-proficient athletes.[26] Thus, individualized resistance based on F-v profiling is recommended in elite athletes.[27] However, F-v profiling is time-consuming, particularly in a team-sport setting where many athletes must be tested and trained in quick succession. Moreover, adolescent athletes often have imbalanced F-v profiles, displaying a force deficiency.[20, 21] Therefore, a more generalized method that specifically targets this deficiency, such as power optimized RST, may be helpful for youth athletes. This method characterizes the "optimal load" (L_{opt}) as that which allows P_{max} to be reached during the maximum resisted-velocity plateau (i.e., 50%v_{dec}) and thus maintained for longer than a single instant during training.[11, 19, 24] Consequently, L_{opt} represents the loading at which the athletes can maximize the time spent in conditions close to maximum horizontal power.

Although a growing number of studies show positive effects of RST at or close to L_{opt} on short-sprint performance,[18, 20, 21, 24, 26, 28] limited research among youth athletes is available.[20, 21] Furthermore, there are few short duration studies (<8 weeks), with most examining the effects of RST during 8–12 week periods. The multi-factorial physical, tactical and technical demands of team sports together with the tight competitive schedule reduces the applicability of such long training periods. Therefore, the present study aimed to compare the effects of a four-week heavy RST program, using a robotic resistance system applying a power optimized loading, with an unresisted sprint training (UST) program on sprint performance among adolescent soccer players. We hypothesized that RST would lead to the largest improvement in sprint performance and that changes in F_0 would be associated with pre-training F_0 values and changes in sprint performance.

METHODS

Subjects

Twenty-seven adolescent male soccer players volunteered to participate in this study, with a mean (± standard deviation (SD)) age of 15.7 ± 0.5 years, a mean height of 175.7 ± 9.4 cm, and a mean weight of 62.5 ± 9.2 kg. All participants competed at the highest national level (per their age group) in Sweden. They were familiar with strength training, but not on a regular basis, and they had no previous RST experience (except for the three familiarization sessions). The study inclusion criteria were as follows: the absence of lower limb injury and the ability to perform maximal sprints and jumps. After baseline testing, the participants were assigned to either the RST group (n = 9), the UST group (n = 10), or the control (CON) group (n = 8). There were no statistically significant differences in age or anthropometrics between the groups at baseline or after the training intervention. All three groups followed the same soccer training routine. At the end of the intervention, three participants (two from the CON group and one from the RST group) could not undergo post-testing because of personal reasons. Hence, the final analysis ultimately included test data from 24 participants. All subjects were informed about the risks and benefits of the study via an institutionally approved document, and they or their guardians signed written consent forms. The Stockholm Regional Board of Ethics approved this study (ref. number DNR 2018/746-31/1).

Design

A four-week randomized controlled trial was conducted to compare the effects of two different sprint training programs among adolescent soccer players: heavy RST vs. UST. The effects of these two training programs were evaluated against the CON group. To ensure as much similarity between experimental groups as possible, both groups were matched based on the participants' F-v profiles obtained from baseline testing. Specifically, participants with similar results were paired, followed by a random division into the RST or UST group. In addition to the four weeks of training, the participants underwent full familiarization, baseline and post-testing. Both experimental groups performed the training twice a week, with each session consisting of five heavy resisted sprints for the RST group and eight unresisted sprints for the UST group. The accumulated duration of the sprints was balanced between the groups. The CON group performed standard soccer training without any additional activities. The sample size was based on previous studies in this field.[18, 19] The primary outcome variables were 5, 10, 20, and 30 m sprint performances, and the secondary outcomes were counter movement jump (CMJ), standing long jump (SLJ), F_0, P_{max}, RF_{max}, and maximal velocity during 30 m sprinting (v_{max}). The variables were measured at baseline and after the training intervention in a fully rested state. We used magnitude-based decision (MBD) with compatibility intervals (CIs) and probabilities based on the t-distribution to provide estimates of the uncertainty in the mean effect size within and between groups.[29] Magnitude-based inference has been criticized because of its increased risk of type I errors.[30] However, this criticism has been addressed [31], and given the small sample size, the study was likely underpowered for null hypothesis significance testing.[30]

Equipment

A computerized sprint resistance system (1080 Motion AB, Lidingö, Sweden) was used for training, testing, and data collection. The unit provided isotonic horizontal resistance in increment loads of 1 kg to target the appropriate resistance. Instantaneous velocity time data was then collected from the manufacturer software, at a rate of 333 Hz. The manufacturer has previously reported the repeatability (±0.7%) and accuracy of velocity (±0.5%) and force (±4.8N) for the 1080 Sprint system (www.1080 motion.com/science). Baseline and post-training measurements were performed with the same protocol and equipment. Vertical jump trials were performed using OptoJump hardware and software (MicroGate, Bolzano, Italy).

General testing procedures

Testing was completed during the participants' late pre-season and early in-season period. The same researchers who supervised all training performed the pre- and post-testing. To minimize possible learning effects, the participants underwent full familiarization (i.e., three familiarization sessions >48 h prior to baseline testing). Testing was performed on two separate days. Day 1 began with two unloaded (1 kg resistance, as the practical minimum provided by the machine) maximal effort 30 m sprints (T30 m) to measure 5, 10, 20, and 30 m split times and to create F-v profiles. The raw velocity-time data and Samozino's inverse dynamics method was used to compile the F-v relationships.[23] Next, four progressively loaded 20 m sprints were performed to compute the participants' L-v profile. The F-v and L-v profiles were used to calculate and measure the individual training load, F_0, P_{max}, RF_{max}, and v_{max}. Day 2 began with three CMJs followed by three SLJs. Prior to any testing, the participants performed a standardized 20 min warm-up (SWU) consisting of jogging, dynamic stretching, technical drills, and four submaximal 30 m stride outs. All sprint tests were conducted outdoors on the same soccer pitch with an artificial "astro" turf surface; the jumps were performed on a hard, flat asphalt surface. All groups performed the tests on the same days during similar weather conditions, and the participants wore the same clothes and footwear during the pre- and post-testing.

Sprint testing and F-v and L-v profiling

Post-SWU, the participants rested for 5 min before being attached to the 1080 Sprint device via a hip belt. The participants positioned themselves in a standing split stance at the starting line, after which they initiated the first T30 m. They were instructed to "lean" into their first step (removing the slack from the line), push off with their front leg, and start sprinting when they felt like they were about to fall. The selected starting leg remained constant throughout all training and testing sessions.

Although sprint data were gathered over a distance of 30 m, an actual sprinting distance of 35 m was utilized to ensure that the participants did not slow down before reaching 30 m. The second T30 m was performed after a 3 min rest. The faster of the two trials was used to compute split times and F-v profiles.

After the T30 m testing, individual horizontal L-v profiles were assessed by utilizing a testing battery of resisted sprints based on the procedures outlined by Cross et al.[16, 19, 24] The testing battery consisted of four 20 m sprints performed with increasing loads. The loads were adjusted to approximately equal weighted sleds loaded with 25%, 50%, 75%, and 100% of the participants' BM. This loading span was selected to facilitate proper plotting of the participants' L-v profiles and to determine each athlete's L_{opt}. Specifically, L_{opt} represents the load that allows maximum power (i.e., aligned with the apex of their individual horizontal power–velocity relationship) to be developed at the maximum resisted-velocity plateau, and subsequently a larger proportion of training to be performed around P_{max} by attaining and maintaining maximum resisted velocity.[19] Table 1 displays an overview of the sprint testing procedure.

Table 1 "Sprint testing procedure" about here.

Vertical and horizontal jump testing

Three CMJs, interspersed by 1 min of rest, were performed 5 min after a SWU, with the highest jump recorded as the test result. The participants were instructed to place their hands slightly above their hips and keep them there throughout the entire jump. Moreover, they were instructed to go "fast down fast up", land on their toes, and not bend their knees during the flight phase or landing.

The SLJ was performed 2 min after the CMJ testing using an extended measuring tape placed on the ground that marked distances of 1, 2, and 3 m with red tape for the participants to see. Three attempts were allowed with 1 min of rest between each jump. The participants were instructed to stand erect with their feet parallel behind the given zero line, to use their arms as a pendulum, and to jump as far as possible, landing on both feet. The jump was measured as the distance from the starting point to the heel of the foot that was furthest back, with the furthest jump recorded as the test result.

Training regimen

Training was performed prior to the regular soccer training and consisted of linear maximal effort sprints. The RST group performed a SWU prior to 5 × 20 m maximal effort resisted sprints. The 1080 Sprint system was used during the resisted sprints, with the load optimized such that the participant's maximal velocity was reduced by half (50%v_{dec}). The training was performed in this manner for every session apart from the first training session during which the participants only performed three resisted sprints. The UST group performed a SWU prior to 8 × 20 m maximal effort unresisted sprints. Each sprint was interspersed by a 3 min rest, and the training was conducted twice a week for four weeks on nonconsecutive days. The remaining team-specific training included four soccer sessions/week ranging from 45 to 90 min. After the fifth intervention session, the participants' regular game season began, and one competitive soccer match/week was added to the weekly load. The CON group performed only regular soccer-specific team training and matches. The participants of all three groups were instructed not to expose themselves to any other training stimuli during the intervention. Table 2 provides further details on the intervention design.

Table 2 "Training intervention design" about here.

Statistical analysis

All data were imported and processed in Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA, USA). Linear regression models were analyzed in IBM SPSS statistics version 26.0.01, and Figures 2 and 3 were processed in Graph Pad Prism 8.3.0. Data in the text and figures are presented as the mean ± SD or ± 90% compatibility intervals, CIs. The practical relevance of the outcome variables was assessed using magnitude-based decisions.[29] The effects of the training (RST, UST, or CON) differences over time (pre to post) and the differences between groups were calculated. The smallest worthwhile change (SWC) was set to 0.2 × SD. Since the sample sizes were small (n = 8, 10, or 6), we used a t-distribution to calculate the 90% CIs and the chances of beneficial, harmful, or trivial changes. Qualitative statements were assessed as follows: 25% to 75%, possibly; 75%–95%, likely; 95%–99.5%, very likely; >99.5%, most likely. If the chances of having beneficial/higher or harmful/lower performances were both >5%, the true difference was considered unclear. Effect sizes were qualitatively described as trivial, small, moderate, large, very large, and extremely large for standardized thresholds of <0.2, ≥0.2, ≥0.6, ≥1.2, ≥2, and ≥4 and for regression coefficients of <0.1, ≥0.1, ≥0.3, ≥0.5, ≥0.7, and ≥0.9, respectively.[29] To provide information about individual responses, we presented the number of individuals who displayed changes that were better, worse, or within the SWC.

To test our hypothesis that pre-training F_0 values were associated with improvements in F_0, we performed a linear regression with group and initial F_0 values as independent variables and changes in F_0 as the dependent variables. The same method was used to test whether the association between changes in F_0 (independent) were associated with changes in 20 m sprint performance (dependent) and training group (independent). Changes in 20 m sprint time (T_{20}) was chosen as the primary outcome variable for sprint performance since 20 m sprinting was the basis of the training interventions.

RESULTS

The RST group likely improved sprinting performance across all time points and comparisons. The improvement increased progressively with decreasing distance from ~4% at 30 m to ~8% at 5 m. Conversely, there were no clear changes in sprinting performance for the UST or CON groups at any time point or for any comparison (Table 3). Thus, there was a likely to very likely beneficial effect for the RST group compared with the UST and CON groups for all sprinting distances. No clear between-group differences were observed when comparing the UST and CON groups (Figure 1).

Table 3 about here

Figure 1 about here

CMJ height possibly increased for the UST group (~6%) but not for the other two groups. SLJ length likely increased for both the RST and UST groups (~6%–7%) but not for the CON group

(Table 4). Thus, there was a very likely, to most likely, better effect in jumping performance for the two intervention groups compared with the CON group (Figure 2).

The performance-related variables F_0, P_{max}, and RF_{max} likely improved in the RST group (~9%–18%). Conversely, there were no improvements in the UST group, but a possible decrease for F_0 (~4%) (Table 4). This resulted in a likely better effect for the RST group compared with the other two groups for F_0, P_{max}, and RF_{max} (Figure 2). v_{max} was unaffected in the RST and UST groups whereas the CON group displayed a very likely decrease (~3%) (Table 4).

Table 4 about here

Figure 2 about here

Change in F_0 was a very large predictor for changes in 20 m sprinting time ($P < 0.001$, r = −0.84), and the pre-intervention F_0 was a large predictor for improvements in F_0 ($P < 0.001$, r = −0.70) (Table 5). The intervention group was a significant predictor for changes in F_0 ($P < 0.006$, r = −0.48) but not for changes in sprint performance ($P < 0.079$, r = 0.18). The overall models explained 80% of the improvement in sprint performance and 48% of the change in F_0.

Table 5 about here

DISCUSSION

This is the first study to compare the effects of a short, power optimized, heavy RST program with a UST program among youth athletes. Our primary finding was that four weeks of heavy RST improved sprint performance among late pubertal adolescent soccer players, while the UST group displayed no improvement. The improved sprint performance was primarily due to increases in maximal horizontal force production and improvements in early sprint acceleration, which was in line with our hypothesis. The CON group, which only received regular soccer training, showed no performance improvements in any of the measured outcome variables.

The RST group displayed similar or greater improvement in sprint performance than that reported in previous studies[17, 18, 24, 32] despite a shorter training period (4 vs. 8–12 weeks), supporting the effectiveness of the training protocol. This can be explained by several factors. First, we used a resistance that reduces velocity by 50% to maximally stimulate the ability to produce horizontal power. Additionally, the resistance was applied by a robotic system, via a hip harness, which is ideal for providing the right amount of horizontal resistance while maintaining an optimal sprinting position. Together, this may be a highly efficient way for stimulating power adaptations. Secondly, the participants in the present study were younger than those in most previous studies. Adolescent athletes may be more sensitive to training-induced adaptations that improve sprint performance.[33] In line with this, the participants had relatively low starting values of F_0, which have been shown to correlate with improvements in horizontal force production and sprint performance.[26] Furthermore, the individual changes in F_0, together with the assigned training group, explained 80% of the improvement in 20 m sprint performance. Therefore, the comparatively large effect of this short training intervention is likely a consequence of a good match between an effective training method and population.

The short training intervention utilized in the present study was primarily chosen to mimic real-world team-sport periodization. Short periods of specific training, called block mesocycles, have been frequently used among team-sport athletes, with studies recommending that these periods last between two and four weeks.[34] The present intervention spanned both the pre- and competitive seasons (two weeks in each); therefore, our results indicate that heavy RST is a suitable training form during this important transition period, particularly because the CON group experienced a performance decrease in some of the measured variables (P_{max} and v_{max}). This decrease may have occurred because the CON group was less prepared for intense match play and became more fatigued compared with the other two groups. Therefore, the CON group might not have been fully recovered when performing the post-tests. Multiple post-intervention assessment points would have enabled these factors to be more clearly elucidated,[28] but the competitive schedules of the athletes did not permit such a design.

Previous studies have demonstrated the importance of developing maximal horizontal force production to improve the early acceleration phase of sprinting.[35, 36] Since team-sport athletes primarily perform short sprints, there is a compelling argument to target the development of this ability during training. Interestingly, the present study indicated that the improvement in sprint performance in the RST group increased gradually from the 30 m to the 5 m sprint (T30 = 3.8%, T20 = 4.2%, T10 = 5.6%, T5 = 7.9%). This finding, combined with the large increases in F_0, P_{max}, and RF_{max}, but not in v_{max}, confirms that RST mainly improved sprint acceleration, which agrees with results from both adult and adolescent populations.[17, 18, 20, 21, 26, 32, 35] The fact that these changes were observed after only four weeks of training indicates that the changes were primarily driven by neural and technical improvements. This in combination with our finding that horizontal jump length, but not vertical jump height, increased, demonstrates that the athletes appear to have disproportionately developed technical capacities, rather than gross physical ones.

Importantly, we did not detect a decrease in v_{max} in the RST group. This agrees with recent findings showing a decrease in v_{max} when applying very heavy loads (75%v_{dec}) but not for loads close to L_{opt} (50%v_{dec}).[21] A possible explanation is that, in theory, RST at L_{opt} would improve both maximum velocity and maximum force since it targets the development of the middle portion of the F-v relationship. However, in light of this, and recent studies, the most efficient training to improve maximal velocity seems to be sprinting at velocities close to or above v_{max} (i.e., assisted sprint training).[25] Nevertheless, our results indicate that power optimized RST does not longitudinally impede the v_{max} of young soccer players following a short intervention.

The present study has some limitations. First, we used MBD to provide usable results from this otherwise small dataset. Therefore, the results should be interpreted with the relatively underpowered nature of this dataset in mind. Secondly, although sprint performance increased by ~4%–8%, which is an unusually large increase for athletes, one should be careful when translating this improvement directly to sport-specific performance. The improved acceleration and horizontal forces could be partly due to improved body orientation during early sprinting phases.[26] Although this improves sprint acceleration, it might not be practically relevant for a soccer player who requires an upright posture throughout the game. Additionally, many accelerations in soccer are performed from a flying start and not from a dead start (e.g., from jogging to sprinting). Future studies should therefore include sprint testing with a flying start and examine the effect of training on the starting angle. Finally, completely unloaded sprinting is not possible when using the 1080 system (se methods section for details). This might have affected v_{max} and the results should therefore be interpreted with this in mind.

PRACTICAL APPLICATIONS

- A loading prescription, applied to stimulate the development of maximal horizontal power, appears to be more beneficial to short-sprint performance than unresisted sprinting. This method could be integrated into the training of youth athletes to enhance sport-specific performance.
- L-v profiling and loading of the desired resistance is greatly simplified by a robotic system. However, this can also be done by more cost-efficient devices such as timing gates, smart phone applications, and a weight adjustable sled.[23]
- Only four weeks of power optimized RST, performed two times per week, was sufficient to improve performance. This greatly improves the applicability of the described method; i.e., it can be used as a block mesocycle during the late pre-season or in-season periods.

CONCLUSIONS

We showed that four weeks of power optimized RST was more beneficial than UST at improving short-sprint performance in adolescent soccer players. The improvement in sprint times increased gradually with decreasing distance. Additionally, maximal horizontal power, maximal horizontal force application, and maximal effectiveness of force application improved, indicating that the training primarily affected sprint acceleration performance. Maximal velocity remained unchanged. Finally, the effect was more pronounced in athletes who were force deficit at baseline. Overall, these results show that power optimized RST is a very efficient and easy method for improving sprint performance in youth athletes.

ACKNOWLEDGMENTS

We would like to thank the participants and coaches from Älvsjö AIK for their cooperation and maximal effort during the training intervention.

CONFLICTS OF INTEREST

No conflicts of interest, financial or otherwise, are declared by the authors.

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FIGURE CAPTIONS

Figure 1. Pairwise comparison of the changes in sprint performance between A. the RST and UST groups, B. the RST and CON groups, and C. the UST and CON groups. T5–T30 denotes the standardized change in sprint performance at 5, 10, 20, and 30 m, respectively. Error bars represent the 90% compatibility intervals of the mean change in performance. The gray area marks the limits of a trivial change. Numbers separated by a slash are the probability (in percentage) of an improvement that is better for the left group/within the trivial range/better for the right group. Abbreviations: RST, resisted sprint training group; UST, unresisted sprint training group; CON, control group only performing ordinary soccer training.

Figure 2. Pairwise comparison of the changes in secondary outcome variables between A. the RST and UST groups, B. the RST and CON groups, and C. the UST and CON groups. Error bars represent the 90% compatibility intervals of the mean change in performance. The gray area marks the limits of a trivial change. Numbers separated by a slash are the probability (in percentage) of an improvement that is better for the left group/within the trivial range/better for the right group. Abbreviations: RST, resisted sprint training group; UST, unresisted sprint training group; CON, control group only performing ordinary soccer training; RF_{max}, maximum ratio of force produced in the forward direction at sprint start; v_{max}, maximal velocity during 30 m sprinting; P_{max}, maximal horizontal power; SLJ, standing long jump; CMJ, counter movement jump; F_0, theoretical maximal horizontal force.

Table 1. Sprint testing procedure

~20 min of SWU followed by 5 min of passive rest prior to sprint testing procedure

Sprint nr	Load	T30 m	F–v profiling	L–v profiling	Rest period
1	Unloaded	✓	✓	-	3 min
2	Unloaded	✓	✓	-	3 min
3	25% BM	-	-	✓	3 min
4	50% BM	-	-	✓	3 min
5	75% BM	-	-	✓	3 min
6	100% BM	-	-	✓	3 min

Abbreviations: SWU, standardized warm up; BM, body mass; F–v profiling, force–velocity profiling; L–v profiling, load–velocity profiling.

Table 2. Intervention design

RST				
Session	**Reps × Distance**	**Sprint type, Load**	**Total sprint duration**	**Warm-up**
1	3 × 20 m	Maximal effort, individual Lopt	20–21 s	SWU
2–9	5× 20 m	Maximal effort, individual Lopt	32–35 s	SWU
UST				
Session	**Reps × Distance**	**Sprint type, Load**	**Total sprint duration**	**Warm-up**
1–9	8 × 20 m	Maximal effort, unloaded	32–35 s	SWU

Abbreviations: RST, resisted sprint training group; UST, unresisted sprint training group; L_{opt}, optimal load for the subjects to work at their P_{max}; SWU, standardized warm-up.

Table 3. Descriptive statistics (mean (SD)) and changes (with 90% CI) in sprint performance in the RST, UST, and CON groups**.**

Group	**Pre Mean (SD)**	**Post Mean (SD)**	**% Change (90% CI)**	**ES (90% CI)**	**Chances (B/T/H)**	**Ind. Resp. (B/T/H)**	**Outcomes**
T30 (s)							
RST	5.34 (0.24)	5.15 (0.20)	-3.67 (-6.43 to- 0.92)	-0.89 (-1.56 to -0.22)	95/4/1	6/1/1	Very likely beneficial
UST	5.42 (0.47)	5.45 (0.38)	0.54 (-3.98 to 5.06)	0.07 (-0.51 to + 0.65)	21/45/35	3/4/3	Unclear
CON	5.39 (0.10)	5.48 (0.20)	1.70 (-0.56 to 3.97)	0.62 (-0.20 to 1.44)	5/13/82	1/1/4	Unclear
T20 (s)							
RST	3.96 (0.22)	3.79 (0.17)	-4.20 (-7.46 to -0.94)	-0.86 (-1.53 to -0.19)	95/4/1	6/1/1	Likely beneficial
UST	4.0 (0.36)	4.06 (0.28)	1.52 (-3.15 to 6.19)	0.19 (-0.39 to 0.77)	12/39/49	4/1/5	Unclear
CON	4.06 (0.1)	4.11 (0.18)	1.27 (-1.60 to 4.14)	0.36 (-0.46 to 1.19)	11/24/65	1/3/2	Unclear
T10 (s)							
RST	2.50 (0.2)	2.36 (0.15)	-5.69 (-10.41 to -0.97)	-0.81 (-1.48 to -0.14)	94/5/1	6/1/1	Likely beneficial
UST	2.55 (0.30)	2.61 (0.21)	2.23 (-3.52 to 7.99)	0.23 (-0.35 to 0.80)	11/36/53	3/2/5	Unclear
CON	2.65 (0.11)	2.68 (0.17)	1.01 (-3.30 to 5.31)	0.19 (-0.63 to 1.02)	19/32/49	2/2/2	Unclear
T5 (s)							
RST	1.67 (0.20)	1.54 (0.15)	-7.87 (-14.85 to -0.89)	-0.76 (-1.43 to -0.09)	92/6/2	7/0/1	Likely beneficial
UST	1.71 (0.26)	1.77 (0.18)	3.45 (-3.93 to 10.82)	0.27 (-0.31 to 0.85)	9/33/59	3/3/4	Unclear
CON	1.84 (0.11)	1.84 (0.16)	0.45 (-5.49 to 6.40)	0.06 (-0.76 to 0.89)	27/35/38	2/2/2	Unclear

Abbreviations: RST, resisted sprint training group; UST, unresisted sprint training group; CON, control group only performing ordinary soccer training; B, beneficial; T, trivial; H, harmful; CI, compatibility interval; T30-T5, time at 30-5 m during sprint testing.

Table 4. Descriptive statistics (mean (SD)) and changes (with 90% CI) in physical performance in the RST, UST, and CON groups**.**

Group	**Pre Mean (SD)**	**Post Mean (SD)**	**% Change (90% CI)**	**ES (90% CI)**	**Chances (B/T/H)**	**Ind. Resp. (B/T/H)**	**Outcomes**
CMJ (cm)							
RST	31.1 (3.9)	32.6 (4.9)	4.66 (-4.73 to 14.05)	0.33 (-0.34 to 1.00)	64/27/9	3/5/0	Unclear
UST	29.2 (4.8)	31.01 (4.9)	6.34 (-3.33 to 16.02)	0.38 (-0.20 to 0.96)	71/24/5	8/1/1	Possibly beneficial
CON	32.0 (4.5)	31.35 (3.6)	-1.98 (-12.48 to 8.52)	-0.16 (-0.98 to 0.67)	21/33/46	1/4/1	Unclear
SLJ (cm)							
RST	211.3 (17.9)	226.4 (20.0)	7.16 (4.16 to 13.16)	0.80 (0.01 to 1.47)	93/5/1	7/1/0	Likely beneficial
UST	206.9 (14.2)	219.10 (17.7)	5.90 (1.43 to 10.37)	0.76 (0.01 to 1.34)	95/5/1	8/2/0	Likely beneficial
CON	226.3 (11.5)	224.0 (13.8)	-0.99 (-5.59 to 3.60)	-0.18 (-1.00 to 0.64)	20/32/48	0/4/2	Unclear
P_{max} *(W/kg)*							
RST	11.7 (2.4)	13.4 (2.5)	14.38 (0.19 to 28.56)	0.68 (0.01 to 1.35)	89/9/2	6/1/1	Likely beneficial
UST	11.6 (4.0)	10.84 (2.1)	-8.62 (-23.66 to 6.42)	-0.33 (-0.91 to 0.17)	6/28/66	3/3/4	Unclear
CON	10.8 (0.5)	10.29 (0.8)	-4.34 (-9.08 to -0.40)	-0.75 (-1.58 to -0.07)	3/8/88	1/0/5	Likely harmful
RF_{max}*(%)*							
RST	36.8 (5.1)	40 (3.8)	8.84 (0.78 to 16.90)	0.74 (0.07 to 1.40)	91/7/2	7/0/1	Likely beneficial
UST	35.6 (6.7)	34.2 (4.2)	-3.93 (-12.87 to 5.00)	-0.26 (-0.83 to 0.32)	9/34/57	3/3/4	Unclear
CON	32.67 (2.58)	32.50 (3.6)	-0.51 (-8.32 to 7.30)	-0.26 (-1.08 to 0.56)	28/35/37	3/1/2	Unclear
v_{max}*(m/s)*							
RST	7.54 (0.42)	7.56 (0.51)	0.23 (-3.89 to 4.35)	0.04 (-0.63 to 0.71)	33/41/26	4/1/3	Unclear
UST	7.62 (0.38)	7.70 (0.61)	1.05 (-2.72 to 4.82)	0.16 (-0.42 to 0.74)	45/40/14	6/0/4	Unclear
CON	8.15 (0.24)	7.91 (0.18)	-2.99 (-4.68 to -1.29)	-1.45 (-2.27 to -0.63)	1/1/99	0/1/5	Very likely harmful
F_0*(N/kg)*							
RST	5.50 (1.66)	6.50 (1.70)	18.17 (0.65 to 35.68)	0.70 (0.03 to 1.37)	90/8/2	7/0/1	Likely beneficial
UST	5.33 (2.17)	4.66 (1.04)	-12.46 (-30.93 to 6.00)	-0.39 (-0.97 to 0.19)	5/23/72	3/3/4	Possibly harmful
CON	4.13 (0.59)	4.18 (0.80)	1.33 (-8.68 to 11.34)	0.11 (-0.71 to 0.93)	42/34/24	4/0/2	Unclear

Abbreviations: RST, resisted sprint training group; UST, unresisted sprint training group; CON, control group only performing ordinary soccer training; B, beneficial; T, trivial; H, harmful; CI, compatibility interval; CMJ, countermovement jump; SLJ, standing long jump; P_{max}, peak power; RF_{max}, maximal effectiveness of total force produced in the forward direction at sprint start; v_{max}, maximal velocity; F_0, theoretical maximal horizontal force.

Table 5. Results from linear regression models with two predictors, n = 24.

Dependent variable = changes in 20 m sprint performance				
Predictors	**r**	**r^2**	**Adjusted r^2**	**P-value**
Training group	0.180	0.032	-	0.079
Changes in F_0	−0.836	0.699	-	<0.001
Overall model	0.903	0.815	0.798	<0.001
Dependent variable = changes in F_0				
Predictors	**r**	**r^2**	**Adjusted r^2**	**P-value**
Training group	−0.478	0.228	-	0.006
Initial F_0	−0.698	0.487	-	<0.001
Overall model	0.722	0.522	0.476	<0.001

Abbreviations: r, correlation coefficient; F_0; theoretical maximal horizontal force.