The Effects of a 6-week Unilateral Strength and Ballistic Jump Training Program on the Force-Velocity Profiles of Sprinting

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Abstract

The aims of this study were: a) to investigate the effects of a unilateral training program, compared to a control group, on F-V profile in soccer players; b) to explore such effects on linear speed. Twenty-four soccer players, randomly assigned to a 6-week unilateral strength and ballistic jump training (UNI) (n = 12) or a control group (CON) (n = 12), performed 30 meter linear sprint test. Findings showed small to moderate improvements ($p < 0.05$) in linear speed time (g = 0.66 to 0.81) and in most F-V variables: maximal running velocity (*V0*) (g = 0.81), maximal power output (*Pmax*) (g = 0.49), maximal ratio of force (*RFmax*) (g = 0.55), optimal velocity (*Vopt*) (g = 0.83) and maximal speed (g = 0.84) from pre- to post-intervention in the UNI group, whereas no meaningful changes were found in the CON group. The between-group comparison indicated small to large significant changes in *V0* (g = 0.95), *RFmax* (g = 0.48), *Vopt* (g = 0.95), maximal speed (g = 0.98) and linear speed time performance (g = 0.42 to 1.02), with the exception of the 0-5 meter distance, in favour of the UNI group. Thus, a unilateral strength and ballistic jump training program can be used to improve the F-V profile and linear speed performance of amateur soccer players.

Key Words: soccer, complex training, linear speed.

INTRODUCTION

Soccer is a high-intensity team sport that requires players to perform reactive, rapid changes of direction in response to a given stimulus (e.g., opponent or pass). A player's physical ability (e.g., strength, power, speed and agility) is also key to success on the pitch (34). Specifically, soccer players are required to decelerate as effectively as possible, change direction, accelerate, achieve top speed to reach the ball before the opponent, and likely perform additional changes of direction to dribble past an opponent and create attacking-scoring opportunities (36). Hence, a player's speed ability is critical in soccer, with many studies previously conducted to improve this component of performance (11, 31, 33). To corroborate this, Andrzejewski et al. (1) pointed out that professional players accomplished ~11 sprints per match. Moreover, 90% of these sprints were < 5 seconds in duration and the typical distance covered was between 10 and 20 meters. While powerful athletic movements (e.g., jumping, changing directions, and sprinting) are observed during 83% of goals scored, linear sprinting is the most dominant movement (i.e., 67% of all goals), compared to jumping and changing direction (11 and 22%, respectively) (12). Therefore, linear sprinting should be prioritized for all soccer players, especially those who are primarily thought of as goal scorers (e.g., strikers and attacking midfielders).

To determine how to assess and improve linear sprinting performance, the force-velocity (F-V) profile has been recently suggested (30). This method uses a computation based on a macroscopic inverse dynamic analysis of the centre of mass (COM) during motion, and describes the F-V relationship using the maximal theoretical horizontal force that could be produced at null velocity (maximal force (*F0*)), and the theoretical maximum velocity that could be produced in the absence of mechanical constraints (maximal running velocity (*V0*)) (25). The recognition of an optimal individual F-V profile, which balances force and velocity outputs, can help practitioners in selecting appropriate training methods to maximise sprint performance (30). Samozino et al. (30) proposed a valid and reliable on-field method to compute the F-V profile, which showed excellent levels of agreement ($r^2 = 0.953$, $p < 0.05$) with force plates. In practical terms, the F-V profile can be extrapolated for each subject, determining whether athletes theoretically need a force or velocity orientated training focus to optimise their profile. It has been observed that major between-participant differences exist in the F-V profile even though athletes may follow the same training sessions (23). This highlights that a training program appears to be necessary to foster physical adaptations and manipulate subsequent force or velocity deficits (2). The F-V profile includes several key components, such as: *F0*, *V0*, maximal power output (*Pmax*), index of force application effectiveness (*RFmax*), and decrease in the RF with increasing running speed (*Drf*) (25).

To date, research in soccer has scarcely examined how these F-V profiles are impacted by training interventions to foster substantial improvements in sprinting performance, with numerous studies being observational in design and in mixed athletic population (7, 10, 16). In fact, investigating the effects of training interventions on the F-V profile seems of utmost importance to clearly understand how training stimuli may directly impact sprinting performance, to substantiate this theoretical construct.

The available evidence to date using resisted sprint training methods (3, 19), has shown that in order to obtain adaptations on specific parts of the F-V curve, load manipulation is necessary. Specifically, and somewhat unsurprisingly, a shift in force characteristics often results from a bias in force-orientated training, and vice versa for velocity. When considering soccer, a combination of heavy and ballistic resistance training (i.e., contrast training or complex training) is recommended to improve physical performance (32, 34), and to overcome time constraints commonly imposed by the time needed for technical and tactical training (35). Furthermore, owing to the paucity of studies investigating the effects of training interventions in comparison with a control group, randomised controlled studies investigating the F-V profile appear necessary. To the best of the authors' knowledge, no studies have adopted a standardized strength and power training program compared to a control group, with the aim to improve the F-V profile and linear speed in male soccer players. Therefore, the aims of the current study were twofold: a) to determine the effects of a 6-week unilateral strength and ballistic jump training on the F-V profile compared to a control group; b) to determine the effects of the aforementioned training program compared to a control in the measure of linear speed (i.e., 0-5, 0-10, 0-15, 0-20, 0-25, and 0-30 meter split times). Our hypothesis was that a unilateral training intervention, focused on strength and ballistic jump training would elicit positive changes on the sprint acceleration F-V profile in soccer players.

METHODS

Experimental Approach to the Problem

In order to determine the effect of a unilateral strength and ballistic jump training intervention on the F-V profile and linear speed performance, a randomized controlled trial design was used in amateur soccer players. Subjects were randomly assigned to either a unilateral training intervention (UNI) or a control (CON) group, using shuffled sealed envelopes. Linear speed performance (i.e., 30-meter linear sprint test) was performed at baseline and 6 weeks after the training intervention in both groups. The experimental intervention (UNI) was based on a 6-week training intervention, conducted twice per week at the end of the competitive season (i.e., when no competitive matches were scheduled), even though subjects continued to train. A 48-hour rest period was provided between the final test and the start of the intervention or the final training session and post-intervention testing.

Subjects

Twenty-four amateur male adult soccer players (25.4 ± 4.9 years; 75.6 ± 6.9 kg; 180 ± 0.10 cm) from three amateur soccer clubs volunteered to participate in this study. A minimum of 18 subjects was established from a priori power analysis using G*Power (Version 3.1, University of Dusseldorf, Germany) implementing statistical power of 0.8 and a type 1 alpha level of 0.05, which has been used in comparable literature (9). To be included in the current study subjects had to meet the following inclusion criteria: 1) older than 18 years of age, 2) a minimum of a 3-years' competitive soccer experience, 3) a minimum of a 1-year of resistance training experience, 4) no injuries occurred in the last 6 months (i.e., no absence from competitions > 28 days) and, 5) no surgery in the last 12 months (e.g., anterior cruciate ligament reconstruction). The subjects were randomly allocated and equally distributed, using shuffled sealed envelopes, to one of the two groups. All subjects were informed about the purpose of the study and the informed consent was obtained before the start of the experimental study according to the Declaration of Helsinki. Ethical approval was granted by the London Sport Institute research and ethics committee, Middlesex University, UK.

Procedures

Subjects completed a standardized dynamic warm up before the testing protocols. This consisted of 2 sets of 10 repetitions of overhead squats, forward lunges, crab walks, glute bridges, and pogo jumps. Three practice trials of incremental 10- and 30-meter linear sprint at 60, 80 and 100% of their perceived maximal effort were completed. Thirty-meter linear sprint test was completed on the grass football pitch. Three minutes of rest was given between the last practice trial and the beginning of the assessments. These were conducted on the same time of the day (i.e., 10 AM, 23° degrees, 42% humidity, sunny and no wind on the grass soccer pitch and 23° degrees and 40% humidity in the gym) to minimize confounding variables for pre- and post-intervention testing. In addition, players were asked to maintain their habitual lifestyle throughout the experimental study. Assessments were executed performing 3 trials of a 30-meter linear sprint test. A 3-minute rest period was provided between trials during the sprint test.

30-meter Linear Sprint. Subjects were instructed to stand behind the starting line, with hands on the ground at a distance of 3 centimetres from the starting line, in a crouched three-point start position (29). They were allowed to choose independently the preferred leg to start the sprint. Vertical poles were placed at 0, 5, 10, 15, 20, 25 and 30 meters. Subjects were instructed to sprint through the poles as fast as they can, whenever they wanted after the signal “go”. Examiners’ verbal instruction was “sprint as fast as possible”. Time was recorded when subjects crossed the starting line and hands left the floor, and finish at the pole placed at 30 meters. All players performed sprints in their own football boots. Performance in seconds was recorded using “My Sprint App”, using an iPhone X with a frame rate recording of 240 fps (29). The device was placed on a 1-meter height tripod, 5 meters away perpendicular to the lane and at a distance of 15 meters from the starting line (29). Average values were taken for the 30-meter linear sprint test.

Intervention Program. At the end of the regular football season, a 6-week resistance training program consisting of 2 sessions (duration of approximately 60 minutes each) per week was conducted (see Table 1), thus avoiding any confounding factor with regular soccer training sessions or matches. The UNI group performed the standardized warm-up before the training program. This was based on coupled exercises (i.e., contrast training (21)), consisting of strength training followed by ballistic jump exercises (i.e., following the order A-, B-, C-), with load progression adapted on the body weight of each subject (Table 1). Velocity ratio of exercises was set at 1:1 (i.e., concentric-eccentric velocity) (21). Between strength and ballistic jump exercises a 90-second rest period was provided, whereas a 180-second inter-set rest period was given within the coupled exercises. Two qualified strength and conditioning coaches supervised each training session, providing verbal feedbacks and encouragements. After each training program, subjects were encouraged to cool down with dynamic stretching and mobility exercises (26).

*****Table 1 here*****

Statistical Analyses

All data were initially recorded as mean and standard deviation (SD) in Microsoft Excel and later transferred to SPSS (version 25.0; SPSS, Inc., Armonk, NY). Normality was analysed using the Shapiro-Wilk test. Homogeneity was tested using the Levene's test. An average-measures two-way random intraclass correlation coefficient (ICC) with absolute agreement and 95% confidence intervals, and coefficient of variation (CV) were used to assess the within session reliability of test measures at baseline and after the training intervention. ICC values were interpreted as follows: > 0.9 = excellent, 0.75–0.9 = good, 0.5–0.75 = moderate, and < 0.5 poor (18). The CV was calculated using the formula: (SD [trials 1–3] / average [trials 1–3] x 100), with values < 10% deemed acceptable (5). The F-V profile was calculated using the spreadsheet for sprint acceleration force-velocity-power profiling (24), derived from the article written by Samozino et al. (30). F-V profile variables of interest included *F0 (N/kg)*, *V0* (m/s), *Pmax (W/kg)*, *FV Slope*, *RF max (%)*, *Drf (%)*, *Vopt (m/s)* and *Max Speed (m/s)*. Paired samples *t*-tests and independent *t*-tests were used to calculate changes in F-V profile variables and linear speed time performance (i.e., 30 meter linear sprint), including split time, within the same group (i.e., UNI or CON) and between-group differences (i.e., UNI vs. CON) from pre- to post-training intervention, with statistical significance set at $p < 0.05$. A Two-way repeated measures ANOVA was used to examine the influence and interaction of time and/or group for each test variable. Hedges' *g* effect sizes with 95% confidence intervals, were also determined to showcase practical significance from pre- to post-intervention (8). Hedges' *g* was classified as follows: 0.0-0.25 = trivial, 0.25–0.50 = small, 0.50–1.00 = moderate, > 1.00 = large (28).

RESULTS

Training compliance was 100%. All data were normally distributed ($p > 0.05$). Table 2 shows within-session reliability data. Relative reliability (ICC) ranged from moderate to good (0.54 to 0.81) in both groups. Absolute reliability (CV) showed acceptable values (< 10%) in both pre- and post-intervention scores. Table 3 reports F-V profile variables and linear speed scores from pre- to post-intervention and between-group differences.

F-V variables

There was a significant time x group interaction for *V0 (m/s)* ($F(1,11) = 8.916$, $p = 0.012$), optimal velocity (*Vopt (m/s)*) ($F(1,11) = 8.802$, $p = 0.013$), and *Max speed (m/s)* ($F(1,11) = 10.470$, $p = 0.008$). Results showed that in the UNI group, moderate significant improvements were found in *V0 (m/s)* ($g = 0.81$; $p < 0.05$), whereas the CON group revealed a small significant reduction in *V0 (m/s)* ($g = -0.34$; $p < 0.05$). Moreover, a moderate significant change was observed in the between-group difference in *V0 (m/s)* ($g = 0.95$; $p < 0.05$) in favour of the UNI group. *Vopt* (m/s) revealed a moderate significant increase in the UNI group ($g = 0.83$; $p < 0.05$), a small significant reduction in the CON group ($g = -0.34$; $p < 0.05$) from pre- to post-intervention, and a moderate significant change in the between-group differences in favour of the UNI group ($g = 0.95$; $p < 0.05$). *Max speed (m/s)* significantly improved in the UNI group from pre- to post-intervention ($g = 0.84$; $p < 0.05$), and between-group differences reported a moderate significant change in favour of the UNI group ($g = 0.98$; $p < 0.05$). There was a significant effect of time for *Pmax (W/Kg)* ($F(1,11) = 7.751$, $p = 0.018$) and maximal ratio of force (*RFmax (%)*) ($F(1,11) = 6.769$, $p = 0.025$). In the UNI group, small significant improvements were found in *Pmax (W/Kg)* ($g = 0.49$; $p < 0.05$), while no meaningful changes ($g = 0.17$; $p > 0.05$) were observed in the CON group. When *RFmax (%)* was examined, a moderate significant increase was found in the UNI group ($g = 0.55$; $p < 0.05$). Similarly, the between-group differences reported a small significant change in favour of the UNI group ($g = 0.48$; $p < 0.05$). Finally, the other variables (i.e., *F0 (N/kg), FV slope* and decrease in ratio of force (*Drf (%)*) did not show any significant within-group changes or between-group differences.

Linear speed time performance

There was a significant time x group interaction for 0-15 ($F(1,11) = 12.713$, $p = 0.004$), 0-20 ($F(1,11) = 5.357$, $p = 0.041$), 0-25 ($F(1,11) = 25.348$, $p < 0.001$), and 0-30 meter ($F(1,11) = 19.183$, $p = 0.001$) linear speed time performance. There was a significant effect of time for 0-5 ($F(1,11) = 12.559$, $p = 0.005$), 0-15 ($F(1,11) = 5.752$, $p = 0.035$), 0-20 ($F(1,11) = 16.068$, $p = 0.002$) and 0-25 meter ($F(1,11) = 5.908$, $p = 0.033$) linear speed time performance. There was a significant effect of group for 0-5 ($F(1,11) = 14.238$, $p = 0.003$), 0-10 ($F(1,11) = 990.852$, $p < 0.001$), 0-30 meter ($F(1,11) = 5.022$, $p = 0.047$) linear speed time performance.

Results showed significant moderate improvements in each split time ($g = 0.64$ to 0.81; $p < 0.05$), apart from the 0-5 m sprint ($g = 0.37$) in the UNI group. In contrast, the CON group did not reveal any significant changes in time performance from pre- to post-intervention in each split time interval ($g = -0.23$ to 0.28). When between-group differences were examined, results revealed small to large significant changes in favour of the UNI group in each split time ($g = 0.42$ to 1.02; $p < 0.05$), with the exception of the 0-5 m sprint, which did not show any substantial changes between groups ($g = 0.15$). Mean and individual changes for each split time of both groups are reported in Figures 1-3.

***** Tables 2 and 3 here*****

***** Figures 1-3 here*****

DISCUSSION

The primary aim of this study was to investigate the effect of a 6-week unilateral strength and ballistic jump training program, in comparison to a control group, in improving the F-V profile variables. The second aim was to determine the effect of such a training intervention on linear speed time performance (i.e., 0-5, 0-10, 0-15, 0-20, 0-25, and 0-30 meter split times). Our results indicated that the training intervention elicited small to moderate significant improvements in most F-V profile variables and maximal speed in the UNI group. Furthermore, small to moderate significant improvements were found in linear speed time performance, with the exception of the 0-5 meter distance, in the UNI group. No significant changes occurred in the control group for any variable. Similarly, the between-group differences showed small to moderate significant changes in *VO*, *RFmax*, *Vopt*, *Max speed*, and small to large improvements in linear speed time performance (with the exception of the 0-5 meter distance) in favour of the UNI group. Therefore, our findings strengthen the notion that both sprint performance and their associated F-V profiles can be improved in soccer players using a combination of unilateral strength and ballistic jump training.

The present study revealed small to moderate significant improvements in *V0* (g = 0.81), *Pmax* (g = 0.49), *RFmax* (g = 0.55), *Vopt* (g = 0.83), and *Max speed* (g = -0.84) in the UNI group from pre- to post-intervention. In contrast, the CON group did not report any meaningful change in the aforementioned variables, showing even a significant reduction in *V0* (g = -0.34) and *Vopt* (g = -0.34). When the two groups were compared, the results showed that small to moderate significant improvements were observed in *V0* (g = 0.95), *RFmax* (g = 0.48), *Vopt* (g = 0.95), and *Max speed* (g = -0.98) in favour of the UNI group. These findings corroborate our hypothesis that a unilateral training intervention, focused on strength and ballistic jump training, can elicit positive changes on the sprint acceleration F-V profile. Linear sprint acceleration is an explosive action that requires maximal strength expression, and a high rate of force in a short time period (15). Interestingly, our training program did improve F-V variables (i.e., *VO*, *Vopt*, *Pmax*, and *Max speed*), suggesting that adequate stimuli were provided to drive substantial changes in several strategy metrics, not just the outcome of sprint time. However, despite our training program having a strong focus on the hip extensor muscles (which are critical during the acceleration phase of sprinting) (4, 20), *F0* did not significantly improve. Similarly, *RFmax* showed moderate improvements only. The reasons may be attributed to the unilateral training program selected. Indeed, it may be hypothesized that a bilateral training approach would have generated greater absolute improvements in force (6), potentially improving the two variables mentioned above. However, further research is needed to clearly elucidate the effects of bilateral and unilateral strength power exercises on the F-V profile variables. Cumulatively, it may be inferred that strength and ballistic jump exercises can improve sprint acceleration time performance shifting the F-V curve spectrum.

Our results are in line with previous research by Cahill et al. (3), who found that strength training coupled with sled training using different loads (i.e., from light to heavy sleds) twice per week for 8 weeks, significantly improved *Pmax* (ES = 0.39 – 1.03), resulting in fairly consistent improvements in split times between 0-20m (ES = 0.41 – 0.87). Similarly, Lahti et al. (19) found significant changes in *VO* (ES = 0.47 – 0.70) when a training program based on resisted (75-85% velocity loss) vs. assisted (105-110% velocity increase) sprint was administered twice per week for 8 weeks. In contrast with our results, *Pmax* was not affected, which may be anecdotally explained by the lower frequency of strength exercises included (strength training was performed only once per week). Also, improvements in split time performance occurred between 0-20m (ES= -1.23) in the resisted sprint group only.

When examining the effects of a 6-week training intervention on the measure of linear speed time performance, our results showed moderate significant improvements in each split time from 10 to 30 meter linear sprint (*g* = 0.64 to 0.81), with the exception of the 0-5 meter, in the UNI group. In contrast, no significant changes were found in the CON group from pre- to post-training intervention in any split time. Moreover, when investigating the between-group differences, our results reported small to large significant improvements from 10 to 30 meter linear sprint (*g* = 0.42 to 1.02) in favour of the UNI group. These findings show that our training program was able to improve linear speed, in all the split times examined. The combination of unilateral high load strength and ballistic jump exercises was therefore able to drive physical adaptations, which translated into an increase in speed performance (i.e., lower time) given a development in strength and power outputs (22). In fact, sprint performance is governed by the simultaneous expression of force and velocity (15). Therefore, our selected training program was able to cover both these decisive mechanical properties to enhance linear speed (13). This is confirmed by the lack of substantial changes in the CON group, confirming that without a specific training intervention, enhancements in linear speed did not occur. However, the reason why the 0-5 meter split time did not show any meaningful change is somewhat challenging to explain. As one possible explanation, it is possible that the role of sprinting from a crouched three-point start position requires precise techniques to build velocity (14), which the current intervention program was unable to assist with. In addition, it is worth noting that the 0-5 meter distance allows only a small "window of opportunity" to show meaningful improvements, given the duration to complete a 5 meter sprint is very short. Finally, figures 1-3 show mean and individual changes from pre- to post-intervention in both groups, revealing a common trend for the UNI group to elicit faster sprinting across all distances.

The current study was not without some limitations. Firstly, the small sample size (i.e., 24 athletes) reduced the power of this study and our specific demographic (i.e., amateur players) precludes our findings from being extrapolated to other cohorts. Second, a 6-week training intervention is a relatively short time period to foster significant muscular adaptations in resistance-trained men, but in this instance, was enough for amateur soccer players; considering also that in the off-season period, athletes may maximise adaptions in 6 weeks (27). A dose-response relationship study is needed to elucidate the minimum training duration to foster significant F-V adaptions. With that in mind, 8-12 weeks of strength and ballistic jump training are generally recommended in athletes to obtain substantial improvements in muscle strength (17). However, a study design that aims to quantify the efficacy of a training programme more regularly (i.e., after each block of training rather than purely pre and post measures) may be of use for practitioners.

PRACTICAL APPLICATIONS

This study showed that the unilateral strength and ballistic jump training elicited small to moderate significant improvements in most F-V variables (i.e., *V0*, *Pmax*, *RFmax*, *Vopt*) and *Max speed* in the UNI group. From a pragmatic perspective, programmes aimed to increase *Pmax* are consistently relevant for heightened physical performance in soccer. Therefore, efficient programming should include the development of both force and velocity capabilities (32, 34, 35). On an individual level, these adaptations can be further maximised by more accurately targeting *Pmax* components (*F0* and *V0*). This can be achieved using tailored force or velocity-oriented training programmes that can optimally shift the individual F-V profile. Players displaying weakness in the force side of the F-V spectrum likely have better relative maximal velocity capabilities, compared to early acceleration. Thus, prioritizing strength exercises (e.g., back squats and split squats) and ballistic jumps (e.g., single and repeated broad jumps), which require high-force and slow stretch-shortening cycle (SSC) development seems like a suitable suggestion. Furthermore, exercises like broad jumps will likely help the development of acceleration owing to the application of force. In contrast, those showing a deficit in the velocity side of the F-V spectrum may indicate that they reach maximal velocity quickly, but are ultimately limited by their top speed capability. Thus, prioritizing methods such as plyometric training and the development of fast SSC mechanics (e.g., pogos, repeated hurdle jumps and even sprinting itself) seems like the most suitable suggestion (25).

DECLARATIONS

Conflict of interest Francesco Bettariga, Luca Maestroni, Luca Martorelli, Anthony Turner and Chris Bishop declare that they have no conflicts of interest relevant to the content of this study.

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Author contributions FB drafted the manuscript. CB, LM, LM, and AT edited and revised the manuscript. FB and LM collected data. All authors approved the final version before submission.

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Table 1. Unilateral training intervention.

Coupled exercises	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**
A-RFESS	3 x 8 35%BW	3 x 7 40%BW	4 x 6 45%BW	4 x 5 50%BW	5 x 4 55%BW	5 x 3 60%BW
SLCMJ	3 x 4	3 x 4	4 x 4	4 x 4	5 x 4	5 x 4
B-SL Hip Thrust	3 x 8 25%BW	3 x 7 30%BW	4 x 6 35%BW	4 x 5 40%BW	5 x 4 45%BW	5 x 3 50%BW
SL Broad Jump	3 x 4	3 x 4	4 x 4	4 x 4	5 x 4	5 x 4
C-SL Romanian Deadlift	3 x 8 30%BW	3 x 7 35%BW	4 x 6 40%BW	4 x 5 45%BW	5 x 4 50%BW	5 x 3 55%BW
SL Drop Jump (20cm)	3 x 4	3 x 4	4 x 4	4 x 4	5 x 4	5 x 4

Legend. RFESS = rear foot elevated split squat; SLCMJ = single leg countermovement jump; SL = single leg; BW = body weight; cm = centimetre.

Table 2. Within session reliability for each test measures at pre- and post-training intervention.

	Pre-intervention				Post-intervention			
Fitness tests	**Unilateral training group**		**Control group**		**Unilateral training group**		**Control group**	
	CV	*ICC (95% CI)*	*CV*	*ICC (95% CI)*	*CV*	*ICC (95% CI)*	*CV*	*ICC (95% CI)*
5m	5.46	0.73(0.27, 0.91)	5.46	0.73(0.27, 0.91)	5.46	0.76(0.30, 0.93)	5.46	0.76(0.30, 0.93)
10m	3.66	0.77(0.40, 0.93)	3.66	0.77(0.40, 0.93)	5.15	0.81(0.42, 0.94)	5.15	0.81(0.42, 0.94)
15m	4.99	0.54(0.21, 0.85)	4.99	0.54(0.21, 0.85)	5.48	0.74(0.29, 0.92)	5.48	0.74(0.29, 0.92)
20m	3.32	0.72(0.25, 0.91)	3.32	0.72(0.25, 0.91)	3.73	0.74(0.32, 0.92)	3.73	0.74(0.32, 0.92)
25m	3.45	0.66(0.54, 0.89)	3.45	0.66(0.54, 0.89)	4.22	0.80(0.38, 0.94)	4.22	0.80(0.38, 0.94)
30m	4.37	0.66(0.10, 0.90)	4.37	0.66(0.10, 0.90)	5.39	0.76(0.22, 0.93)	5.39	0.76(0.22, 0.93)

Legend. CV = coefficient of variation; ICC = intraclass correlation coefficient; CI = confidence intervals; m = meter.

Table 3. Unilateral training group and control group F – V profile variables and 5, 10, 15, 20, 25 and 30 meters sprint performance.

Test	**Unilateral training group**		**Within-group effect size (95% CI) and *P* value**	**Control group**		**Within-group effect size (95% CI) and *P* value**	**Between-group effect size (95% CI) and *P* value**
	Pre	*Post*		*Pre*	*Post*		
F0 (N/kg)	9.06 ± 1.04	9.25 ± 1.08	0.17 (-0.68 to 1.02) *p* = 0.583	9.28 ± 1.92	9.80 ± 2.08	0.25 (-0.60 to 1.10) *p* = 0.084	-0.21 (-1.06 to 0.64) *p* = 0.427
V0 (m/s)	8.08 ± 0.53	8.46 ± 0.35	0.81 (-0.07 to 1.69) ***p* = 0.023**	8.04 ± 0.72	7.80 ± 0.66	-0.34 (-1.19 to 0.52) ***p* = 0.050**	0.95 (0.05 to 1.84) ***p* = 0.002**
Pmax (W/kg)	18.30 ± 2.29	19.59 ± 2.72	0.49 (0.37 to 1.35) ***p* = 0.028**	18.42 ± 2.67	18.92 ± 3.12	0.17 (0.68 to 1.01) *p* = 0.239	0.31 (-0.55 to 1.16) *p* = 0.205
FV Slope	-1.13 ± 0.16	-1.09 ± 0.12	-0.25 (-1.10 to 0.60) *p* = 0.480	-1.18 ± 0.34	-1.28 ± 0.36	0.28 (-0.58 to 1.13) *p* = 0.084	-0.51 (-1.37 to 0.35) *p* = 0.079
RF max (%)	0.46 ± 0.02	0.47 ± 0.02	0.55 (-0.31 to 1.42) ***p* = 0.009**	0.45 ± 0.02	0.45 ± 0.02	0.00 (-0.85 to 0.85) *p* = 0.701	0.48 (-0.38 to 1.34) ***p* = 0.041**
Drf (%)	-0.10 ± 0.02	-0.1 ± 0.01	0.31 (-0.54 to 1.16) *p* = 0.569	-0.11 ± 0.03	-0.12 ± 0.03	-0.32 (-1.17 to 0.53) *p* = 0.119	0.76 (-0.12 to 1.64) *p* = 0.056
Vopt (m/s)	4.04 ± 0.26	4.23 ± 0.17	0.83 (-0.06 to 1.71) ***p* = 0.023**	4.02 ± 0.36	3.9 ± 0.33	-0.34 (-1.19 to 0.52) ***p* = 0.050**	0.95 (0.06 to 1.85) ***p* = 0.002**

Max Speed (m/s)	7.79 ± 0.46	8.13 ± 0.31	0.84 (-0.05 to 1.73) ***p* = 0.014**	7.73 ± 0.58	7.54 ± 0.56	-0.32 (-1.17 to 0.53) *p* = 0.051	0.98 (0.08 to 1.88) ***p* = 0.001**
5m	1.28 ± 0.07	1.25 ± 0.06	0.37 (-0.49 to 1.22) *p* = 0.102	1.35 ± 0.06	1.33 ± 0.07	0.28 (-0.57 to 1.13) *p* = 0.107	0.15 (-0.70 to 1.00) *p* = 0.796
10m	2.06 ± 0.08	2.01 ± 0.08	0.66 (-0.22 to 1.53) ***p* = 0.004**	2.08 ± 0.07	2.10 ± 0.11	-0.15 (-0.99 to 0.70) *p* = 0.489	0.75 (-0.12 to 1.63) ***p* = 0.010**
15m	2.77 ± 0.10	2.70 ± 0.11	0.67 (-0.20 to 1.55) ***p* = 0.002**	2.71 ± 0.16	2.70 ± 0.18	0.04 (-0.80 to 0.89) *p* = 0.715	0.42 (-0.43 to 1.28) ***p* = 0.018**
20m	3.41 ± 0.14	3.32 ± 0.13	0.64 (-0.23 to 1.51) ***p* = 0.002**	3.44 ± 0.08	3.42 ± 0.09	0.19 (-0.66 to 1.13) *p* = 0.419	0.67 (-0.20 to 1.54) ***p* = 0.024**
25m	4.07 ± 0.17	3.95 ± 0.15	0.72 (-0.15 to 1.60) ***p* = 0.001**	4.08 ± 0.12	4.10 ± 0.16	-0.13 (-0.97 to 0.72) *p* = 0.430	0.94 (0.05 to 1.84) ***p* = 0.0009**
30m	4.69 ± 0.20	4.53 ± 0.18	0.81 (-0.08 to 1.69) ***p* = 0.0008**	4.74 ± 0.21	4.80 ± 0.25	-0.23 (-1.08 to 0.62) *p* = 0.214	1.02 (0.11 to 1.92) ***p* = 0.0005**

Legend. *F0* = maximal force; *V0* = maximal running velocity; *Pmax* = maximal power output; FV = force-velocity; *RFmax* = maximal ratio of force; *Drf* = decrease in ratio of force; *Vopt* = optimal velocity; m = meter; s = second; N = newton; Kg = kilogram; W = watt; CI = confidence interval; *p* = p-value.

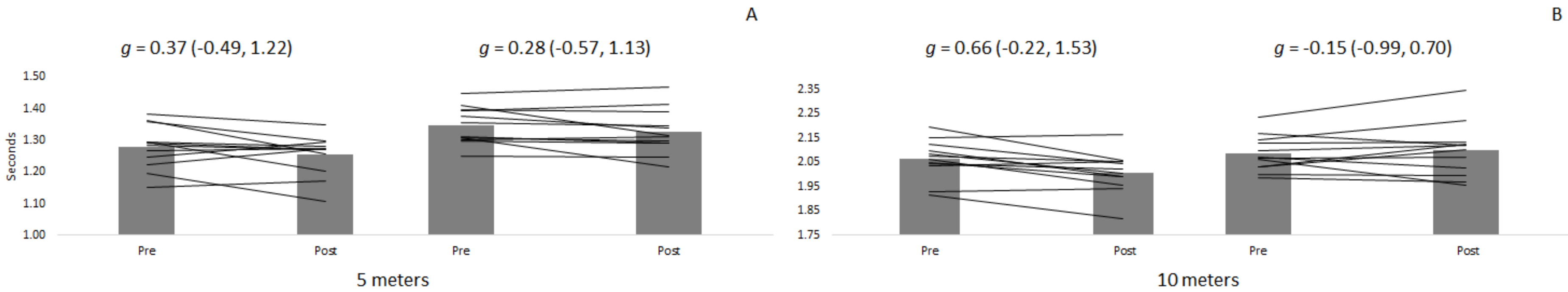

Figure 1. Mean and individual changes, with Hedges' *g* effect size data (95% confidence intervals), from pre- to post-training intervention in the unilateral training group (left) vs. control group (right) in the 5 (A) and 10 (B) meter sprint test.

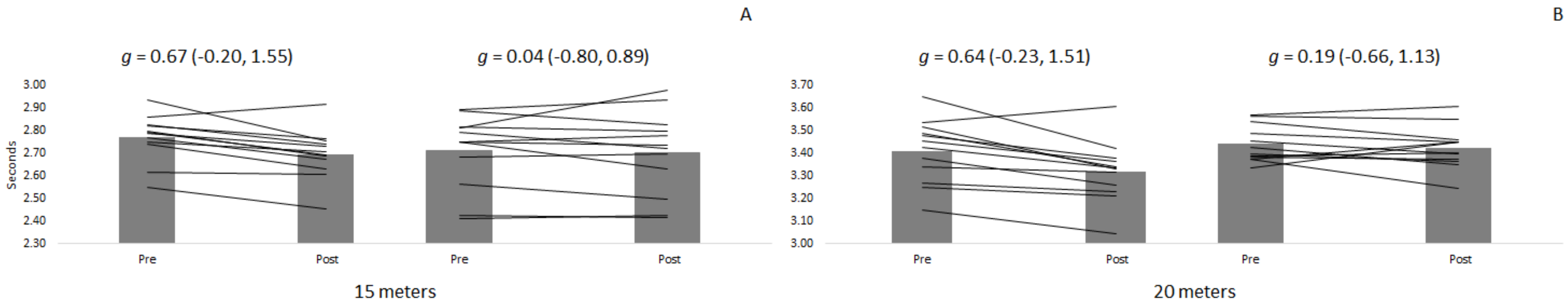

Figure 2. Mean and individual changes, with Hedges' *g* effect size data (95% confidence intervals), from pre- to post-training intervention in the unilateral training group (left) vs. control group (right) in the 15 (A) and 20 (B) meter sprint test.

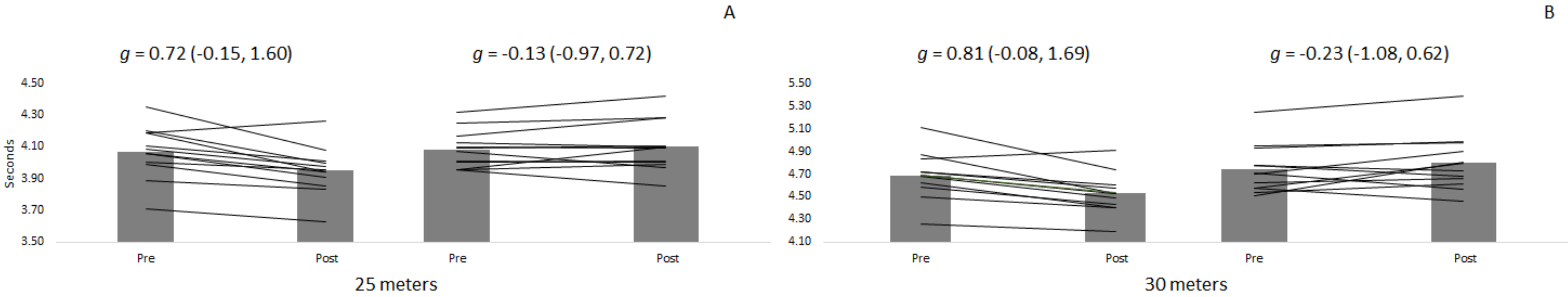

Figure 3. Mean and individual changes, with Hedges' *g* effect size data (95% confidence intervals), from pre- to post-training intervention in the unilateral training group (left) vs. control group (right) in the 25 (A) and 30 (B) meter sprint test.