International Journal of Sports Physiology and Performance, **(Ahead of Print)**
https://doi.org/10.1123/ijspp.2020-0867

Human Kinetics
ORIGINAL INVESTIGATION

Impact of Sled Loads on Performance and Kinematics of Elite Sprinters and Rugby Players

Fernando Pareja-Blanco, Lucas A. Pereira, Valter P. Reis, Victor Fernandes, Ademir F.S. Arruda, Aristide Guerriero, Pedro E. Alcaraz, Tomás T. Freitas, and Irineu Loturco

Purpose: To examine the changes in resisted sprint performance and kinematics provoked by different sled loads in elite sprinters and rugby players. ***Methods:*** Eight elite male sprinters and 10 rugby union players performed 20-m sprints under 3 loading conditions (0%, 20%, and 60% body mass [BM]). Sprint time was measured in 0 to 5, 5 to 10, and 10 to 20 m, while stride length and hip, knee, and ankle angles were measured using an 8-sensor motion analysis system at the same distances. ***Results:*** Sprinters were significantly faster than rugby players in unresisted and resisted sprints using 20% BM (effect size, "ES" [90% confidence limit, CL] range: 0.65 [0.03 to 1.27]; 3.95 [3.10 to 4.81]), but these differences were not significant at 60% BM. Compared to rugby players, sprinters showed lower velocity decrement in resisted sprints using 20% BM (ES [90% CL] range: 0.75 [0.06 to 1.44]; 2.43 [0.83 to 4.02], but higher velocity decrement using 60% BM (ES [90% CL] range: 1.13 [0.43 to 1.82]; 1.46 [0.81 to 2.11]). No significant differences were detected in stride length between sprinters and rugby players for any sprint condition (ES [90% CL] range: 0.02 [–0.72 to 0.76]; 0.84 [0.13 to 1.54]). Rugby players showed higher hip flexion in resisted sprints (ES [90% CL] range: 0.30 [–0.54 to 1.14]; 1.17 [0.20 to 2.15]) and lower plantar flexion in both unresisted and resisted sprints (ES [90% CL] range: 0.78 [0.18 to 1.38]; 1.69 [1.00 to 2.38] than sprinters. ***Conclusions:*** The alterations induced by resisted sprints in sprint velocity and running technique differed between sprinters and rugby players. Some caution should be taken with general sled loads prescriptions, especially when relative loads are based on distinct percentages of BM, as training responses vary among sports and individuals.

Keywords: sprint training, acceleration, maximum speed, sled towing, track and field, team sports

Resisted sprint methods allow athletes to reproduce the unresisted sprinting technique with the advantage of providing specific mechanical overload.[1] One of the most popular resisted sprint methods is resisted sled training (RST), which involves maximum sprint efforts while towing a sled device.[2] A meta-analysis showed that RST may induce substantial improvements in sprint performance, mainly during the maximum acceleration phase (ie, ≤10 m), with trivial effects in the maximum velocity phase (ie, ≥20 m).[3]

However, sled loading strategies vary greatly between studies. Light loads (ie, 10%–12.5% of body mass [BM]) are commonly recommended, since they bear close resemblance to the "traditional" sprinting technique.[4–8] In this regard, some studies suggested that running velocity should not fall below 90% of the athlete's maximum velocity, especially when seeking improvements in the high-velocity end of the force–velocity continuum (ie, top-speed phase).[7–9] Conversely, it has recently been suggested that heavier loads (from 40% to 80% BM) should be used to promote greater improvements at the opposite end of this continuum (ie, high-force/low-velocity portion).[9–12] Training under these loading conditions results in higher velocity decrements and increased contact times,[13,14] which may potentially induce negative effects on maximum velocity.[9] Nevertheless, these loading conditions also allow athletes to increase horizontal force production, which is key for sprint acceleration.[15]

From a kinematic standpoint, heavier sled loads cause greater alterations in sprint technique (eg, decrease in step length, flight time, and running velocity; higher trunk lean and hip flexion) than lighter loads.[7,10,13,16,17] However, the great interindividual variability in sprint velocity decrements induced by each percentage of BM (interindividual coefficient of variations from 10% to 30%) should be highlighted.[18] Accordingly, it has been shown that differences in speed, strength, and power abilities may explain the individual responses during sled towing, since faster, stronger, and more powerful athletes require heavier sled loads (relative to % BM) to experience similar decrements in sprint velocity.[18] Thus, it is likely that a given percentage of BM could provide heterogeneous training stimuli for different types of athletes. To date, no study has analyzed the alterations in resisted sprint performance provoked by various load ranges in athletes with distinct characteristics and training backgrounds.

Knowledge of the particular requirements and characteristics of each sport will assist practitioners in properly designing effective training programs. For example, although rugby players are stronger in absolute terms, sprinters exhibit higher relative strength levels.[19,20] In addition, whereas rugby players rely heavily on high levels of dynamic and isometric strength to effectively execute their game tasks,[21,22] sprinters need to be able to apply large amounts of force at higher velocities.[19,23] Nonetheless, despite the clear difference in the level of importance, speed ability is paramount for performance in both sport disciplines.[24,25] Therefore, there is a

---

Pareja-Blanco is with the Physical Performance & Sports Research Center and the Dept of Sport and Computer Sciences, Faculty of Sport Sciences, Universidad Pablo de Olavide, Seville, Spain. Pereira, Reis, Fernandes, Freitas, and Loturco are with the NAR—Nucleus of High Performance in Sport, São Paulo, Brazil. Pereira, Freitas, and Loturco are also with the Dept of Human Movement Science, Federal University of São Paulo, Santos, São Paulo, Brazil. Arruda and Guerriero are with the CBRu—Brazilian Rugby Confederation, São Paulo, Brazil. Alcaraz and Freitas are with the UCAM Research Center for High Performance Sport—Catholic University of Murcia, Murcia, Spain; Alcaraz is also with the Faculty of Sport Sciences at the university. Loturco is also with the University of South Wales, Pontypridd, Wales. Pareja-Blanco (fparbla@upo.es) is corresponding author.

strong case for coaches implementing RST to enhance the competitive performance of these athletes. The current understanding of RST prescription is based on general data (eg, sled loads prescribed according to %BM).[5,16] Whether this criterion is equally applicable to athletes with different physical characteristics and needs such as rugby players and sprinters is still unclear. As running technique varies with sprint distances[15,16] and the relevance of acceleration and maximal velocity phases also differs between rugby players and sprinters,[26] comparisons between unresisted and resisted conditions across sprint distances are required. This information could help coaches to select more appropriate sled loads for different types of athletes. The purpose of this study was to compare the changes in resisted sprint performance and kinematics provoked by different sled loads in sprinters and rugby players.

Methods

Participants

Eight elite male sprinters (23.3 [2.6] y; 75.2 [7.6] kg; 1.78 [0.06] m) and 10 professional male rugby union players (21.3 [3.3] y; 89.7 [18.8] kg; 1.79 [0.05] m) participated in this study. The sample comprised 1 sprinter who participated in the last Olympic Games (Rio 2016) and the other subjects had recently been involved in Pan American and South American competitions. Rugby players were members of the Brazilian National Development Team, belonging to a national project named “TOP-100” and organized by the Brazilian Rugby Confederation. At the time of the study, all athletes had at least 5 years of experience in sport-specific-related activities and/or structured strength and conditioning programs. The typical training schedules of both groups of athletes are presented in Table 1. Prior to participation in the study, athletes were informed of the experimental procedures and signed an informed consent. The study was conducted according to the Declaration of Helsinki and approved by the Anhanguera University Ethics Committee (4.478.689).

Study Design

This cross-sectional study compared the differences in resisted sprint performance and kinematics between sprinters and rugby players. Some of the data reported in the present study (related to rugby players) have already been presented in a previous study (Pareja-Blanco et al[16]) but the data analysis and results reported herein are original. Unresisted 20- and 20-m resisted sprint tests with loads corresponding to 20% and 60% BM were performed. Sprint distances and resisted sprint loads were defined in accordance with the coaching staff of both sports and were based on their regular training practices. Stride length (SL) and hip, knee, and ankle angles were measured during all sprints. Both sprinters and rugby players were assessed during the second half of the competitive period. All athletes were highly familiarized with RST.

Procedures

Sprinting Speed. Four pairs of photocells (Smartspeed, Fusion Sport, Australia) were set at a height of 110 cm and positioned at the starting line and at distances of 5, 10, and 20 m along the sprinting course. Athletes sprinted 6 times (2 under each condition: 0%, 20%, and 60% BM in randomized order) starting from a standing position 0.5 m behind the starting line. Sprint velocity (VEL) was calculated as the time interval to cover the measured distance. Velocity decrement (Vdec) was calculated as the decrement in mean sprint velocity induced by each sled load relative to the unresisted condition. A 5-minute rest interval was imposed between attempts and the fastest time for each condition was retained. A custom-made sled with a 3.5-m-long strap was attached to the athletes’ chest. To avoid weather influences, resisted and unresisted sprint measurements were performed on indoor running tracks. However, to increase the ecological validity, sprinters performed the tests on a synthetic rubber surface composed of polyurethane, whereas rugby players sprinted on an artificial turf surface composed of polyethylene and 100-µm-thick monofilament fibers. Athletes executed the sprints wearing their own spikes or cleats. Prior to data collection, athletes completed a standardized warm-up protocol including general (ie, running at moderate pace for 10 min followed by dynamic stretching for 3 min) and specific exercises (ie, submaximal sprint efforts).

Sprint Kinematics. Lower body kinematic parameters were assessed during sprints with a capture and motion analysis system (Noraxon myoMotion, Scottsdale, AZ). Eight inertial sensors were placed according to the manufacturer’s guidelines on the athletes’ feet (strapped to the top of the shoe, below the ankle), shanks (frontal attachment on the tibia bone), thighs (frontal placement on the quadriceps, on the area of lowest muscle belly displacement in relation to the underlying bone), pelvis (bony area of the sacrum), and lower thorax (on the spinal cord at approximately L1/T12). Prior to each sprint, the system was calibrated with the athlete in the upright position to determine the 0° angle for each segment analyzed and allow the creation of a 3D biomechanical model, generated using Noraxon MR3.10 software (Scottsdale, AZ). Instantaneous changes in body segments were recorded with the software at 200 Hz. Kinematic variables were assessed in the hip, knee, and ankle joints (ie, 0° means full hip/knee extension, and neutral ankle position). The initiation and completion of each sprint were determined by video analysis through visual inspection, synchronized with the biomechanical model in MR3.10 software and with the photocells. Raw data were extracted to a customized spreadsheet to determine the mean angles. The mean SL was automatically calculated by the MR3.10 software. All kinematic parameters were calculated for the following sprint distances: 0 to 5, 5 to 10, and 10 to 20 m.

Statistical Analyses

Data are presented as mean (SD). Absolute and relative reliability were tested for all variables through the coefficient of variation and intraclass correlation coefficient using the 1-way random-effects model. Normality of data was tested using the Shapiro–Wilk test. Some variables of joint kinematics obtained during unresisted and resisted sprints did not present normal distribution. A 3×2 factorial analysis of variance with Tukey post hoc comparisons using one between-group factor (sprinters vs rugby players) and one within-group factor (0% vs 20% vs 60% BM) was performed. For variables that did not follow a normal distribution, the nonparametric Friedman test and Mann–Whitney U test for pairwise comparisons were performed. Statistical significance was set as $P < .05$. The magnitudes of between-group differences were expressed as standardized mean differences (effect size; ES) using Hedge g on the pooled SD[27] along with 90% confidence limits (CLs). The magnitudes of ES were interpreted using the following thresholds: <0.2, 0.2 to 0.6, 0.6 to 1.2, 1.2 to 2.0, 2.0 to 4.0, and >4.0 for trivial, small, moderate, large, very large, and near perfect,

Table 1 Typical Weekly Training Schedule of Rugby Players and Sprinters During the Competitive Period

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Rugby	Rest	Core training 20′ S/PT 60′ Traditional exercises: HS, DL, HT, lunges, and stiff (60%–90% 1RM/OPL) TEC/TAC 120′ Rest/lunch 80′ Conditioning 30′	Core training 20′ S/PT 60′ Traditional exercises: BP, PBP, pull-up, and dips (60%–90% 1RM) TEC/TAC 120′ Rest/lunch 80′ Conditioning 30′	Core training 20′ S/PT 60′ Traditional exercises: HS, DL, HT, lunges, and stiff (60%–90% 1RM/OPL) Resisted sprints: pull 20 m (30%–50% BM) Push 10 m (80%–150% BM)	Core training 20′ S/PT 60′ Traditional exercises: BP, PBP, pull-up, and dips (60%–90% 1RM) TEC/TAC 120′ Rest/lunch 80′ Conditioning 30′	Rest	Match
Sprinters	Rest	1×150 m 1×110 m Resisted sprints: 3×30 m (15% BM)	Plyometrics: 2×5 CMJ 10×3 rebound 2×30 m (focus on acceleration) 6×100 m (focus on technique; progressive increases in sprint velocity)	2×30 m 2×40 m (starting block) JS 6×4 OPL Plyometrics: 4×4 DJ 45 cm 4×4 SJ 4×10 Assisted jump	Plyometrics: 2×5 CMJ 8×3 rebound General exercises: BP, PBP, leg flexion, and extension 3×12 (50%–60% 1RM)	3×10 m 2×20 m (starting block) 1×90 m 1×120 m Resisted sprints: 3×30 m (15% BM)	1×150 m JS 6×4 OPL Plyometrics: 4×4 DJ 45 cm 4×4 SJ 4×10 Assisted jump

Abbreviations: 1RM, 1-repetition maximum; BM, body mass; BP, bench press; CMJ, countermovement jump; DL, deadlift; DJ, drop jump; HS, half-squat; HT, hip thrust; OPL, optimum power load; PBP, prone-bench pull; SJ, squat jump; S/PT, strength and power training; TEC/TAC, technical and tactical training.

respectively.[28] All statistical analyses were performed using SPSS software (version 20.0; SPSS Inc, Chicago, IL). Figures were designed using SigmaPlot (version 12.0; Systat Software Inc, San Jose, CA).

Results

Differences in nonnormally distributed data are presented using distinct symbols. Unresisted and resisted sprint VEL and SL presented intraclass correlation coefficient > .90, while joint kinematics presented intraclass correlation coefficient > .70. The coefficient of variations values for all variables tested were <10%.

Table 2 depicts the comparisons of unresisted and resisted sprint performances and Vdec in resisted sprints over the different distances between sprinters and rugby players. Figure 1 shows individual data of unresisted and resisted conditions for both athletic populations. Significant group × load interactions were observed in sprint velocities and Vdec for all distances ($P < .05$). Sprinters were significantly faster than rugby players in unresisted and resisted sprints using 20% BM in all distances (ES [90% CL] ranging from 0.65 [0.03 to 1.27] to 3.95 [3.10 to 4.81]; $P < .001–.05$). For the resisted sprints with 60% BM, in the 0- to 5-m distance, sprinters were significantly slower than rugby players (ES [90% CL] = 1.04 [0.31 to 1.77]; $P < .05$), while in 5- to 10- and 10- to 20-m distances, no significant differences were observed between groups (ES [90% CL] = 0.27 [–0.38 to 0.92] and 0.28 [–0.41 to 0.96], respectively; $P > .05$). Moreover, sprinters demonstrated lower Vdec than rugby players in resisted sprints using 20% BM (ES [90% CL] = 0.75 [0.06 to 1.44], 2.43 [0.83 to 4.02], and 1.95 [1.09 to 2.79], for 0 to 5, 5 to 10, and 10 to 20 m, respectively; $P < .001–.05$). In contrast, sprinters demonstrated higher Vdec than rugby players in resisted sprints using 60% BM (ES [90% CL] = 1.46 [0.81 to 2.11], 1.42 [0.69 to 2.16], 1.13 [0.43 to 1.82], for 0 to 5, 5 to 10, and 10 to 20 m, respectively; $P < .05$). Both groups presented significant decreases in sprint velocities as sled load increased ($P < .001$; ES >1.20 for all comparisons).

Figure 2 shows individual SL data in unresisted and resisted conditions at different distances for sprinters and rugby players. No group × load interaction was observed in the SL and SL decrease for any distance ($P > .05$; Table 2). No significant differences were observed in the SL in unresisted and resisted sprints in any distance when comparing sprinters and rugby players (ES [90% CL] ranging from 0.02 [–0.72 to 0.76] to 0.84 [0.13 to 1.54]; $P > .05$). No significant between-group differences were observed in SL decreases using both 20% and 60% BM loads for the 0- to 5-m split distance (ES [90% CL] = 0.51 [0.15 to 1.16] and 0.43 [–0.17 to 1.04], respectively; $P > .05$). A significantly lower decrease in SL was observed in sprinters than in rugby players at both 20% and 60% BM loads for 5- to 10- and 10- to 20-m split distances (ES [90% CL] = 0.69 [0.07 to 1.32] and 2.22 [1.57 to 2.87] for 5 to 10 m, and 2.14 [1.52 to 2.76] and 1.67 [1.06 to 2.28] for 10 to 20 m, with 20% and 60% BM, respectively; $P < .001–.05$). Both groups presented significant decreases in the SL as sled load increased for all distances ($P < .001–.05$; ES > 1.20 for all comparisons), with the exception of the 10- to 20-m distance where sprinters did not show significant differences between unresisted and 20% BM in SL ($P > .05$; ES [90% CL] = 0.48 [0.08 to 0.89]).

Table 3 shows the comparisons of the hip, knee, and ankle kinematics in unresisted and resisted sprints over different distances between sprinters and rugby players. Significant group × load interactions were observed for hip kinematics in the 10- to 20-m distance and for ankle kinematics in the 0- to 5-m distance ($P < .05$). No significant group × load interactions were observed for the other variables. Significant differences in hip kinematics between sprinters and rugby players were observed in the unresisted sprint in the 10- to 20-m distance (ES [90% CL] = 1.12 [0.28 to 1.96]; $P < .05$) and in the resisted sprint with 60% BM in the 0- to 5-m distance (ES [90% CL] = 1.17 [0.20 to 2.15]; $P < .05$). No significant between-group differences were observed for knee kinematics in any condition (ES [90% CL] ranging from 0.20 [–0.27 to 1.11] to 0.98 [0.18 to 1.78]; $P > .05$). Sprinters and rugby players demonstrated significantly different ankle kinematics in all unresisted and resisted sprints (ES [90% CL] ranging from 0.78 [0.18 to 1.38] to 1.69 [1.04 to 2.33]; $P < .05$). Moreover, rugby players demonstrated higher changes in hip and ankle kinematics compared to sprinters in all resisted sprints over all distances (ES [90% CL] ranging from 1.02 [0.15 to 1.89] to 1.82 [0.58 to 3.07] for hip kinematics; and ranging from 0.93 [–0.52 to 2.37] to 2.68 [0.87 to 4.49] for ankle kinematics; $P < .05$). Finally, no significant between-group differences were observed in knee kinematic changes in all resisted sprint conditions (ES [90% CL] ranging from 0.02 [–0.62 to 0.66] to 0.59 [–0.10 to 1.29]; $P > .05$).

Discussion

This study provides new knowledge about the acute performance and kinematic responses to similar loading conditions of athletes from 2 different sports during resisted sprint efforts. Overall, as expected, sprinters were faster than rugby players under unresisted and light loading (ie, 20% BM) conditions; nonetheless, these differences were not observed with heavier sled loads (ie, 60% BM). Furthermore, sprinters experienced lower Vdec than rugby players at 20% BM, whereas rugby players demonstrated lesser impairments in sprint velocity at 60% BM. Running technique was differently altered by distinct loads in sprinters and rugby players during resisted sprints, although no differences in SL were observed between groups. Thus, some caution should be taken when prescribing similar sled loads for different athletic populations. It should be highlighted that the different surfaces and shoes employed for each athletic group may have influenced our results. However, these parameters are sport-specific, and, therefore, should be considered as an unavoidable limitation, as these athletes usually train and compete under these “real scenarios.”

Our findings suggest particular responses to different loads by each population, as sprinters achieved faster velocities under unresisted and light loading conditions (ie, 20% BM), along with lower Vdec with this load, whereas rugby players showed faster sprint velocities over the early acceleration phase (ie, 0–5 m) and lesser magnitudes of Vdec with heavier sled loads (ie, 60% BM). Indeed, it can be expected that stronger athletes are able to apply higher levels of force onto the ground, which is critical for acceleration capacity.[29–31] Moreover, it was previously reported that the magnitude of Vdec related to resisted sprints is negatively associated with CMJ height ($r = –.73$), and CMJ and SJ relative peak power ($r = –.80$) in male sprinters with sled loads of 8%, 13%, and 18% of BM.[32] In this regard, rugby players showed higher values of absolute strength (especially with heavy loads), while sprinters attained greater relative strength values.[20] Additionally, other mechanisms rather than only relative strength–power values can also explain resisted sprint performance. The principle of specificity may partially explain these differences, since kinetic and kinematic characteristics of heavy-sled loads are much more similar to the demands that occur during rugby-match activities

Table 2 Comparison of Sprint Velocity and Stride Length in Both Unresisted and Resisted Sprints and Changes in Resisted Sprints Over Different Distances Between Sprinters and Rugby Players

	0–5 m			5–10 m			10–20 m		
	Sprinters	**Rugby**	**% diff**	**Sprinters**	**Rugby**	**% diff**	**Sprinters**	**Rugby**	**% diff**
Absolute values									
Velocity, $m \cdot s^{-1}$									
Unresisted	5.07 (0.43)	4.75 (0.19)*	6.6	7.25 (0.32)	6.68 (0.28)*	8.5	8.38 (0.21)	7.52 (0.22)*	11.5
20% BM	4.40 (0.38)	3.87 (0.25)*,+	13.8	6.09 (0.18)	5.31 (0.28)*,+	14.8	7.09 (0.23)	6.05 (0.31)*,+	17.1
60% BM	2.85 (0.20)	3.08 (0.20)*,+$,Ø	7.7	3.73 (0.33)	3.83 (0.21)+,$,Ø	2.6	4.11 (0.35)	4.00 (0.28)+,$,Ø	2.7
Stride length, cm									
Unresisted	185.1 (22.8)	174.6 (21.0)	6.1	200.1 (8.0)	202.8 (20.1)	1.3	272.8 (19.3)	291.1 (15.6)	6.2
20% BM	159.5 (20.0)	146.0 (13.5)$^{+}$	9.2	175.3 (20.9)	174.8 (19.4)$^{+}$	0.3	260.6 (27.8)	259.1 (26.9)$^{+}$	0.4
60% BM	131.10 (12.8)	129.0 (15.2)+,$	1.6	143.6 (10.8)	151.6 (15.4)+,$	5.2	186.6 (11.9)	190.9 (16.5)+,$	2.2
Percentage changes in relation to unresisted									
Vdec, %									
20% BM	12.8 (6.7)	18.5 (5.4)*	30.5	15.9 (1.7)	20.4 (4.9)*	22.3	15.5 (1.9)	19.5 (2.5)*	20.9
60% BM	43.5 (5.1)	35.1 (3.3)*,$,Ø	24.1	48.5 (3.7)	42.6 (3.6)*,$,Ø	14.0	51.0 (3.3)	46.8 (2.8)*,$,Ø	9.0
Stride length, %									
20% BM	13.4 (8.8)	19.6 (4.2)	31.8	12.4 (10.2)	21.5 (3.8)*	42.1	4.5 (4.0)	20.3 (1.0)*	77.8
60% BM	27.6 (15.4)	35.6 (3.1)	22.4	28.2 (5.7)	43.1 (3.4)*,$	34.6	31.1 (8.4)	47.2 (2.7)*,$	33.8

Abbreviations: BM, body mass; diff, difference; Vdec, velocity decrement relative to unresisted condition. Note: Data are mean (SD). Ø$P < .05$, significant group × load interaction; *$P < .05$, significant differences between sprinters and rugby players; +$P < .05$, significant differences in relation to unresisted condition in both groups; \$$P < .05$, significant differences in relation to 20% BM in both groups.

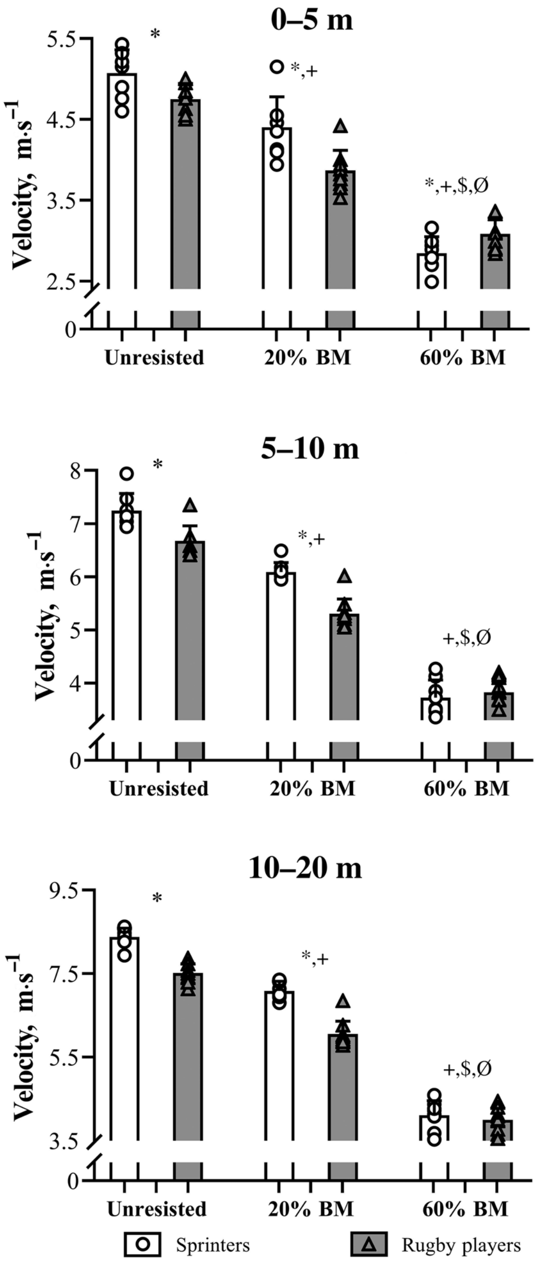

Figure 1 — (A) Individual data of unresisted and resisted sprint performances over the different distances tested for sprinters and rugby players. Data are presented as mean (SD). BM indicates body mass. Ø$P < .05$, significant group × load interaction. *$P < .05$, significant differences between sprinters and rugby players; +$P < .05$, significant differences in relation to unresisted condition in both groups; \$$P < .05$, significant differences in relation to 20% BM in both groups.

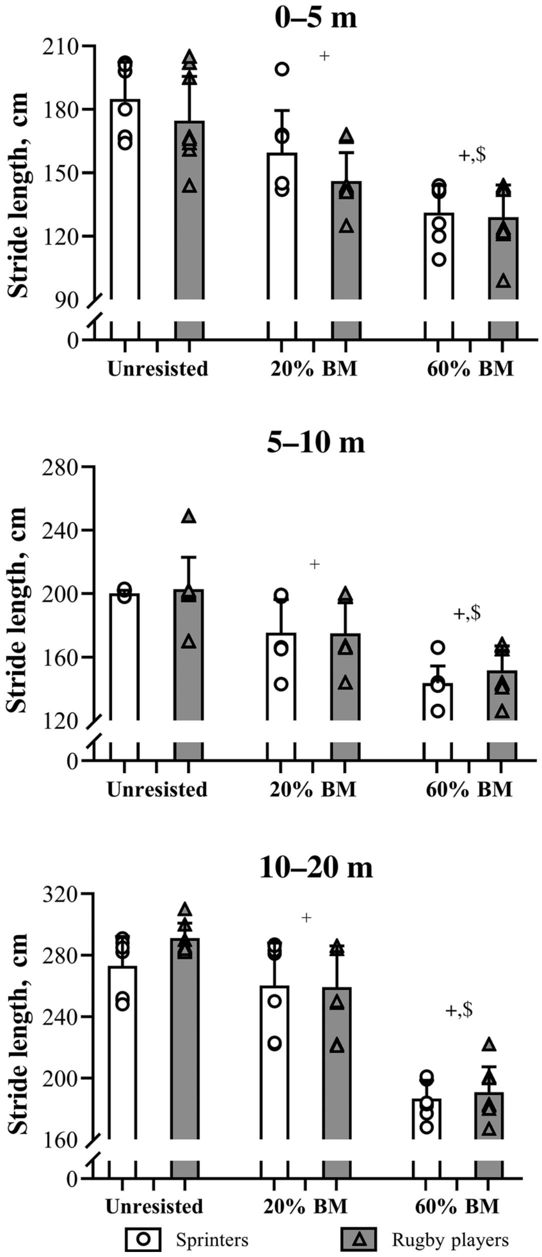

Figure 2 — Individual data of stride length in unresisted and resisted sprints over the different distances tested for sprinters and rugby players. Data are presented as mean (SD). BM indicates body mass. +$P < .05$, significant differences in relation to unresisted condition in both groups (at 10- to 20-m distance only rugby players demonstrated difference between 20% and unresisted); \$$P < .05$, significant differences in relation to 20% BM in both groups.

(compared to those which sprinters cope with).[22,26] Finally, it should be noted that sprinters regularly use sled loads of approximately 15% BM during training routines, whereas rugby players frequently undertake resisted sprint training using pull and push efforts with 30% to 50% and 80% to 150% BM, respectively (Table 1). However, as previously mentioned, the fact that both groups completed the assessments on their specific training surfaces implies that the coefficient of friction will be different. Hence, the relationships between load and Vdec will probably differ between both surfaces, irrespective of the athletes' background, and/or performance level. Even so, these findings highlight that the prescription of sled loads based solely on respective percentages of BM may fail to provide a uniform and consistent overload among athletes. Thus, sled load prescription should consider athletes' characteristics and needs, sport-specific demands, and training environment.

Higher running velocities are achieved via greater horizontal force application, shorter ground contact times, and greater SL.[15,33,34] Therefore, since no significant differences were observed in SL between sprinters and rugby players, the faster

Table 3 Comparison of the Hip, Knee, and Ankle Kinematics in Both Unresisted and Resisted Sprints and Changes in Joint Kinematics in Resisted Sprints Over Different Distances Between Sprinters and Rugby Players

	0–5 m		5–10 m		10–20 m	
	Sprinters	**Rugby**	**Sprinters**	**Rugby**	**Sprinters**	**Rugby**
Absolute values						
Hip, deg						
Unresisted	37.7 (4.2)	37.5 (6.8)	33.7 (4.1)	29.3 (6.2)	30.0 (3.6)	25.5 (4.6)*
20% BM	38.3 (6.1)	43.7 (8.0)	34.6 (5.8)	37.4 (7.7)+	32.1 (5.8)	34.0 (7.5)+
60% BM	40.5 (5.0)	47.1 (8.1)#,&	38.2 (6.5)	43.6 (8.9)+,$	35.1 (7.0)	40.7 (8.0)+,$,Ø
Knee, deg						
Unresisted	65.3 (4.9)	69.7 (4.4)	67.1 (5.2)	69.9 (4.5)	68.1 (5.0)	70.4 (4.1)
20% BM	66.8 (2.6)	68.6 (5.1)	66.8 (3.9)	68.9 (4.8)	68.2 (4.2)	69.1 (4.5)
60% BM	61.6 (18.0)	68.4 (4.9)	64.4 (3.7)	67.5 (5.7)	62.0 (4.3)	66.7 (5.0)
Ankle, deg						
Unresisted	−10.5 (5.5)	−0.8 (3.5)*	−17.3 (9.3)	−7.3 (4.1)#	−26.7 (11.2)	−11.2 (7.0)#
20% BM	−9.7 (7.5)$^{+}$	2.1 (3.8)*,+	−16.6 (10.1)	−3.8 (4.1)#	−21.4 (12.3)	−4.8 (5.8)#
60% BM	−8.4 (5.9)$^{+,\$}$	2.8 (4.9)*,+,$,Ø	−14.0 (7.1)	−0.6 (4.0)*	−19.9 (14.1)	−2.1 (4.2)#,&
Percentage changes in relation to unresisted						
Hip, %						
20% BM	1.9 (13.9)	17.7 (19.0)*	3.0 (16.2)	31.8 (38.2)*	7.6 (19.3)	35.2 (27.2)*
60% BM	8.1 (14.3)	27.1 (21.6)*	13.9 (19.6)	54.1 (43.8)*	17.4 (22.0)	62.4 (33.0)*
Knee, %						
20% BM	2.7 (7.6)	−1.6 (3.2)	−0.1 (6.1)	−1.4 (3.2)	0.5 (7.0)	−1.8 (2.6)
60% BM	−6.0 (26.4)	−1.9 (3.7)	−3.6 (6.2)	−3.5 (3.8)	−8.8 (5.3)	−5.3 (4.4)
Ankle, %						
20% BM	23.3 (50.3)	115.3 (105.2)*	4.1 (19.2)	61.9 (56.2)*	20.4 (19.8)	49.2 (38.7)*
60% BM	−3.2 (90.7)	134.5 (101.5)*	13.1 (51.1)	66.4 (117.4)#	17.5 (39.3)	65.1 (46.5)*

Abbreviation: BM, body mass. Note: 0° indicates full hip and knee extension. For ankle joint, 0° means neutral ankle position, while negative values indicate plantar flexion and positive values indicate dorsiflexion.

Significant group × load interaction: Ø$P < .05$. Statistically significant differences with sprinters: *$P < .05$ (parametric analysis) and #$P < .05$ (nonparametric analysis). Statistically significant differences with unresisted condition: +$P < .05$ (parametric analysis) and &$P < .05$ (nonparametric analysis). Statistically significant differences with 20% BM condition: \$$P < .05$ (parametric analysis).

velocities attained by sprinters under unresisted conditions were due to higher step rates at reduced contact times,[35] which is in line with previous research comparing elite and nonelite sprinters.[35–37] However, at increased loads, step rate tends to decrease[8,38] and contact time tends to increase,[13,38] as athletes have to produce a greater horizontal force to overcome the inertia of heavier sled loads.[14] Therefore, the differences in step rate are possibly reduced under heavy loading conditions, which may explain the lack of differences in sprint velocities between sprinters and rugby players at these loads (eg, 60% BM).

Over the first meters in unresisted sprints, athletes adopt a forward-leaning position by lowering their center of mass, thus enhancing their capacity to apply force in the horizontal direction, which is specific to sprint acceleration.[1,7] Conversely, in longer distances (10–20 m), a straighter body position is adopted, which is more related to top-speed phases, as this body position may generate a longer path to accelerate their foot down and backward prior to touchdown, thus contributing to an increased and earlier vertical force production during ground contact.[33,34,39] Rugby players showed a more forward-leaning posture at heavier sled loads, which is in agreement with the literature[7,17,40]; nonetheless, sprinters maintained their hip kinematics under different loading conditions (Table 3). Since heavy-sled loads require high levels of horizontal force to overcome the extra load,[13,14] the increased forward-leaning position adopted by rugby players may also explain their superior performance at 60% BM. With respect to ankle angles, it should be clarified that the high interindividual variability observed in the percentage change is likely due to a mathematical question, since absolute values of ankle angles are very close to the neutral position (ie, 0°; Table 3). As a result, larger relative changes occur when you are dealing with absolute changes for smaller values; hence, huge interindividual differences are expected. In this context, sprinters showed higher plantar flexion in all conditions when compared to rugby players. Furthermore, rugby players exhibited lower plantar flexion with increased loads, which seems to be a strategy to prolong the contact time, helping athletes to enhance force application to overcome the overload. Bentley et al[13] also observed an increased range of movement in the ankle joint during resisted sprint training (sled loads up to 25% BM) in rugby players, attributed to increased dorsiflexion at foot strike and increased plantar flexion at toe-off. This is likely due to the extra time spent during the amortization phase of the stretching-shortening cycle.[41] It is worth mentioning that when rapid force application is a priority, longer contact times may become counterproductive.[40] As mentioned above, faster athletes display increased stride frequency due to reduced contact time (compared to slower athletes).[35–37] The higher plantar flexion values presented by sprinters could imply higher ankle joint stiffness, which, among other factors, allows them to apply substantial amounts of force at higher velocities while sprinting. Indeed, rugby players have shown a decrease in vertical stiffness with increased sled loads.[17] It should be noted that lower leg stiffness has been linked to poor ability to store and restitute elastic energy, which may negatively affect sprint performance.[42,43]

The fact that sprinters and rugby players completed the measurements under different testing settings (ie, synthetic rubber track or artificial turf surface) could have potentially influenced our outcomes. However, this is a natural limitation, as these elite athletes train and compete under these sport-specific conditions. Therefore, the research would lack ecological validity if sprinters were required, for example, to sprint on a grass surface wearing cleats or rugby players on a synthetic rubber track wearing spikes.[26] The main purpose of this study was not to state whether rugby players or sprinters perform better under different resisted sprint conditions (in this case, the environment settings need to be equalized), but rather, to report what actually happens when similar sled loads are used by sprinters or rugby players within their competitive environments.

This study is limited by its cross-sectional design, which does not allow for causal inferences about training effects. Thus, although we observed differences related to acute loading responses, we cannot determine whether these athletes would respond differently to similar sled loads during RST programs. In addition, resisted sprint running was evaluated over a short-distance (ie, 20 m), precluding comparisons and inferences concerning overall sprint performance. However, this is the first investigation to simultaneously analyze the influence of different overloads on the resisted sprint performance of sprinters and rugby players. Further research is required to examine and compare the outcomes of training studies applying similar sled loads to elite sprinters and rugby players within their sport-specific environments, as well as to investigate these effects in other sport disciplines.

Practical Applications

This study provides valuable insights for practitioners and researchers for a better understanding of sled load selection and resisted sprint training prescription. Here, we present further evidence that sled loads prescribed based solely on different percentages of BM do not provide a uniform training stimulus among different athletic populations. For these reasons, coaches should prescribe sled loads taking into consideration: (1) the sport-specific demands, (2) the athletes' characteristics and needs, and (3) the environmental training conditions (ie, specifically, the typical training surface). These observations are essential for effective and appropriate training prescription.

Conclusions

Our results indicate that some caution should be taken when prescribing RST as distinct percentages of BM for different athletic populations, since a "similar" training stimulus resulted in different alterations in running technique and sprint velocity within their sport environments.

References

1. Cronin J, Hansen KT. Resisted sprint training for the acceleration phase of sprinting. *Strength Cond J*. 2006;28(4):42–51. doi:10.1519/00126548-200608000-00006
2. Petrakos G, Morin JB, Egan B. Resisted sled sprint training to improve sprint performance: a systematic review. *Sports Med*. 2016;46(3):381–400. PubMed ID: 26553497 doi:10.1007/s40279-015-0422-8
3. Alcaraz PE, Carlos-Vivas J, Oponjuru BO, Martinez-Rodriguez A. The effectiveness of resisted sled training (RST) for sprint performance: a systematic review and meta-analysis. *Sports Med*. 2018;48(9):2143–2165. PubMed ID: 29926369 doi:10.1007/s40279-018-0947-8
4. Alcaraz PE, Palao JM, Elvira JL. Determining the optimal load for resisted sprint training with sled towing. *J Strength Cond Res*. 2009;23(2):480–485. PubMed ID: 19197200 doi:10.1519/JSC.0b013e318198f92c
5. Bachero-Mena B, Gonzalez-Badillo JJ. Effects of resisted sprint training on acceleration with three different loads accounting for 5, 12.5, and 20% of body mass. *J Strength Cond Res*. 2014;28(10):2954–2960. PubMed ID: 24736770 doi:10.1519/JSC.0000000000000492
6. Spinks CD, Murphy AJ, Spinks WL, Lockie RG. The effects of resisted sprint training on acceleration performance and kinematics in soccer, rugby union, and Australian football players. *J Strength Cond Res*. 2007;21(1):77–85. PubMed ID: 17313259 doi:10.1519/00124278-200702000-00015
7. Lockie RG, Murphy AJ, Spinks CD. Effects of resisted sled towing on sprint kinematics in field-sport athletes. *J Strength Cond Res*. 2003;17:760–767. PubMed ID: 14636109
8. Letzelter M, Sauerwein G, Burger R. Resistance runs in speed development. *Modern Athlete and Coach*. 1995;33:7–12.
9. Cahill MJ, Oliver JL, Cronin JB, et al. Influence of resisted sled-pull training on the sprint force–velocity profile of male high-school athletes. *J Strength Cond Res*. 2020;34(10):2751–2759. PubMed ID: 32773545 doi:10.1519/JSC.0000000000003770
10. Kawamori N, Newton RU, Hori N, Nosaka K. Effects of weighted sled towing with heavy versus light load on sprint acceleration ability. *J Strength Cond Res*. 2014;28(10):2738–2745. PubMed ID: 23539079 doi:10.1519/JSC.0b013e3182915ed4
11. Cross MR, Brughelli M, Samozino P, Brown SR, Morin JB. Optimal loading for maximizing power during sled-resisted sprinting. *Int J Sports Physiol Perform*. 2017;12(8):1069–1077. PubMed ID: 28051333 doi:10.1123/ijspp.2016-0362
12. Pareja-Blanco F, Saez de Villarreal E, Bachero-Mena B, et al. Effects of unloaded sprint and heavy sled training on sprint performance in physically active women. *Int J Sports Physiol Perform*. 2020:15(10):1356–1362. PubMed ID: 33004682 doi:10.1123/ijspp.2019-0862
13. Bentley I, Sinclair JK, Atkins SJ, Metcalfe J, Edmundson CJ. Effect of velocity-based loading on acceleration kinetics and kinematics during sled towing. *J Strength Cond Res*. 2021;35(4):1030–1038. PubMed ID: 30299389
14. Kawamori N, Newton R, Nosaka K. Effects of weighted sled towing on ground reaction force during the acceleration phase of sprint running. *J Sports Sci*. 2014;32(12):1139–1145. PubMed ID: 24576071 doi:10.1080/02640414.2014.886129
15. Morin JB, Edouard P, Samozino P. Technical ability of force application as a determinant factor of sprint performance. *Med Sci Sports Exerc*. 2011;43(9):1680–1688. PubMed ID: 21364480 doi:10.1249/MSS.0b013e318216ea37

16. Pareja-Blanco F, Pereira LA, Freitas TT, et al. Acute effects of progressive sled loading on resisted sprint performance and kinematics. *J Strength Cond Res*. Published online May 20, 2020. PubMed ID: 32614156 doi:10.1519/JSC.0000000000003656
17. Zabaloy S, Carlos-Vivas J, Freitas TT, et al. Muscle activity, leg stiffness, and kinematics during unresisted and resisted sprinting conditions. *J Strength Cond Res*. Published online July 9, 2020. PubMed ID: 32658032 doi:10.1519/JSC.0000000000003723
18. Lizana JA, Bachero-Mena B, Calvo-Lluch A, et al. Do faster, stronger, and more powerful athletes perform better in resisted sprints? *J Strength Cond Res*. Published online July 7, 2020. PubMed ID: 32639382 doi:10.1519/JSC.0000000000003719
19. Loturco I, McGuigan M, Freitas TT, Valenzuela PL, Pereira LA, Pareja-Blanco F. Performance and reference data in the jump squat at different relative loads in elite sprinters, rugby players, and soccer players. *Biol Sport*. 2021;38(2):219–227. PubMed ID: 34079166 doi:10.5114/biolsport.2020.98452
20. Loturco I, Pereira LA, Freitas TT, Bishop C, Pareja-Blanco F, McGuigan M. Maximum strength, relative strength, and strength deficit: relationships with performance and differences between elite sprinters and professional rugby union players. *Int J Sports Physiol Perform*. 2021;16(8):1148–1153. PubMed ID: 33588376 doi:10.1123/ijspp.2020-0342
21. Dobbin N, Hunwicks R, Jones B, Till K, Highton J, Twist C. Criterion and construct validity of an isometric midthigh-pull dynamometer for assessing whole-body strength in professional rugby league players. *Int J Sports Physiol Perform*. 2018;13(2):235–239. PubMed ID: 28605261 doi:10.1123/ijspp.2017-0166
22. Darrall-Jones JD, Jones B, Till K. Anthropometric and physical profiles of English academy rugby union players. *J Strength Cond Res*. 2015;29(8):2086–2096. PubMed ID: 25647656 doi:10.1519/JSC.0000000000000872
23. Loturco I, Kobal R, Kitamura K, et al. Predictive factors of elite sprint performance: influences of muscle mechanical properties and functional parameters. *J Strength Cond Res*. 2019;33(4):974–986. PubMed ID: 30913203 doi:10.1519/JSC.0000000000002196
24. Deutsch MU, Kearney GA, Rehrer NJ. Time–motion analysis of professional rugby union players during match-play. *J Sports Sci*. 2007;25(4):461–472. PubMed ID: 17365533 doi:10.1080/02640410600631298
25. Mero A, Komi PV, Gregor RJ. Biomechanics of sprint running. A review. *Sports Med*. 1992;13(6):376–392. PubMed ID: 1615256 doi:10.2165/00007256-199213060-00002
26. Wild JJ, Bezodis IN, North JS, Bezodis NE. Differences in step characteristics and linear kinematics between rugby players and sprinters during initial sprint acceleration. *Eur J Sport Sci*. 2018; 18(10):1327–1337. PubMed ID: 29996724 doi:10.1080/17461391.2018.1490459
27. Hedges LV, Olkin O. Estimation of a single effect size: parametric and nonparametric methods. In: *Statistical Methods for Meta-analysis*. Academic Press; 2014:76–104.
28. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc*. 2009;41(1):3–12. PubMed ID: 19092709 doi:10.1249/MSS.0b013e31818cb278
29. McBride JM, Blow D, Kirby TJ, Haines TL, Dayne AM, Triplett NT. Relationship between maximal squat strength and five, ten, and forty yard sprint times. *J Strength Cond Res*. 2009;23(6):1633–1636. PubMed ID: 19675504 doi:10.1519/JSC.0b013e3181b2b8aa
30. Wisloff U, Castagna C, Helgerud J, Jones R, Hoff J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *Br J Sports Med*. 2004;38(3): 285–288. PubMed ID: 15155427 doi:10.1136/bjsm.2002.002071
31. Loturco I, Suchomel T, Bishop C, Kobal R, Pereira LA, McGuigan M. One-repetition-maximum measures or maximum bar-power output: which is more related to sport performance? *Int J Sports Physiol Perform*. 2019;14(1):33–37. PubMed ID: 29809068 doi:10.1123/ijspp.2018-0255
32. Martínez-Valencia MA, Linthorne NP, Alcaraz PE. Effect of lower body explosive power on sprint time in a sled-towing exercise. *Sci Sports*. 2013;28(6):e175–e178. doi:10.1016/j.scispo.2013.02.004
33. Weyand PG, Sternlight DB, Bellizzi MJ, Wright S. Faster top running speeds are achieved with greater ground forces not more rapid leg movements. *J Appl Physiol*. 2000;89(5):1991–1999. doi:10.1152/jappl.2000.89.5.1991
34. Colyer SL, Nagahara R, Takai Y, Salo AIT. How sprinters accelerate beyond the velocity plateau of soccer players: waveform analysis of ground reaction forces. *Scand J Med Sci Sports*. 2018;28(12): 2527–2535. PubMed ID: 30230037 doi:10.1111/sms.13302
35. Mero A. Force-time characteristics and running velocity of male sprinters during the acceleration phase of sprinting. *Res Q Exerc Sport*. 1988;59(2):94–98. doi:10.1080/02701367.1988.10605484
36. Monte A, Muollo V, Nardello F, Zamparo P. Sprint running: how changes in step frequency affect running mechanics and leg spring behaviour at maximal speed. *J Sports Sci*. 2017;35(4):339–345. PubMed ID: 27028346 doi:10.1080/02640414.2016.1164336
37. Murphy AJ, Lockie RG, Coutts AJ. Kinematic determinants of early acceleration in field sport athletes. *J Sports Sci Med*. 2003;2:144–150. PubMed ID: 24688275
38. Cronin J, Hansen K, Kawamori N, McNair P. Effects of weighted vests and sled towing on sprint kinematics. *Sports Biomech*. 2008;7(2): 160–172. PubMed ID: 18610770 doi:10.1080/14763140701841381
39. Weyand PG, Sandell RF, Prime DN, Bundle MW. The biological limits to running speed are imposed from the ground up. *J Appl Physiol*. 2010;108(4):950–961. doi:10.1152/japplphysiol.00947.2009
40. Maulder PS, Bradshaw EJ, Keogh JW. Kinematic alterations due to different loading schemes in early acceleration sprint performance from starting blocks. *J Strength Cond Res*. 2008;22(6):1992–2002. PubMed ID: 18978610 doi:10.1519/JSC.0b013e31818746fe
41. Wilson GJ, Murphy AJ, Pryor JF. Musculotendinous stiffness: its relationship to eccentric, isometric, and concentric performance. *J Appl Physiol*. 1994;76(6):2714–2719. doi:10.1152/jappl.1994.76.6.2714
42. Nagahara R, Zushi K. Development of maximal speed sprinting performance with changes in vertical, leg and joint stiffness. *J Sports Med Phys Fitness*. 2017;57(12):1572–1578. PubMed ID: 27406013 doi:10.23736/S0022-4707.16.06622-6
43. Haugen T, McGhie D, Ettema G. Sprint running: from fundamental mechanics to practice—a review. *Eur J Appl Physiol*. 2019;119(6): 1273–1287. PubMed ID: 30963240 doi:10.1007/s00421-019-04139-0