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EFFECTS OF VERTICAL AND HORIZONTAL STRENGTH EXERCISES ON SPRINT PERFORMANCE AND SPRINT MECHANICAL OUTPUTS IN AMATEUR SOCCER PLAYERS

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- A. Study design/planning
- B. Data collection/entry
- C. Data analysis/statistics
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Abstract:

Background: The aim of this study was to investigate the effects of combined vertical and horizontal strength exercises on sprint mechanical parameters and sprint performance among amateur soccer players.

Methods: The study followed a controlled experimental design. Twenty amateur soccer players were assigned to either an experimental group (EG, $n = 11$) or a control group (CG, $n = 9$). In addition to the soccer training, the EG group conducted a six-week training program involving combined horizontal and vertical strength exercises. Sprint performance and sprint mechanical parameters were computed using a field method based on velocity-time data pre- and post-intervention. The repeated measures ANOVA test was used for between-group comparisons.

Results: The results suggest a significant ($p < 0.05$) improvement in sprint performance at 0-10 meter distance ($p = 0.02$), 0-15 meter distance ($p = 0.01$), 0-20 meter distance ($p = 0.03$), and the maximal value for the ratio of force - RFmax ($p = 0.03$) in EG compared to CG.

Conclusions: The horizontal and vertical strength exercises can improve sprinting performance at distances longer than 5 m but do not improve the most of examined mechanical sprinting parameters in amateur soccer players.

Introduction

Sprint running is a key feature of physical performance in soccer. Typical sprint running distances observed in soccer rarely exceed 30 meters [1,2]. Recent research has shown that horizontal power output (a product of force and velocity capabilities) in the early stages of acceleration has a strong influence on sprint running performance [3,4]. Recently, it has become possible to assess biomechanical variables (e.g., force, velocity, and power) via force-velocity profiling (F-V) using relatively simple field tests (e.g., jumping and sprint running tests). The following sprinting mechanical variables were examined with the F-V profiling: theoretical horizontal maximal force (F0 [N/kg]), theoretical maximal horizontal velocity capacities (V0 [m/s]) and maximal horizontal power output (Pmax [W/kg]), the maximal value for the ratio of force (RFmax [%]), the rate of decrease in the ratio of force (DRF [%]), and the index of the athlete's individual balance between force and velocities capacities (F-V slope) were obtained.

Recent research has shown an increase in sprint performance and horizontal force production capacities in low-level rugby and soccer players after specific training modalities (such as RST) [5,6]. Horizontally-oriented strength exercises may be similar to the spatial-temporal patterns associated with sprinting (e.g., RST, unilateral plyometrics, or both). This may be considered an effective method to improve sprint performance and the mechanical properties of sprinting regardless of the level of sports performance.

The study by Jiménez-Reyes et al. [3] has shown a positive relationship between vertical and horizontal F-V variables in low-level soccer players. Based on this study, it could be hypothesized that incorporating mixed vertical and horizontal resistance exercises into training regimens may improve sprint performance (and sprint mechanical parameters) in sub- and non-elite athletic populations. At lower levels of sports performance, coaches and practitioners often have limited access to specific training equipment and strength training facilities. Without certain training equipment (e.g., sleds, parachutes, etc.), coaches cannot utilize specific or at least mixed-method strength training. Such constraints may force coaches to use more general exercises (in terms of intra- and intermuscular and outer structures of movement) that are not crucial to the main task (i.e., sprint running).

In such circumstances, the solution could be to utilize a combination of resistance exercises using vertical and horizontal orientations with a different spatial-temporal structure than sprint running. The optimal combination of these could provide sufficient stimuli for short- and long-distance sprint performance development [7].

From a practical perspective, it could be valuable for searching for new combinations of training exercises that strength and conditioning staff may use to improve sprints at short distances and related F-V variables.

The main objective of this study was to evaluate the effects of combined vertically- and horizontally-oriented strength exercises on sprinting performance. This study also aimed to evaluate the influence of these exercises on the mechanical properties of amateur soccer players. Given the abovementioned research, it could be hypothesized that an increase in sprint performance will be observed in EG. There are few studies about the impact of such exercises on sprinting F-V variables. This prevents formulating a hypothesis. It is well known that the starting and acceleration phases of sprinting are determined by the concentric strength (and power) of the muscles [8]. It could be assumed that there is a possibility of positive transfer (via similarities at the intra- and intermuscular level) from these exercises into the level of mechanical parameters related to acceleration during sprinting (e.g. maximal horizontal force – F0) among amateur soccer players.

Materials and Methods

Participants

The study followed a controlled experimental design aiming to evaluate the effects of strength training on FVP variables and sprint performance in low-level soccer players. The study included twenty amateur male soccer players from two soccer clubs at the same sports skill level, which was the fifth competition division in Poland. The EG consisted of 12 outfield players (one dropped out) aged x±SD: 22.46 ± 3.88 (finally EG consisted of 11 players). The CG consisted of 13 outfield players (four players dropped out), aged x±SD: 25.2±6.01 (finally CG consisted of 9 players). The research was conducted in 2020 during the pre-season period. The implementation of the measurements took place between May and June and lasted 6 weeks. During the intervention, the participants in the control (CG) and experimental (EG) groups trained 4 times a week. Each week included 3 training units and a control match. The soccer-specific training included technical and tactical drills and small-sided games. The duration of each soccer training was 90 minutes. The presented regimen was the same for both groups. The data about training/match intensity was not collected. The participants in the research had been informed about the assumptions and the course of the experiment. All of them gave written consent to participate in the study and were informed about the anonymity of their personal data and that they would not be published in the study. The research protocol was approved by the local Bioethics Committee (Resolution No. 6/0177/2019), and all research procedures were carried out in compliance with the Declaration of Helsinki.

Training intervention

The intervention training was six weeks long during the preparation period with eight training sessions (one familiarization session, six main sessions, and one de-load session). In the EG group, functional exercises aimed at strengthening the lower limbs were additionally conducted. Details of the EG training and the organization of the entire preparation period are shown in Table 1 and Figure 1. The experimental training was supervised by a strength and conditioning coach. All EG players performed exercises with the same absolute external load. The purpose of such a training solution was to simulate the potential training conditions without access to advanced training methods and strength training facilities, which could be a main limitation at lower levels [9].

Table 1. Strength exercises implemented into soccer-specific training regimen for an entire preparation period

weeks						
0	1	2	3	4	5	6
first training session of the week					post-test: somatic features + sprint test	first season game
pre-test: somatic features + sprint test	1) RESS+5kg, 3x10; 2) KBS+12kg, 3x12; 3) NHE, 3x8	1) RESS+8kg, 3x10; 2) KBS +16kg, 3x12; 3) NHE, 3x10	1) RESS+8kg, 3x10; 2) KBS +16kg, 3x12; 3) NHE, 3x10	deload: 1) RESS, 3x10; 2) KBS +16kg, 3x10;		
second training session of the week						
familiarization with exercises: 1) RESS+5kg, 2x10; 2) KBS+12kg, 2x12; 3) NHE, 2x8	1) RESS+5kg, 3x10; 2) KBS +12kg, 3x12; 3) NHE, 3x8	1) RESS+8kg, 3x10; 2) KBS +16kg, 3x12; 3) NHE, 3x10	1) RESS+8kg, 3x10; 2) KBS +16kg, 3x12; 3) NHE, 3x10	off		

Note: RESS – rear elevated split squat; KBS – Russian kettlebell swing; NHE – Nordic hamstrings exercise; 3x10 – sets x repetitions; +8kg – additional weight/or weight of the kettlebell

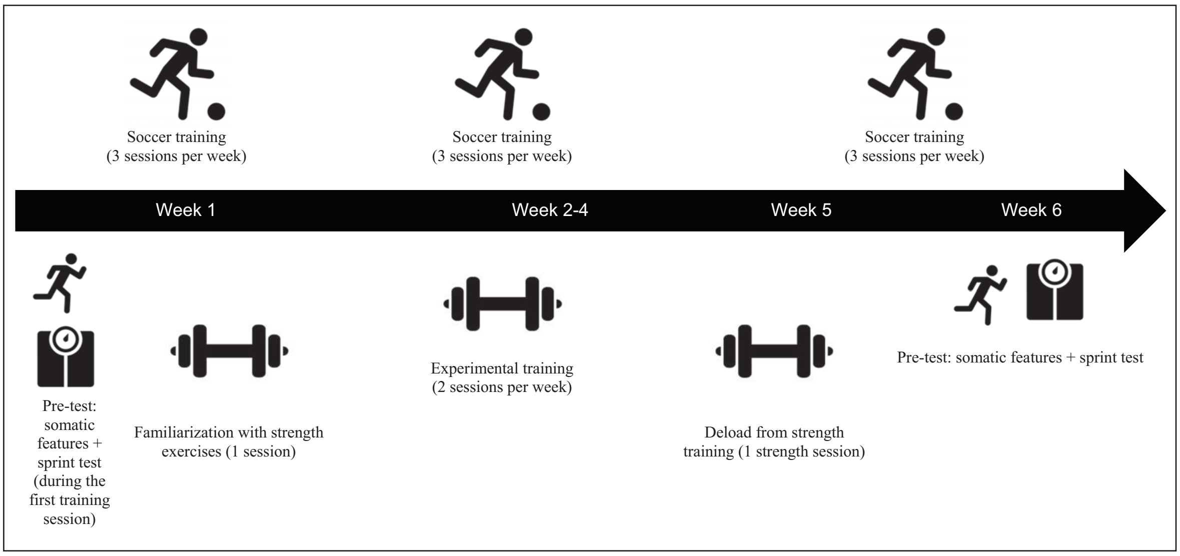

Figure 1. Graphical representation of study design

Somatic measurements

Before sprinting tests, the following somatic measurements were conducted: body height (BH) using an anthropometer, body weight (BW), and percentage of fat mass FM (%) using Tanita model BC – 730 scale (Tanita, Japan).

Sprint performance

After appropriate warm-up (standard for all the participants, including 5 min jogging, single leg squats, lunges, dynamic stretching, and four build-up sprints from a fixed 3-point position without leaning backwards before rolling forward), sprint performance was measured using STALKER ATS Pro II radar device (Applied Concepts, Dallas, TX USA). In this study, the sprints over a 30-meter distance [10] were performed twice. For further analyses and F-V computing, the time measurements were taken at distances of 5, 10, 15, and 20 meters. The device was placed on a tripod 10 m behind the participants at a height of 1 m corresponding approximately to the height of the participant's center of mass (CM) [11]. Each participant performed two maximal accelerations from a fixed 3-point starting position with a 3-minute passive recovery period between them. The sprint performance was averaged and mechanical outputs were computed [12]. This method provides a simple way of obtaining force-velocity relationships from primary laws of motion using running speed and the body mass of the athlete (for more details see [13]. Individual force-velocity relationships (F0, V0, Pmax, RFmax, F-V slope, DRF) were extrapolated from the spreadsheet for sprint acceleration force-velocity profiling [14].

Statistical analysis

The arithmetic mean and standard deviation ($\bar{x}$ and sd) were used in the analysis of the data. The distribution of the dependent variables was evaluated using the Shapiro-Wilk test. A 2 x 2 (EG, CG, pre, post) repeated measures analysis of variance (ANOVA) was performed for each parameter. Partial eta squared (ηp^2) effect sizes for training*group interaction were calculated. An effect of $\eta p^2 \geq 0.01$, ≥ 0.059, ≥ 0.138 indicates a small, moderate, and large effect, respectively [15]. When a significant interaction was detected, a Bonferroni post-hoc analysis was applied for pairwise comparisons. The p-value was set at $p < 0.05$. Cohen's d effect sizes (ES) were calculated to examine the effects of the training regimen [15]. Standardized effects (ES) were also interpreted using threshold values (with 95% CI) for recreational athletes according to Rhea [16]. The threshold values were as follows: small change 0.35 – 0.80; moderate change 0.8 – 1.50; large change >1.50. The absolute (CV) and relative (ICC) reliability for sprinting and mechanical outputs (with 90% CI) and minimal detectable changes (MDC) for used measurement technology (via radar) from both trials (first and second) were evaluated according to Edwards et al. [17] guidelines. The thresholds for reliability values were interpreted as follows: ICC > 0.75 and CV $<10\%$ = acceptable; ICC < 0.75 or CV $>10\%$ = moderate; ICC <0.75 and CV $>10\%$ = poor [18]. The reliability results are presented in Table 2. The Student's t-test for independent variables was performed to check for potential pre-intervention between-group differences regarding performance variables. In this study, we did not calculate the sample size at baseline. The number of participants is a limitation of the study. Thus, the power of statistic calculations was low (under 0.8) for all between-group comparisons.

Table 2. The reliability values with minimal detectable change in this study

Variable	CV (90% CI)	ICC (90%CI)	Average reliability	MDC (90%CI)
F0 (N/kg)	7.3 (5.7-10.1)	0.84 (0.68-0.93)	acceptable/high	0.40
V0 (m/s)	5.7 (4.5-7.9)	0.63 (0.34-0.82)	moderate	0.71
Pmax (W/kg)	8.9 (7.0-12.4)	0.68 (0.41-0.84)	moderate	1.71
FV Slope	10 (7.8-13.9)	0.84 (0.67-0.92)	acceptable/high	0.053
RF max (%)	3.5 (2.8-4.9)	0.84 (0.68-0.92)	acceptable/high	0.013
Drf (%)	10.1 (7.9-14.1)	0.83 (0.66-0.92)	moderate	0.005
5m (s)	2.7 (2.2-3.8)	0.86 (0.71-0.93)	acceptable/high	0.032
10m (s)	2.9 (2.3-3.9)	0.78 (0.56-0.89)	acceptable/high	0.061
15m (s)	2.8 (2.3-3.9)	0.73 (0.49-0.87)	moderate	0.088
20m (s)	2.6 (2.0-3.6)	0.75 (0.52-0.88)	acceptable/high	0.093

Note. CV – absolute reliability values (with 90% confidence intervals); ICC – relative reliability values (with 90% confidence intervals), MDC – minimal detectable change values for each variable in this study

Results

The results revealed significant differences between groups in pre-training in the following variables: Pmax (W/kg) and sprint time at a 10-meter distance. In post-training conditions, there were no significant differences between EG and CG. Absolute values for each parameter in pre– test and post–test conditions together with ANOVA results are presented in Table 3. Large significant training interactions were observed for F0 (f = 5.21, p = 0.034), RF_{max} (f = 11.52, p = 0.003), P_{max} (f = 9.03, p = 0.007), and all split time measurements (f = 8.40, p = 0.009 for 5 m split; f = 10.89, p = 0.003 for 10 m split; f = 11.62, p = 0.003 for 15 m split; f = 10.94, p = 0.003 for 20 m split The pairwise comparisons showed a difference between the control group and the experimental group in post-intervention values in terms of RF_{max} (f = 5.42, p = 0.031, post-hoc p-value = 0.002) and split times at 0-10 (f = 6.45, p = 0.02, post-hoc p –value = 0.002), 0-15 (f = 7.10, p = 0.015, post-hoc p –value = 0.001) and 0-20 meters (f = 5.39, p = 0.03, post-hoc p –value = 0.003). The effect sizes observed in both groups are presented in Figure 2.

Table 3. Overview of the primary and secondary outcomes in the training and control groups. Data presented in x±sd unless stated otherwise

	EG (n = 11)		CG (n = 9)		ANOVA					
	pre	post	pre	post	training	ηp^2	group	ηp^2	training* group	ηp^2
F0 (N/kg)	6.60±1.17	7.23±1.07#	7.30±1.16	7.39±1.16	**0.034**	**0.22**	0.39	0.04	0.104	0.14
V0 (m/s)	9.58± 0.76	9.95±1.14	9.90±0.89	9.96±0.92	0.265	0.07	0.67	0.01	0.419	0.04
Pmax (W/kg)	15.68±2.52	17.80±2.19#	17.86±2.06	18.33±2.92	**0.007**	**0.33**	0.19	0.09	0.071	0.17
FV Slope	-0.70±0.15	-0.74±0.15	-0.75±0.16	-0.75±0.15	0.32	0.05	0.65	0.01	0.34	0.05
RF max (%)	0.42±0.03	0.45±0.03#*	0.45±0.03	0.45±0.04	**0.003**	**0.39**	0.29	0.06	**0.031**	**0.23**
Drf (%)	-0.06±0.01	-0.07±0.01	-0.07±0.01	-0.07±0.01	0.414	0.04	0.7	0.01	0.396	0.04
5m (s)	1.46±0.10	1.41±0.09#	1.40±0.11	1.39±0.11	**0.009**	**0.32**	0.41	0.04	0.111	0.13
10m (s)	2.21±0.13	2.11±0.11#*	2.11±0.12	2.10±0.14	**0.004**	**0.38**	0.28	0.06	**0.020**	**0.26**
15m (s)	2.88±0.14	2.75±0.13#*	2.74±0.13	2.73±0.18	**0.003**	**0.39**	0.23	0.08	**0.015**	**0.28**
20 (s)	3.50±0.16	3.36±0.15#*	3.35±0.15	3.33±0.20	**0.004**	**0.38**	0.24	0.08	**0.032**	0.23

Note. significant results of ANOVA were presented in bold; # variables with average change value more than MDC threshold; *significant Bonferroni post-hoc pairwise comparisons ($p < 0.05$)

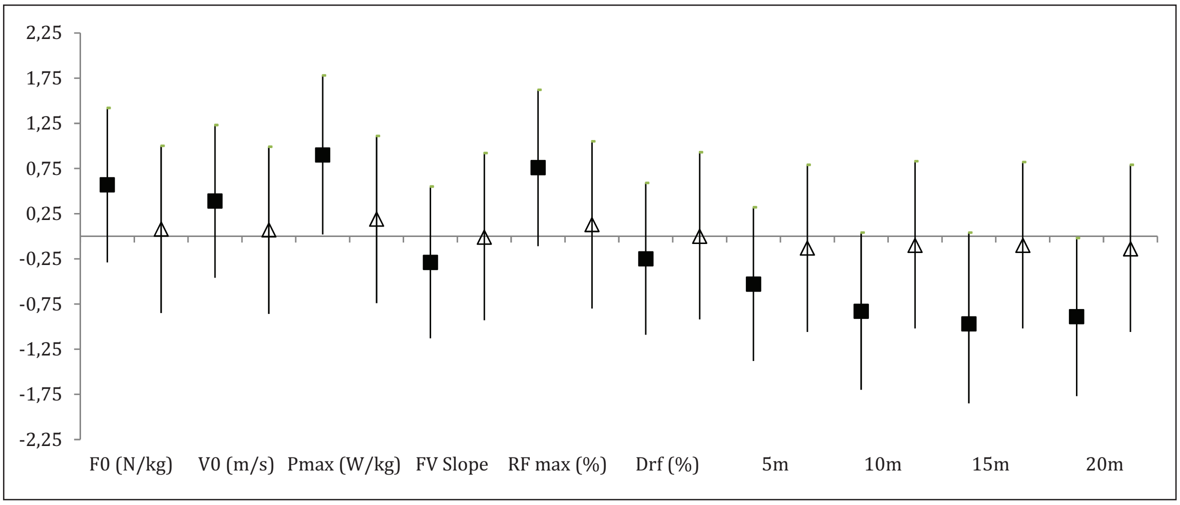

Figure 2. The effect sizes (with 95 CI) observed in both groups in term of measured biomechanical variables and sprint performance.

Note. EG – black squares, CG – white triangles

Discussion

The primary objective of this study was to evaluate the effect of a six-week strength training intervention on sprint performance and sprint mechanical properties during the pre-season. The study found improvements in sprint performance in EG and changes in only one mechanical parameter. In the EG group, the RF_{max} and 0–10, 0–15, and 0–20 meter split times improved compared to the control group. These changes in group differences were small to moderate.

During the initial 20 meters of sprinting, the magnitude of horizontal forces was at its highest, subsequently decreasing as the athlete transitioned to the maximal sprinting phase [19]. Previous research [7] has indicated that among sprint athletes, sprinting efficiency at short distances (0–10 meters) is correlated with horizontally oriented strength exercises. However, the efficiency at longer distances (10–40 meters) is correlated with vertically oriented strength exercises. During high-speed running, athletes produce high vertical ground reaction forces, which reduce ground contact times and facilitate high running velocities [4]. It may be that the observed differences in sprint performance at longer distances were attributed to the intervention used in the EG (which contained vertically oriented strength training). This is in accordance with previous studies by Loturco et al. [7] and Samozino et al. [4], who showed that strength training leads to improvements in sprint performance. In terms of sprint mechanical outcomes, this study revealed only an RF_{max}-level difference between EG and CG.

This specific parameter represents the capability to transfer the highest proportion of total force in a horizontal direction at the beginning of a sprint. Increasing the RF_{max} could be a reason for the increase in the F0 parameter, a combination of vertical power and RF_{max} [20]. Therefore, RF_{max} improved with strength training in EG might have influenced the level of the F0 parameter. Nevertheless, the training regimen used in this study did not increase RF_{max} enough to improve F0 (and in consequence improve the time to 5 m variable) significantly.

Samozino et al. [4] showed maximum mechanical-horizontal power output as the main factor of sprint running performance at distances up to 30 meters. In team sports, such as soccer, athletes perform sprints over short distances [1). In the present study, there were trends towards significance in training *x* group, and training interactions regarding P_{max}. The trend towards significance in P_{max} in EG may be attributed to the strength training intervention to improve intermuscular coordination. It is noteworthy that the experimental group used strength training methods of moderate intensity and volume in addition to their usual soccer training. Soccer training is often characterized by a significant amount of sprint-related training activities [21]. Therefore, changes observed in P_{max} may have been determined by the soccer training mode. In this regard, the lack of changes between the EG and the CG groups supports this conclusion.

In previous research concerning amateur soccer players, the main improvements in the strength-specific (RST) training group were observed in the following parameters: RF_{max} (moderate positive), P_{max} (small positive), F0 (moderate positive), DRF (moderate negative), time to 5 meters (moderate positive), and time to 20 meters (small positive) (6). Bettariga et al. [22], after 6 weeks of training using unilateral strength and ballistic exercises less specific to sprinting noted significant improvements in all distances longer than 0–5 meters and the following mechanical parameters: V0, P_{max}, RF_{max}. Morin et al. [6] used resisted sprint training modes, which are more specific for acceleration in sprint running than the exercises used in our study. It is noteworthy that in the EG group in our study, there was less improvement in 0–5 meters but more improvement in the split times at 0–10, 0–15, and 0–20 meters compared to the findings of a study by Morin et al. These findings could be related to differences in the dynamic correspondence [23] in terms of the direction of force application in exercises used in this study versus exercises used in the Morin et al.'s study [6]. The present study used RESS and KBS exercises that applied force in a vertical direction. Therefore, the observed improvements (at 0–10, 0–15, and 0–20 split times) seem to be consistent with suggestions presented by Loturco et al. [7] about the potential positive effects of vertically oriented exercises on sprint performance at longer distances.

A comparison of the EG and CG groups in a study by Morin et al. [6] revealed differences only in P_{max} (slightly positive) and RF_{max} (positive) but did not show changes in split times. The present study's comparison of the EG and CG groups revealed differences in mechanical outputs ($RF_{max,} p = 0.03$; P_{max}, $p = 0.07$) similar to those in a study by Morin et al. However, in the present study, improvements in sprint performance occurred at longer distances. These findings are opposite to the results of a study by Morin et al., which revealed improvements at shorter distances (0–5 meters).

A comparison of our results with those presented by Bettariga et al. [22] revealed partly similar and narrower positive adaptations, particularly in F-V variables after unilateral strength and ballistic exercises. The main reason for the similarity of results obtained between our study and that published by Bettariga et al. [22] could be that we chose the same unilateral single-leg strength exercise (RESS) which could provide a stimulus for unilateral force production in the stance phase. A comparable exercise in terms of the direction of hip movement is the horizontally oriented hip thrust and kettlebell swing (that incorporate a horizontal direction of movement) [24]. Finally, exercises that emphasize the work of a hamstring muscle group (Romanian deadlift and Nordic hamstring exercise). The main reason for differences between our and Bettariga et al. [22] results may be as follows: firstly, in the Bettariga et al. [22] study, strength exercises were performed with an external load adjusted for the body weight of participants, whereas in our study, exercises were not matched for body weight. This may therefore provide a better individual stimulus for participants in the study by Bettargia et al. [22]. Secondly, these researchers used jumping-based exercises with vertical (countermovement and drop jump) and horizontal (standing broad jump) directions of movement to enhance the stretch-shortening cycle (SSC) during rapid movements and increase leg stiffness which contributes to running with maximal speed [19]. For a substantial change in F-V parameters among low-skilled soccer players, the training program should involve both exercises with external load and ballistic unilateral exercises, according to our and Bettariga et al.'s studies. Yet, for significant improvements in sprinting at a 0–5-meter distance and the F0 parameter, both training programs were insufficient.

The above considerations suggest that when the training objective is to improve sprint performance at shorter distances, the RST mode (a more horizontally oriented exercise) may be efficacious, as suggested by data from the meta-analysis conducted by Alcaraz et al. [25]. However, if the training objective is to improve sprint performance at longer distances, then exercises that project force vertically may be more effective. A combination of both horizontal and vertical modalities may offer a hybrid between the two extremes [21]. However, when this mixed methods approach was used in amateur soccer players, the results were inconclusive [26].

All these considerations suggest the need for additional research on the effects of mixed methods (in terms of the direction of force application) of strength training on sprint mechanical parameters in low-level soccer players.

Limitations

Due to organizational features (at the coach's request), the experimental group (EG) and control group (CG) consisted of players from different soccer clubs. Given the above-mentioned constraints, there was a possibility of significant differences between EG and CG regarding measured variables. Both groups were significantly different in pre-intervention conditions regarding Pmax and sprint time at a distance of 10m. In post-training conditions, there were no significant differences between EG and CG. Given these limitations, it is possible that training could serve as a stimulus for bridging the performance gap between EG and CG for certain variables. Another major limitation of this study was the lack of statistical power of the different tests used.

Conclusions

Strength training exercises with different spatial-temporal structure used to improve sprint running may have a positive effect on sprint performance at distances longer than 5 meters in low-level competitive soccer players. The study indicated that strength exercises did not provide a sufficient stimulus for improvement in sprint running at a 5-meter distance among low-skilled soccer players. Furthermore, this training program failed to produce significant changes in most of the F-V variables except RF_{max}. It is likely that to improve speed on 0–5-meter distance and make wider adaptations in regard to the F-V profile, this training program should incorporate ballistic exercises with a spatial-temporal structure more specific to sprint running.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Institutional Review Board Statement: The research protocol was approved of by the local Bioethics Committee pursuant to Resolution (no. 6/0177/2019).

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