



Relationship between neuromuscular profile and total volume of resisted sprint training in male professional soccer players

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Abstract

Purpose This 11-week study aimed to correlate the neuromuscular profile and the total volume of resisted sprint training (RST) under different velocity loss (VL) magnitudes in male professional soccer players.

Methods Seventeen soccer players (age 25.8 ± 4.3 years; height 180.0 ± 8.6 cm; weight 77.7 ± 9.7 kg) were randomly allocated into two training groups, who trained at distinct percentages of VL: 10% of VL (G10, $n=8$) or 20% of VL (G20, $n=9$). The velocity-based sled training consisted of 20 m resisted sprints executed with a progressive loading increase (45–65% of body-mass). Sprint times (10 m and 20 m), vertical jump height [countermovement jump (CMJ) and squat jump (SJ)], knee flexion and extension peak torque, as well as isometric rate of torque development, and lower limb lean mass were correlated with the total volume of RST performed by G10 and G20 groups.

Results The G10 performed 31% less repetitions and total RST distance than G20 ($p=0.002$). Significant negative Pearson's correlations (large-to-very large) were observed between total volume performed by G10 and CMJ height [$r=-0.85$, confidence interval at 95% (95% CI) = -0.98 to -0.58 , $p=0.02$, Cohen's D effect size (ES) = 0.41] as well as SJ height ($r=-0.90$, 95% CI = -0.99 to -0.66 , $p=0.005$, ES = 0.80), and knee extension concentric peak torque ($r=-0.69$, 95% CI = -0.99 to -0.91 , $p=0.05$, ES = 0.03). No further correlation was found ($p>0.05$).

Conclusions When lower magnitudes of VL were used during training sessions (10%), the stronger and more powerful players performed lower volume of RST. Interestingly, this relationship is not confirmed when higher magnitudes of VL (20%) are prescribed (greater fatigue incidence).

Keywords Speed performance · Acceleration · Athletic performance · Football · Team-sports

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Introduction

Resisted sprints have been frequently used to improve sprint capabilities in soccer players, since high-velocity actions are decisive in modern tournaments [1, 2]. In this sense, weighted sled towing appears to be one of the most frequently used strategies to enhance acceleration in soccer [3–5]. Nevertheless, there are important controversies regarding the “optimal sled load” to be adopted [1, 3–10] and, consequently, different loading strategies have been used by coaches and researchers in an attempt to better and more precisely prescribe resisted sprint training (RST) for elite soccer players [3–5].

In this context, it has been observed that the individual level of strength, power, and speed may have a significant influence

on resisted sprint performance. For example, Lizana et al. [11] observed moderate-to-large correlations between resisted sprint times (with 10, 30, and 50% BM) and unloaded sprint times ($r=0.79\text{--}0.89$), unloaded and loaded jump height ($r=-0.62$ to -0.71), and squat power with different loads ($r=-0.56$ to -0.71). Of note, the magnitude of these associations increased with increasing sled loads, indicating that faster, stronger, and more powerful athletes required heavier sled loads to experience similar exercise intensities. Similarly, Loturco et al. [12] reported that the velocity decreases in female soccer players with higher levels of power output in the half-squat tend to be less affected by progressive sled-loading, especially at shorter distances (≤ 10 m). However, it remains to be determined whether these significant associations persist throughout a longitudinal intervention and, more importantly, whether the total volume of resisted sprints performed until a given condition [i.e., a similar percentage of velocity loss (VL)] could be influenced by the athletes' neuromuscular profile, since these relationships have been analyzed with the loading magnitude (i.e., intensity), but not with training volume.

In traditional strength training, it is well established that greater magnitudes of VL may be counterproductive to improve neuromuscular performance (i.e., decreased power adaptations and reductions in the percentage of myosin heavy chain IIX, compared to lower magnitudes of VL) [13]. Under the same rationale, a previous study assessing the effects of different magnitudes of VL during a "velocity-based RST program" (performed with 45–65% BM) in professional soccer players revealed a greater acceleration improvement for the 10% VL group compared to the 20% VL group (who completed a volume of RST 30% higher than the former) [3]. This suggests that a higher volume of RST (with greater magnitudes of VL) may be not necessary to optimize speed performance in team-sport athletes.

To the best of our knowledge, there is a lack of studies examining the relationship between the neuromuscular profile of soccer players and the total volume of RST that could be completed under different magnitudes of VL. Therefore, the present study aimed to verify whether faster sprint times, higher jump heights, and better performances in strength-related measurements are associated with the volume of resisted sprints performed by elite soccer players at different %VL (i.e., 10 and 20% VL). Since stronger and more powerful athletes are less impacted by increasing sled loads [11], we hypothesized that these athletes would require a greater volume of RST to present similar percentages of VL during resisted sprint trials.

Methods

Experimental design

This is a quasi-experimental longitudinal study assessing the relationships between the total volume of resisted

sprints performed under two different magnitudes of VL (i.e., 10 and 20%) during 11 weeks of moderate-to-heavy sled training with sprint and jump performance, isokinetic measures, and lower limb lean mass evaluated before the respective pre-season in which resisted sprints training was performed. To correlate the total volume imposed by different magnitudes of VL during longitudinal moderate-to-heavy sled training, the participants were divided into two different velocity-based percentage groups (i.e., 10 and 20%). The players performed 11 weeks of moderate-to-heavy sled training (i.e., once a week, excepted for one congested week with two sequential matches) along with traditional soccer training. They completed 10 sled training sessions and 10 matches (i.e., 7 official and 3 non-official) throughout this period. The study was conducted during the season 2019–2020.

Participants

The initial sample comprised 22 male professional soccer players from a Brazilian soccer club participating in the first division state and National cup. Informed consent was acquired from all participants prior to testing. Participants were asymptomatic and free of injuries, participating in training sessions on average 6 times per week, and not using any type of stimulants that could affect their performance. The study was approved by the local Ethics Committee (approval number 2.622.456) and performed in accordance with the Helsinki Declaration for ethical principles. Five athletes were excluded: three were transferred to other clubs and two experienced contact knee injuries. Thus, seventeen professional soccer players (age 25.8 ± 4.3 years; height 180.0 ± 8.6 cm; weight 77.7 ± 9.7 kg) completed the study. The athletes were randomly divided into two groups with distinct VL thresholds: 10% of VL during repetitions (G10, $n=8$, one defender, one left side, three midfielders, and three attackers), and the other with 20% of VL (G20, $n=9$, two defenders, one left side, one right side, three midfielders, and two attackers). The randomization was conducted through paper envelopes and after the baseline evaluation. The allocation was done by an independent and blinded researcher.

Procedures

The assessments were executed in the following order: (a) DXA (starting from body composition to avoid accentuated fluid changes during performance procedures) [14], (b) jump and sprint tests, and (c) isokinetic test. After inclusion, the athlete performed the pre-training

evaluations. Each assessment was supervised by the same researcher, who was blinded to which group each participant belonged to. During the physical testing and training sessions, the players were encouraged by two researchers and their technical staff to perform the trials as fast and as hard as possible. The athletes were previously familiarized with the testing (i.e., regular evaluation at our facilities) and training procedures [i.e., a familiarization session of four sprint bouts with 45% body-mass (BM)].

Body composition

Lower limb lean mass was evaluated by dual-energy X-ray absorptiometry (DXA—Lunar, Model DPX-L; Lunar Radiation Corp., Madison, WI), which was calibrated prior to testing. The individuals wore light clothing, and were instructed to remove any metal material and wear clothes without zippers, buttons or any similar accessory. Each player was asked to lie down in the supine position without moving during the measurements for approximately 5 min, while the arm of the equipment scanned their body, from head to foot. The lower limb lean mass was automatically calculated by the equipment's software (Encore version 14.1, Lunar Prodigy Madison, USA).

Sprint performance

Three photocells (Speed-Test, Cefise, São Paulo, Brazil) were positioned at the starting line and at the distances of 10 and 20 m. The soccer players sprinted three times, starting from a standing position, 1 m behind the starting line. The tests were conducted on the same outdoor soccer field where the team usually trained, with players using the same soccer cleats. A 3-min rest interval was allowed between the attempts. The fastest time was considered for analyses.

Jump performance

Participants performed the squat jump (SJ) and countermovement jump (CMJ) trials on a contact mat (Cefise, Jump-System Pro, São Paulo, Brazil), with the hands fixed on the hips. Jump height was determined using the flight-time calculation [15]. During the SJ, participants were required to initiate the movement with their knees close to 90° and avoid any countermovement; during the CMJ, they initiated the movement from a standing position. They were given 3 trials to obtain their maximum jump height in each test, with 10 s of rest between them, and a variation of $\leq 3\%$ being established as the minimum between valid attempts [16].

Isokinetic assessment

Maximal isometric and isokinetic knee flexion and extension peak torque (PT) and isometric rate of torque development

(RTD) were assessed using an isokinetic dynamometer (Cybex Norm, Ronkonkoma, NY, USA). Participants were seated with their hips and thighs firmly strapped to the seat of the dynamometer, with the hip angle at 85°. After that, the participants warmed up performing 12 submaximal knee extension and flexion repetitions at 120° s⁻¹ using the dominant leg. Participants were then instructed to perform five maximal concentric knee extension and flexion repetitions at 60° s⁻¹ through a 90° range of motion (i.e., 0° full extension). After that, they performed five maximal eccentric knee flexion repetitions at 60° s⁻¹. Thereafter, the participants were instructed to isometrically produce the maximal knee extension and flexion force as fast as possible for 3 s (each attempt) at 30° [17–19]. The rest interval between the consecutive attempts was fixed at 2 min. The torque–time curve was obtained using Miotool software sampled at 2000 Hz. Maximal PT was defined as the highest torque value determined with the dynamometer's HUMAC2009 software (with gravity corrections). The RTD was derived from the average slope of the moment–time curve (Nm s⁻¹) over time intervals of 0–350 ms relative to the onset of contraction, which was considered the point at which the torque exceeded 2.5% of maximal voluntary contraction (MVC) [17–19] and determined using the MATLAB software routine. The isometric force–time analysis on the absolute scale included the maximal RTD, defined as the greatest torque value obtained in 0–350 ms using Excel software. The maximal RTD values were determined by dividing the force–time curve at successive moving time intervals of 50 ms (i.e., 0–50, 1–51, 2–52). In addition to the maximal RTD, the RTDs at 0–50 ms (early) and 100–200 ms (late) intervals were calculated.

Training intervention

The training intervention consisted of 11 weeks of moderate-to-heavy sled training (4 pre-season and 7 in-season) composed by 20 m straight-line sprint bouts using a weighted sled (Fitnessbeat, Brazil). A 2.5 m cable connected the sled to the players by means of a waist harness. The intensity was progressively prescribed according to individual body-mass (BM). Along with the sled-mass (i.e., 6 kg), the load started from 45% BM in the first session, increasing 5% in each training session until the fifth week, in which 65% BM was reached and maintained until the end of intervention. VL thresholds (10 and 20%) across repetitions were monitored using a radar gun (Bushnell 101911; 02-13, Kansas, USA), positioned and directed posteriorly to the participants' center of mass. Prior to each session, athletes performed 10 min of a specific warm-up including moderate running, dynamic stretching, skipping exercises, and preparatory sprint drills. During the sessions, the G10 and G20 performed repetitions until the velocity decreased

to 10 and 20%, respectively, compared to the maximum velocity achieved with sled in the first 4 repetitions of each session. During the entire intervention period, 33.1, 24.3, 27.2, and 15.4% of the soccer players reached their maximum velocity in the first, second, third, and fourth repetition, respectively. Moreover, the trials performed before the fastest repetition were also counted in the total volume calculation. The magnitudes of VL were controlled using an Excel spreadsheet. While one researcher assessed the velocity using the radar gun, a second researcher immediately added the values to the spreadsheet and identified the respective decrements in velocity across repetitions. When the athlete reached twice consecutively the correspondent percentage of reduction (i.e., ≥ 10 or 20%), according to the group, the training was immediately interrupted. Thus, this approach provided an individualized total resisted sprints volume (i.e., the total distance performed in all sessions). The rest between each repetition was fixed at 30 s, given the necessary time to approach the training sessions for the next players. Each training session lasted from 35 to 45 min. The sled training was always performed on the same outdoor lawn (synthetic) and the athletes used soccer cleats and the same uniform. In case of raining events, the sessions were conducted on an indoor space with a similar synthetic grass [20]. Four players trained simultaneously with four sleds, positioned side-by-side, while the same experienced sport scientist assessed all trials using the radar gun. Besides sled intervention, the professional athletes had to be involved in the same traditional soccer training routine (379.1 ± 26.1 min of training per week), consisting of small-sided games, non-periodized core stability and strengthening exercises, offensive and defensive transitions as well as tactical aspects (i.e., positional situations, dead balls, ball circulation). Three researchers (R.G., M.I., and F.V.) accompanied the workouts to ensure that no additional effort would be done. Thus, only the RST programs were different between groups. The BM was measured with an electronic scale (Urano, PP180A; Rio Grande do Sul, Brazil) with an accuracy of 0.1 kg.

Statistical analysis

Data are presented as means \pm SD. The Shapiro–Wilk and Levene tests were used for normality and homogeneity, respectively. Training and participants' characteristics were compared using an independent t test. The relationships between variables were determined using Pearson's coefficients (r) and respective confidence interval at 95% (95% CI). The correlation coefficients were qualitatively interpreted as follows: 0.1, trivial; 0.1–0.3, small; 0.3–0.5, moderate; 0.5–0.7, large; 0.7–0.9, very large; and 0.9 nearly perfect [21]. Cohen's D effect sizes (ES) were calculated by differences between group means divided by the pooled SD. ES were interpreted as follows: $ES \leq 0.2$, trivial effect; 0.2–0.5, small effect; 0.5–0.8, moderate effect; and $ES > 0.8$, large effect. Data were analyzed using SPSS statistical software package (version 22, Chicago, USA) and the level of significance was set at $\alpha = 0.05$.

Results

Data showed normality and homogeneity of variance ($p > 0.05$). There was no any adverse event during training and testing procedures. The characteristics of participants and their training routines are described in Table 1. The G10 performed $\sim 31\%$ less repetitions and total resisted sprint distance than G20 ($p = 0.002$) (Table 1). Significant large-to-very large negative correlations were observed between total volume performed by G10 and CMJ height [675.0 ± 184.5 m, 95% CI 547.2–802.8 m; 39.5 ± 4.6 cm, 95% CI 36.3–42.7 cm; $r = -0.85$, 95% CI -0.98 to -0.58 , $p = 0.02$, $ES = 0.41$; coefficient of variation (CV): G10 = 11.6%, G20 = 10.1%; Fig. 1] as well as SJ height (675.0 ± 184.5 m, 95% CI 547.2–802.8 m; 35.0 ± 3.5 cm, 95% CI 32.6–37.4 cm; $r = -0.90$, 95% CI -0.99 to -0.66 , $p = 0.005$, $ES = 0.80$; CV: G10 = 9.9%, G20 = 11.4%; Fig. 2), and knee extension concentric PT

Table 1 Participants' and training characteristics

	10% Group (G10, $n = 8$)	20% Group (G20, $n = 9$)	Cohens' D effect size
Age (years)	26.25 ± 5.31	25.44 ± 3.57	0.05
Weight (kg)	75.76 ± 9.76	79.45 ± 9.94	0.14
Height (cm)	178.62 ± 9.48	181.22 ± 8.19	0.10
Played minutes (min)	544.12 ± 355.47	572 ± 284.98	0.03
Velocity loss (%)	$14.73 \pm 2.67^*$	$26.46 \pm 4.00^*$	0.15
Repetitions	$33.75 \pm 9.22^*$	$48.78 \pm 7.50^*$	0.62
Total distance (m)	$675.00 \pm 184.47^*$	$975.56 \pm 149.93^*$	0.62

*Independent t -test showed differences between groups for total distance ($p = 0.002$), repetitions ($p = 0.002$), and velocity loss ($p = 0.0002$) while played minutes were not different ($p = 0.86$)

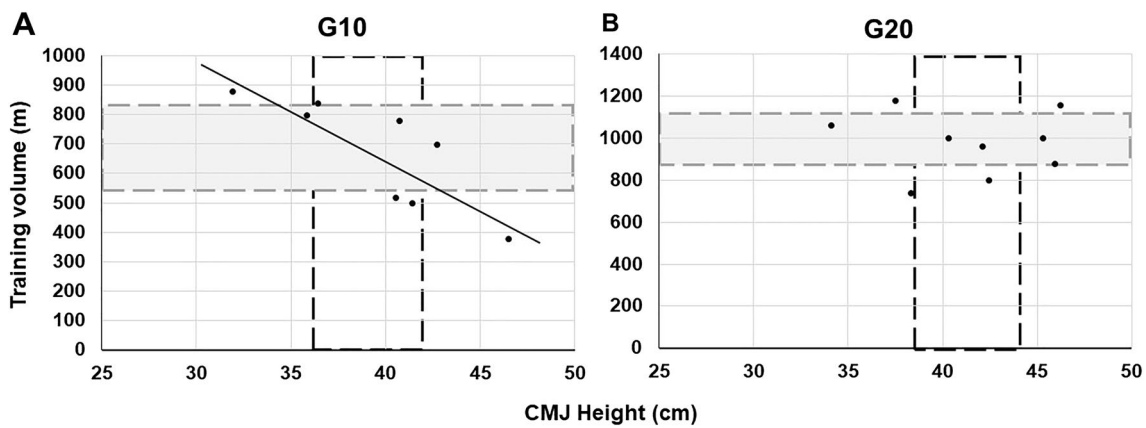


Fig. 1 **A** The correlation between countermovement jump (CMJ) height and total sled training volume for 10% of velocity loss group (G10). **B** The correlation between countermovement jump (CMJ) height and total sled training volume for 20% of velocity loss group

(G20). Dashed gray rectangle space represents the 95% confidence interval of the training volume for each group. Dashed black rectangle space represents the 95% confidence interval of the CMJ height for each group

(675.0 ± 184.5 m, 95% CI 547.2–802.8 m; 247.6 ± 39.0 N m, 95% CI 220.6–274.7 N m; $r = -0.69$, 95% CI -0.99 to 0.91 , $p = 0.05$, ES = 0.03; CV: G10 = 15.8%, G20 = 9.7%; Fig. 3). No further correlations between variables were found ($p > 0.05$). Complete results are exposed in Table 2. Lastly, Table 3 demonstrates the total distance and the number of repetitions performed per sled training session by each training group during the intervention period.

Discussion

The main finding of the present study was that CMJ and SJ height as well as concentric knee extension PT showed large-to-very large negative correlations with the total

training volume of RST performed by G10. Interestingly, these relationships were not found in G20. In practical terms, this means that athletes with superior neuromuscular performance will require a lower volume of resisted sprints to achieve similar levels of VL, at least when lower magnitudes of VL are considered (i.e., 10%) during a 11-week RST with moderate-to-heavy loads (45–65% BM). The present findings are different from our initial hypothesis suggesting that stronger and more powerful soccer players would require a greater volume of RST to present similar percentages of VL during resisted sprint bouts. These results are unprecedented and provide useful insights for RST prescription, especially for team-sport athletes.

Previous studies have already demonstrated some important relationships between resisted sprints and different

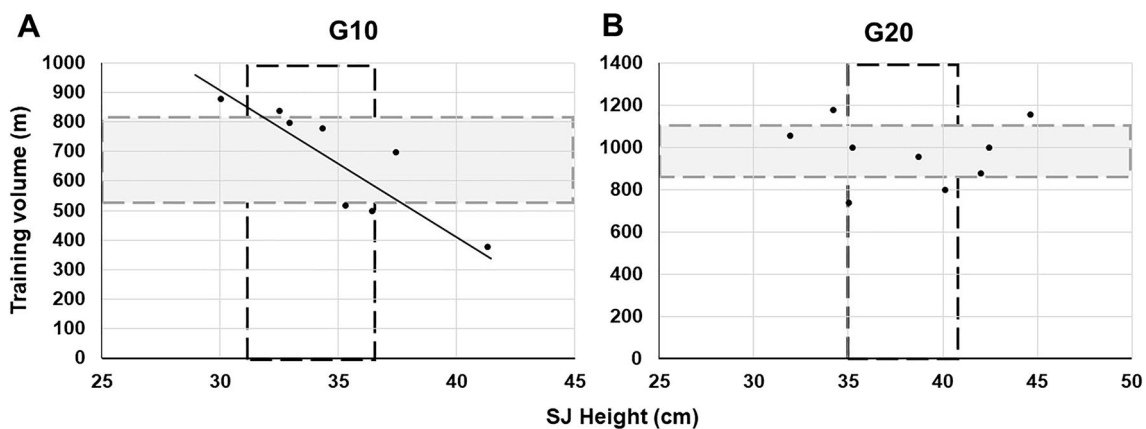


Fig. 2 **A** The correlation between squat jump (SJ) height and total sled training volume for 10% of velocity loss group (G10). **B** The correlation between squat jump (SJ) height and total sled training volume for 20% of velocity loss group (G20). Dashed gray rectangle

space represents the 95% confidence interval of the training volume for each group. Dashed black rectangle space represents the 95% confidence interval of the SJ height for each group

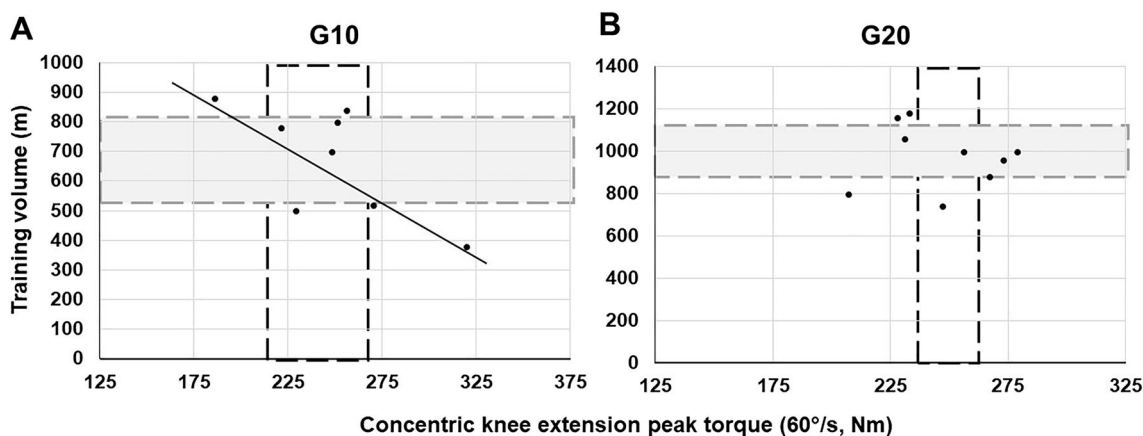


Fig. 3 **A** The correlation between concentric knee extension peak torque at 60°/s and total sled training volume for 10% of velocity loss group (G10). **B** The correlation between concentric knee extension peak torque at 60°/s and total sled training volume for 20% of veloc-

ity loss group (G20). Dashed gray rectangle space represents the 95% confidence interval of the training volume for each group. Dashed black rectangle space represents the 95% confidence interval of the concentric knee extension peak torque at 60°/s for each group

measures of neuromuscular performance using cross-sectional designs. Interestingly, Lizana et al. [11] analyzed the relationships between strength, power, and speed parameters and resisted sprint performance across a range of sled loads (i.e., 10, 30, and 50% of BM) in physically active young male. Their results revealed that resisted sprint times were moderate-to-large correlated with unloaded sprint times, unloaded and loaded jump height, and squat power. In addition, negative correlations were observed between VL induced by each respective sled load and jump and squat performance, with the magnitude of these coefficients increasing with increasing sled loads (from 0.46 to 0.70). Likewise, Martínez-Valencia et al. [22] observed significant negative associations between the “maximum sled load” (i.e., sled load that precludes athletes from increasing their speed in relation to the previous sprint split) and 20 m resisted sprint time ($r = -0.47$, for resisted sprints with 5% BM). From these data, it is plausible to infer that faster, stronger, and more powerful athletes may require heavier sled loads to experience similar RST intensities (or percentages of VL). Nevertheless, these results were obtained in cross-sectional studies, under different experimental designs (e.g., a fixed number of resisted sprints), without taking into account the potential influences of neuromuscular performance in the % VL induced by each distinct sled load across the multiple resisted sprint sets.

As a consequence, the present findings contradict our initial hypothesis, revealing that stronger and more powerful soccer players experience a similar %VL (i.e., 10% VL) with a lower volume of RST (as demonstrated by the negative large-to-very large correlations found between vertical jump performance, concentric knee extension PT, and RST volume; see Table 2). It seems reasonable to speculate that these negative relationships are related to the fact that

athletes with superior jump performance and knee extension PT have a higher proportion of “fast-fatigable” type IIx muscle fibers [23] and, for this reason, achieved higher levels of VL beforehand, thus performing a lower volume of RST under 10% VL. In contrast, when the VL threshold is higher (i.e., 20% VL), these associations could disappear because it is likely that the greater fatigue rates observed in G20 may interfere with this relationship. Figure 1A, for instance, reveals that players with a CMJ < 40 cm performed twice the amount of training volume (> 800 m) to achieve a VL of 10% compared to those players with a CMJ height above 45 cm (< 400 m). It seems, therefore, that stronger and more powerful players require a lower number of repetitions to achieve similar levels of VL during RST, but only under lower magnitudes of VL (e.g., 10% VL).

Since only the G10 presented a significant correlation between some specific neuromuscular capacities (i.e., CMJ and SJ height, and concentric knee extension PT) and the total training volume of resisted sprints, it is plausible to assume that, when lower magnitudes of VL are prescribed (i.e., up to 10%), the degree of neuromuscular fatigue is increased in athletes with superior levels of strength and power [13, 24–27]. Nonetheless, under greater magnitudes of VL (i.e., 20%), “speed endurance” (i.e., the ability to maintain higher levels of sprinting speed over an extended period) [25] is likely paramount. From these results, it can be inferred that stronger and more powerful players will require a lower volume of resisted sprints solely at lower magnitudes of VL. When this magnitude is increased, these “superior capabilities” are seemingly not dominant and might be influenced by endurance-related factors.

The current study has some important limitations. First, we did not test or compare the magnitudes of VL (and their possible correlations) under different sled load intensities

Table 2 Pearson's correlation magnitudes between sprint performance, jump performance, rate of torque development, lower limb lean mass, and knee flexion and extension maximal strength with total training volume performed during 11 weeks of intervention

	Groups	Pre-intervention tests	Cohen's <i>D</i>	<i>r</i> (95% CI)	<i>P</i> value
10 m sprint time (s)	G10	1.60±0.05	0.42	0.58 (0.09 – 0.97)	0.16
	G20	1.57±0.11			
20 m sprint time (s)	G10	2.83±0.07	0.31	0.60 (0.03 – 0.99)	0.14
	G20	2.79±0.17			
CMJ (cm)	G10	39.49±4.57	0.41	– 0.85 (– 0.98 to – 0.58)	0.02*
	G20	41.34±4.17			
SJ (cm)	G10	35.01±3.46	0.80	– 0.90 (– 0.99 to – 0.66)	0.005*
	G20	38.23±4.36			
KE MRTD (N m s ⁻¹)	G10	1388.19±678.77	0.76	– 0.42 (– 0.95 to 0.83)	0.29
	G20	1872.74±598.00			
KE RTD 0–50 ms (N m s ⁻¹)	G10	579.82±391.26	0.72	– 0.53 (– 0.96 to 0.81)	0.17
	G20	837.71±316.46			
KE RTD 100–200 ms (N m s ⁻¹)	G10	1419.19±450.49	0.84	0.06 (– 0.88 to 0.69)	0.88
	G20	1806.73±476.84			
KF MRTD (N m s ⁻¹)	G10	975.54±182.23	1.09	– 0.51 (– 0.97 to 0.41)	0.19
	G20	1409.68±534.85			
KF RTD 0–50 ms (N m s ⁻¹)	G10	311.91±91.78	0.99	– 0.40 (– 0.90 to 0.37)	0.31
	G20	530.24±296.47			
KF RTD 100–200 ms (N m s ⁻¹)	G10	1005.03±141.03	1.15	– 0.48 (– 0.94 to 0.22)	0.22
	G20	1304.48±339.53			
Lower limb lean mass (kg)	G10	22.09±3.25	0.33	– 0.24 (– 0.91 to 0.80)	0.55
	G20	23.16±3.19			
KE MVC (N m)	G10	217.62±52.25	0.26	0.11 (– 0.64 to 0.86)	0.78
	G20	230.22±45.66			
KE PT 60° s ⁻¹ (N m)	G10	247.62±39.04	0.03	– 0.69 (– 0.99 to 0.91)	0.05
	G20	246.77±23.96			
KF MVC (N m)	G10	148.12±30.60	0.10	0.45 (0.25 to 0.98)	0.25
	G20	144.88±34.45			
KF PT 60° s ⁻¹ (N m)	G10	139.50±20.34	0.39	– 0.31 (– 0.95 to 0.63)	0.45
	G20	150.33±33.79			
KF Ecc PT 60° s ⁻¹ (N m)	G10	180.62±28.01	0.39	– 0.08 (– 0.84 to 0.81)	0.83
	G20	193.55±37.17			

KE knee extension, KF knee flexion, MRTD maximal rate of torque development, RTD rate of torque development, CMJ countermovement jump, SJ squat jump, MVC maximal voluntary contraction, PT peak torque, Ecc eccentric, *r* Pearson's correlation coefficient, 95% CI confidence interval at 95%, Cohen's *D* Cohen's *D* effect size, G10 10% group, G20 20% group

*Significant Pearson's negative correlations between total volume performed by G10 and CMJ height ($r = -0.85$, $p = 0.016$) as well as SJ height ($r = -0.90$, $p = 0.005$), and knee extension concentric peak torque stayed near to significance ($r = -0.70$, $p = 0.05$). No further significant correlation was found ($p > 0.05$)

(i.e., sled loads lighter than 45% BM). In addition, the small sample size and the absence of an accurate “speed endurance marker” (i.e., repeated sprint ability, for example) may also compromise the extrapolation and interpretation of our data. However, it is important to emphasize that this study was performed with soccer players from a professional soccer club, during the transition period between the pre-season and the first phase of the competitive season. As such, this study represents a “real-world” situation and, hence, presents all limitations and strengths inherent to this type of

investigation. Further studies are needed to test whether different volumes of RST under similar magnitudes of VL may produce similar improvements in the physical performance of athletes with distinct strength-power levels. Our findings can be transferred from theory to practice indicating that soccer players with superior neuromuscular performance will require a lower volume of RST to achieve similar levels of VL, especially when lower magnitudes of VL are applied (i.e., ≤ 10%) under moderate-to-heavy loading conditions (i.e., 45–65% BM). Even without constantly monitoring VL

Table 3 Number of repetitions and total distance performed per sled training session within each group during the intervention period

Session	1	2	3	4	5	6	7	8	9	10
10% Group (G10, n=8)										
Repetitions	2.8±0.7	3.4±1.1	2.9±0.8	3.4±1.5	3.0±1.4	3.1±1.4	4.0±1.5	3.3±1.0	3.4±1.3	2.9±0.8
Total distance (m)	55.0±14.1	67.5±21.2	57.5±16.7	67.5±30.1	60.0±28.3	62.5±27.1	80.0±30.2	65.0±20.7	67.5±26.0	57.5±16.7
20% Group (G20, n=9)										
Repetitions	5.5±1.2	5.0±0.9	4.8±0.7	5.1±1.7	4.6±1.1	4.6±1.4	5.3±1.2	4.3±1.5	4.1±1.0	4.3±1.0
Total distance (m)	110.0±23.9	100.0±18.5	95.0±14.1	102.5±34.5	92.5±21.2	92.5±28.2	105.0±23.3	85.0±29.8	82.5±19.8	85.0±20.7

during RST, practitioners should be aware that stronger and more powerful athletes will possibly experience similar RST intensities by performing a lower number of resisted sprints.

Conclusions

Professional soccer players able to jump higher and produce greater levels of concentric knee extension PT require lower volumes of RST to experience similar intensities of RST, specifically under lower magnitudes of VL (i.e., ≤10%) and at moderate-to-heavy sled intensities (i.e., 45–65% BM). These relationships were not observed under higher magnitudes of VL (i.e., 20%). The observance of these relationships is important to create more effective and tailored RST strategies in team-sports which commonly comprise athletes with different physical and technical characteristics and training backgrounds.

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Author contributions RG, IL, and EC have given substantial contributions to data acquisition and analysis, manuscript writing and revision, FV and MI to data acquisition and analysis, RR, JT, RP, and IG to manuscript writing and revision. All authors read and approved the final version of the manuscript.

Declarations

Conflict of interest No potential conflict of interest was reported by the authors.

Ethical approval All the procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. This article does not contain any studies with animals performed by any of the authors. The present study was evaluated and approved by the Federal University of Rio Grande do Sul's Ethics and Research Committee under number 2.622.456.

Informed consent The participants were informed about the research procedures and invited to read and sign the informed consent form if they agreed. Informed consent was obtained from all the individual participants included in the study.

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