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Performance and reference data in the jump squat at different relative loads in elite sprinters, rugby players, and soccer players

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ABSTRACT: The aims of this study were to compare the outcomes and provide reference data for a set of barbell mechanical parameters collected via a linear velocity transducer in 126 male sprinters (n = 62), rugby players (n = 32), and soccer players (n = 32). Bar-velocity, bar-force, and bar-power outputs were assessed in the jump-squat exercise with jump-squat height determined from bar-peak velocity. The test started at a load of 40% of the athletes' body mass (BM), and a load of 10% of BM was gradually added until a clear decrement in the bar power was observed. Comparisons of bar variables among the three sports were performed using a one-way analysis of variance. Relative measures of bar velocity, force, and power, and jump-squat height were significantly higher in sprinters than in rugby (difference ranging between 5 and 35%) and soccer (difference ranging between 5 and 60%) players across all loads (40–110% of BM). Rugby players exhibited higher absolute bar-power (mean difference = 22%) and bar-force (mean difference = 16%) values than soccer players, but these differences no longer existed when the data were adjusted for BM (mean difference = 2.5%). Sprinters optimized their bar-power production at significantly greater relative loads (%BM) than rugby (mean difference = 22%) and soccer players (mean difference = 25%); nonetheless, all groups generated their maximum bar-power outputs at similar bar velocities. For the first time, we provided reference values for the jump-squat exercise for three different bar-velocity measures (i.e., mean, mean propulsive, and peak velocity) for sprinters, rugby players, and soccer players, over a wide range of relative loads. Practitioners can use these reference values to monitor their athletes and compare them with top-level sprinters and team-sport players.

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INTRODUCTION

Linear position and velocity transducers (LPTs and LVTs) are frequently used to collect mechanical outputs in different types of resistance training exercises [1–4]. In general, these devices are connected to the barbell to assess bar velocity and bar power [2–6]. Based on these measures, coaches can prescribe strength-power training sessions under different velocity ranges (i.e., velocity-based training; VBT), with distinct purposes (i.e., optimizing adaptations in the low-force/high-velocity or in the high-force/low-velocity zone of the force-velocity spectrum) [7–10] or under "optimum loading conditions" (i.e., using loads that maximize power output; the "optimum power load"; OPL) [5, 11, 12]. These devices have also been employed to monitor velocity loss during resistance training sessions, since different magnitudes of velocity loss may lead to dissimilar structural and functional muscle adaptations [13, 14].

Linear encoders may be considered one of the most popular training and testing devices, due to their low cost (compared to force plates), relative ease of use, and high degree of accuracy [15–17]. As a consequence, numerous studies with different objectives (e.g., assessing training effects or searching for correlations between mechanical and performance variables) involving both upper- and lower-limb exercises and using LPT or LVT measurements have been conducted [7, 10, 13, 18]. Among these investigations, it is possible to identify a clear line of research: studies on the effects and relationships of loaded jumps (i.e., jump squat, JS) and performance [18–21]. This fact is even more pronounced at the top level, as the JS is probably the most commonly prescribed weighted jump in sport settings [5, 22]. For example, it was previously shown that JS power was more strongly associated with sprint and jump performance than the squat one-repetition maximum load in both individual and team-sport athletes [18]. Moreover, there is a general consensus among coaches and researchers that JS-based training programmes are effective for improving performance in a wide variety of sport activities such as track and field, rugby, and soccer [20, 21, 23, 24]. However, there is a lack of reference data for the mechanical parameters of the JS (e.g., bar-velocity and bar-power output, and JS height at different load ranges) in athletes from different disciplines.

The majority of recent studies on this topic executed with elite athletes have been carried out using a progressive loading test, based on distinct percentages of individual body mass (BM) (e.g., from 40% BM, with a gradual increase of 10% BM, until a decrease in power output is detected) [5, 11, 18]. This approach enables coaches to rapidly and accurately determine the OPL, as well as to monitor variations in bar velocities at different loading ranges (i.e., % BM), which in turn reflect variations in relative levels of strength and power. Knowing the values provided by these tests would allow comparisons across sports and between athletes from different performance levels. Thus, the purpose of this study was to provide reference data for a set of mechanical parameters collected during JS attempts in a large sample of top-level sprinters and rugby and soccer players.

MATERIALS AND METHODS

Participants

One hundred twenty-six top-level male athletes from three disciplines (rugby union players: n = 32; 24.8 ± 5.1 years; 186.1 ± 5.4 cm; 90.2 ± 10.8 kg; soccer players: n = 32; 23.8 ± 2.9 years; 176.2 ± 5.5 cm; 72.5 ± 7.2 kg; and sprinters: n = 62; 25.1 ± 3.9 years; 179.1 ± 4.5 cm; 77.3 ± 10.0 kg) took part in this study. Rugby players were members of the Brazilian National Team. Soccer players participated in the first division of the *Paulista* State Championship. Sprinters regularly participated in national and international competitions, comprising four athletes who participated in the last Olympic Games (Rio-2016), two athletes already qualified for the next Olympic Games, and the team that won the 4x100 m 2019 IAAF World Relays, which has also qualified for the next Olympic Games. Before participating in this study, all subjects gave written informed consent in accordance with the Declaration of Helsinki. The study protocol was approved by the local research ethics committee.

Study Design

This cross-sectional study aimed to provide a dataset of JS-derived measures in elite sprinters, rugby players, and soccer players. The measurements were performed during the competitive phase of the season, at the same time of the day, and all athletes were well familiarized with the testing procedures due to their constant and regular training routines in our facilities. Athletes were required to be in a fasting state for at least 2 h, avoiding caffeine and alcohol consumption for 24 h before the procedures. Before the test, athletes performed a standardized warm-up protocol including general (i.e., running at a moderate pace for 10 min followed by dynamic lower limb stretching for 3 min) and submaximal JS attempts (e.g., 3 sets of 6 repetitions with 3 minutes of rest interval between sets) using only the barbell as resistance.

Procedures

Jump Squat Derived Variables

Bar-velocity, -force, and -power measures were collected in the JS exercise, performed on a Smith-machine device (Hammer Strength, Rosemont, IL, USA). Athletes were instructed to complete three repetitions at maximal velocity for each load, with a 5-min interval provided between sets. The test started at a load corresponding to 40% of the athletes' BM. Subjects were required to execute a knee flexion until the thigh was parallel to the ground and, after a command, jump as fast as possible without their shoulder losing contact with the barbell. The measurement was conducted by an experienced evaluator who monitored and controlled the bar displacement in real time with the linear encoder. To guarantee a similar movement pattern, attempts with bar-displacement variations higher than 5% were discarded [25]. Athletes performed the eccentric phase in a controlled manner, maintaining a static position for ~1 s (supporting the weight of the barbell) at the end of this phase to reduce the contribution of the rebound effect and provide more reproducible measurements [26]. A load of 10% BM was gradually added in each set until a clear decrement (≥ 5%) in the mean power (MP), mean propulsive power (MPP), and/or peak power (PP) was observed. The mechanical outputs were measured by an LVT (T-Force, Dynamic Measurement System; Ergotech Consulting S.L., Murcia, Spain) attached to the Smith-machine barbell [15–17, 27]. The T-Force device consists of a cable extension encoder interfaced to a computer by means of a 14-bit resolution analogue-to-digital data acquisition board and specific software, able to collect the mechanical parameters of each repetition, providing real-time feedback and storing data for further analysis. The vertical instantaneous velocity (v) was sampled at a frequency of 1000 Hz. Eccentric (negative v) and concentric (positive v) phases of the movement were automatically detected by the system attending to the velocity signal. The variables were calculated by the proprietary software as follows: displacement was obtained by integration of v data with respect to time; instantaneous acceleration (a) was obtained from differentiation of v with respect to time; instantaneous force (F) was calculated as $F = m \cdot (a + g)$, where m is the moving mass (kg) and g is the acceleration due to gravity; instantaneous power output resulted from the product of the vertical applied force and bar velocity ($P = F \cdot v$) [3]. Comparisons of bar velocities between athletes from the three sports were performed using different velocity-based measures, as follows: MV – mean bar velocity value calculated during the entire concentric phase of each repetition; MPV – mean bar velocity value calculated during the propulsive phase, defined as the portion of the concentric action during which the measured acceleration is greater than acceleration due to gravity; and PV – the highest bar velocity value registered at a particular instant (1 ms) during the concentric phase [3, 28]. A detailed description of this procedure can be found elsewhere [5, 6, 29]. In addition, absolute and relative to BM bar-force and bar-power outputs (mean force [MF], mean propulsive force [MPF], peak force [PF], MP, MPP, and PP) were calculated under the same criteria established for bar-velocity measures and retained for data analysis. Finally, JS height (JSH) was calculated from the PV using the formula previously established by García-Ramos et al. [30] (JSH = 16.577 · PV – 16.384; R^2 = 0.931, standard error of estimate = 1.47 cm) and subsequently used in the data analysis.

Statistical Analyses

Data are presented as means ± standard deviation. Data normality was checked using the Shapiro-Wilk test. Comparisons of the tested variables among the three sports disciplines tested were performed using a one-way analysis of variance. The Bonferroni post-hoc test was used to identify where the differences occurred. The significance level was set at $P < 0.05$. Effect sizes along with 90% confidence intervals were calculated to estimate the magnitude of the differences and interpreted using the thresholds proposed by Hopkins et al. [31] as follows: < 0.2, trivial; ≥ 0.2, small; ≥ 0.6, moderate; ≥ 1.2, large; ≥ 2.0, very large and; ≥ 4.0, almost perfect. The assessment of JS variables using LVT is routine in our facilities, and these measurements commonly present high levels of relative and absolute reliability (intraclass correlation coefficient (ICC) ≥ 0.90 and coefficient of variation (CV) ≤ 5%) [5, 6, 31].

RESULTS

Figure 1 depicts individual values of representative athletes from each sport discipline for MV, MPV, PV, and JSH associated with relative percentages of body mass. Figure 2 displays individual values of representative athletes from each sport discipline for MP, MPP, PP, MF, MPF, and PF associated with relative percentages of body mass. Table 1 presents the comparison of the JS-derived variables at the OPL among rugby and soccer players, and sprinters. With regards to the OPL, sprinters revealed significantly higher values for almost all variables tested compared to rugby and soccer players ($P < 0.05$), with the exception of velocity-based variables (MV, MPV, and PV) and JSH.

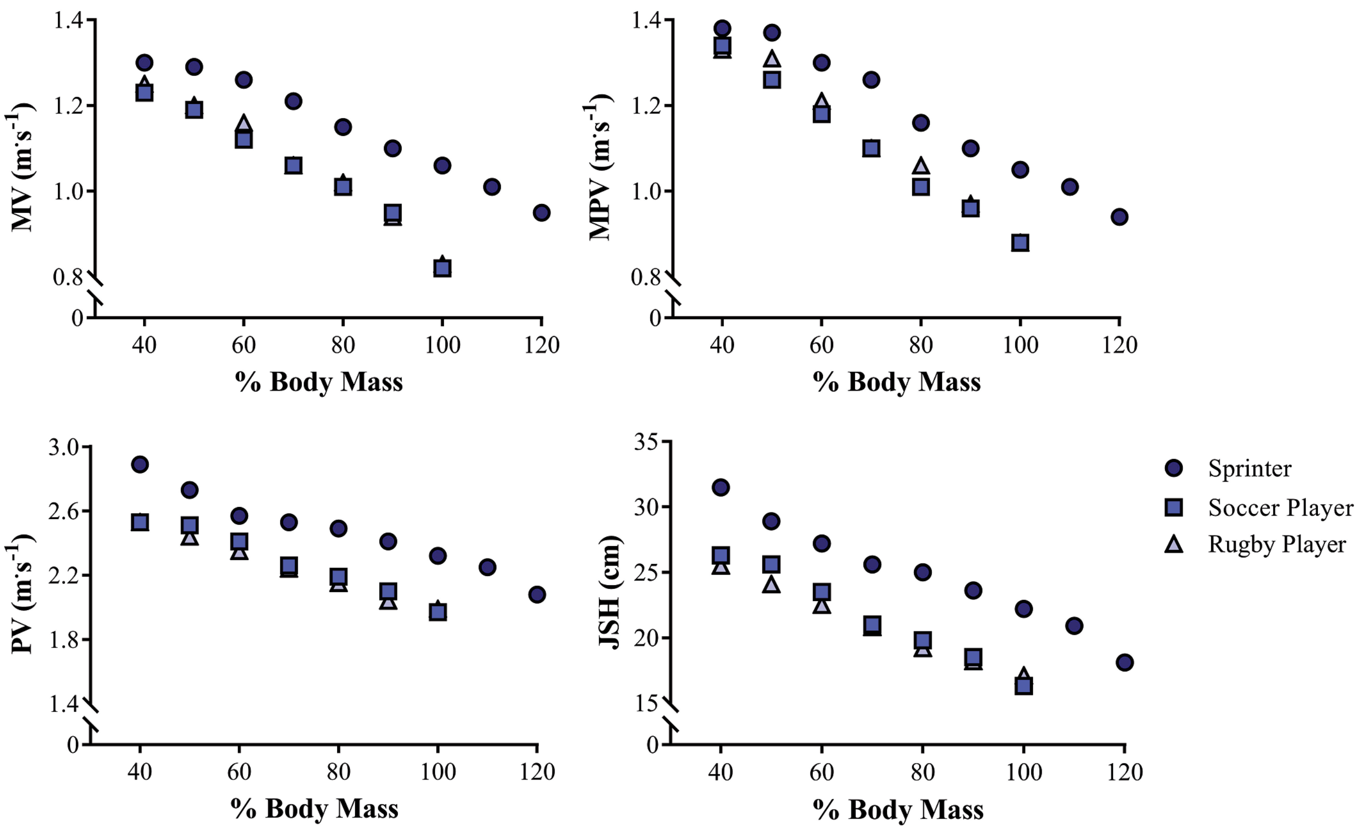

FIG. 1. Individual values of representative athletes from each sport discipline for mean velocity (MV), mean propulsive velocity (MPV), peak velocity (PV), and jump squat height (JSH) associated with distinct percentages of body mass (actual measures).

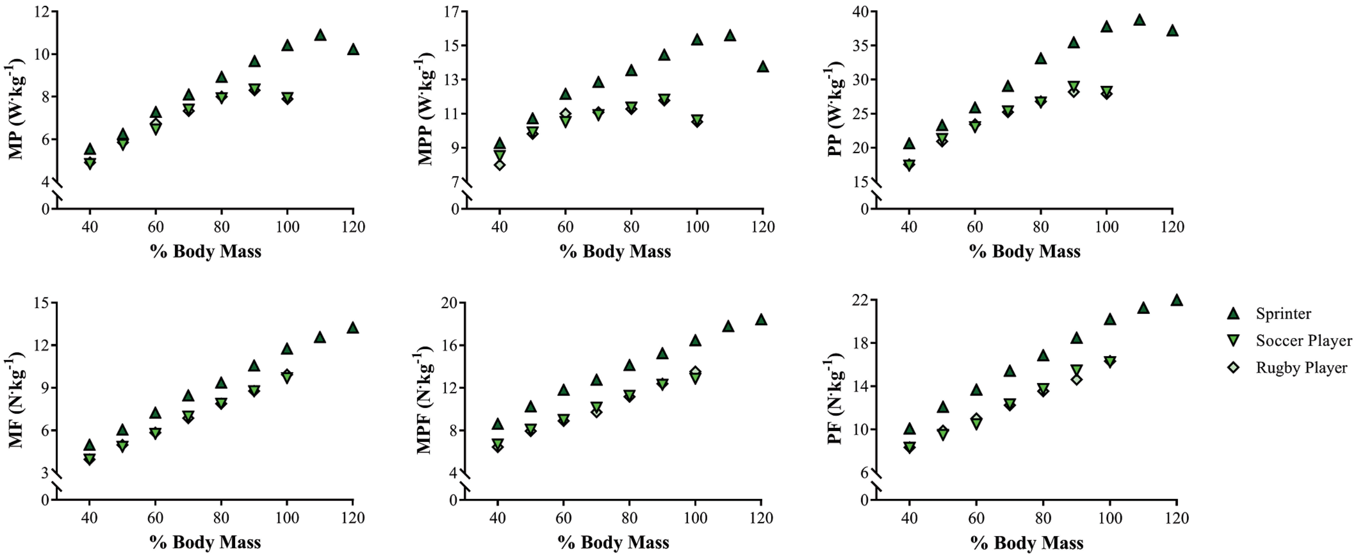

FIG. 2. Individual values of representative athletes from each sport discipline for mean power and force (MP and MF), mean propulsive power and force (MPP and MPF), and peak power and force (PP and PF) associated with distinct percentages of body mass (actual measures).

TABLE 1. Comparison of the jump squat derived variables at the optimum power load between rugby and soccer players, and sprinters.

	Rugby (N = 32)	Soccer (N = 32)	Sprinters (N = 62)	Effect Sizes (± 90% CI)		
				R x So	R x Sp	So x Sp
MF (N)	792.1 ± 89.5	684.5 ± 98.0*	861.7 ± 114.4*#	1.16 (0.47)	0.75 (0.43)	1.76 (0.38)
MPF (N)	1066.3 ± 148.7	888.7 ± 140.7*	1170.1 ± 148.9*#	1.16 (0.41)	0.68 (0.37)	1.95 (0.36)
PF (N)	1336.4 ± 173.1	1162.1 ± 159.9*	1478.5 ± 205.7*#	0.98 (0.40)	0.80 (0.39)	1.93 (0.39)
MP (W)	743.0 ± 100.3	583.7 ± 92.9*	808.2 ± 115.1*#	1.55 (0.39)	0.63 (0.37)	2.36 (0.38)
MPP (W)	996.2 ± 142.6	820.5 ± 151.6*	1150.6 ± 166.1*#	1.20 (0.42)	1.06 (0.37)	2.31 (0.37)
PP (W)	2286.5 ± 326.1	1964.7 ± 283.6*	2699.8 ± 411.4*#	0.96 (0.38)	1.24 (0.39)	2.53 (0.41)
MF_{REL} ($N \cdot kg^{-1}$)	9.29 ± 0.80	9.44 ± 0.93	11.31 ± 1.89*#	0.18 (0.48)	2.45 (0.59)	1.96 (0.51)
MPF_{REL} ($N \cdot kg^{-1}$)	11.99 ± 1.08	12.23 ± 1.30	15.37 ± 2.57*#	0.22 (0.46)	3.03 (0.57)	2.36 (0.50)
PF_{REL} ($N \cdot kg^{-1}$)	15.04 ± 1.34	16.02 ± 1.42	19.39 ± 3.23*#	0.71 (0.43)	3.15 (0.58)	2.32 (0.55)
MP_{REL} ($W \cdot kg^{-1}$)	8.24 ± 0.77	8.04 ± 0.87	10.50 ± 1.13*#	0.27 (0.43)	2.85 (0.42)	2.77 (0.39)
MPP_{REL} ($W \cdot kg^{-1}$)	11.06 ± 1.21	11.29 ± 1.55	14.97 ± 1.78*#	0.18 (0.47)	3.14 (0.42)	2.31 (0.37)
PP_{REL} ($W \cdot kg^{-1}$)	25.40 ± 2.80	27.08 ± 2.63	35.05 ± 3.94*#	0.59 (0.40)	3.36 (0.41)	2.95 (0.42)
MV ($m \cdot s^{-1}$)	0.91 ± 0.17	0.93 ± 0.07	0.94 ± 0.05	0.13 (0.32)	0.20 (0.30)	0.17 (0.32)
MPV ($m \cdot s^{-1}$)	1.01 ± 0.06	1.01 ± 0.07	1.03 ± 0.06	0.08 (0.42)	0.24 (0.35)	0.15 (0.34)
PV ($m \cdot s^{-1}$)	2.10 ± 0.14	2.09 ± 0.11	2.15 ± 0.11	0.03 (0.37)	0.36 (0.34)	0.48 (0.36)
MP_{BM} (%BM)	89.4 ± 7.2	88.1 ± 7.4	110.6 ± 9.6*#	0.17 (0.41)	2.90 (0.40)	2.98 (0.39)
MPP_{BM} (%BM)	83.8 ± 5.5	81.3 ± 9.1	104.0 ± 10.5*#	0.44 (0.55)	3.57 (0.48)	2.45 (0.37)
PP_{BM} (%BM)	88.8 ± 7.1	88.1 ± 7.4	107.3 ± 10.6*#	0.09 (0.42)	2.55 (0.42)	2.53 (0.41)
JSH (cm)	18.3 ± 2.2	18.3 ± 1.8	19.2 ± 1.8	0.03 (0.37)	0.36 (0.34)	0.48 (0.36)

Note: CI: confidence interval; R: rugby; So: soccer; Sp: sprinters; MF: mean force; MPF: mean propulsive force; PF: peak force; MP: mean power; MPP: mean propulsive power; PP: peak power; REL: relative to body mass (BM); MV: mean velocity; MPV: mean propulsive velocity; PV: peak velocity; JSH: jump squat height. *$P < 0.05$ Significant difference in relation to rugby players; #$P < 0.05$ Significant difference in relation to soccer players.

TABLE 2. Comparison of force and power variables at distinct loads relative to body mass[1], between rugby and soccer players, and sprinters.

		% Body Mass							
		40	**50**	**60**	**70**	**80**	**90**	**100**	**110**
MF$_{REL}$ (N·kg^{-1})	Rugby	3.90 ± 0.08	4.91 ± 0.12	5.86 ± 0.11	6.87 ± 0.11	7.87 ± 0.15	8.80 ± 0.12	-	-
	Soccer	3.91 ± 0.09	4.87 ± 0.16	5.86 ± 0.11	6.82 ± 0.28	7.75 ± 0.25	8.82 ± 0.27	-	-
	Sprinters	4.13 ± 0.48$^{*\#}$	5.17 ± 0.62$^{*\#}$	6.15 ± 0.74$^{*\#}$	7.19 ± 0.81$^{*\#}$	8.32 ± 0.87$^{*\#}$	9.34 ± 0.98$^{*\#}$	10.38 ± 1.14	11.40 ± 1.16
MPF$_{REL}$ (N·kg^{-1})	Rugby	6.25 ± 0.36	7.57 ± 0.45	8.73 ± 0.46	9.76 ± 0.50	10.78 ± 0.58	11.71 ± 0.55	-	-
	Soccer	6.49 ± 0.44	7.68 ± 0.53	8.91 ± 0.58	9.99 ± 0.69	10.97 ± 0.71	11.92 ± 0.92	-	-
	Sprinters	6.98 ± 1.04$^{*\#}$	8.38 ± 1.27$^{*\#}$	9.64 ± 1.45$^{*\#}$	10.81 ± 1.60$^{*\#}$	12.07 ± 1.76$^{*\#}$	13.18 ± 1.99$^{*\#}$	14.26 ± 2.13	15.20 ± 2.11
PF$_{REL}$ (N·kg^{-1})	Rugby	7.60 ± 0.51	9.34 ± 0.61	10.71 ± 0.65	12.06 ± 0.73	13.30 ± 0.79	14.45 ± 0.66	-	-
	Soccer	8.15 ± 0.42	9.79 ± 0.74	11.24 ± 0.76	12.60 ± 0.74	13.91 ± 0.73	14.00 ± 4.63	-	-
	Sprinters	8.88 ± 1.32$^{*\#}$	10.53 ± 1.58$^{*\#}$	12.09 ± 1.87$^{*\#}$	13.55 ± 1.99$^{*\#}$	15.14 ± 2.23$^{*\#}$	16.39 ± 2.43$^{*\#}$	19.25 ± 2.56	20.38 ± 2.51
MP$_{REL}$ (W·kg^{-1})	Rugby	4.67 ± 0.35	5.58 ± 0.39	6.39 ± 0.45	7.12 ± 0.45	7.74 ± 0.56	8.22 ± 0.60	-	-
	Soccer	4.70 ± 0.29	5.57 ± 0.41	6.41 ± 0.45	7.17 ± 0.56	7.61 ± 0.65	8.08 ± 0.82	-	-
	Sprinters	5.14 ± 0.36$^{*\#}$	6.16 ± 0.40$^{*\#}$	7.07 ± 0.47$^{*\#}$	7.91 ± 0.47$^{*\#}$	8.79 ± 0.50$^{*\#}$	9.37 ± 0.53$^{*\#}$	10.08 ± 0.58	10.72 ± 0.72
MPP$_{REL}$ (W·kg^{-1})	Rugby	7.71 ± 0.91	8.87 ± 1.02	9.71 ± 1.05	10.26 ± 1.01	10.75 ± 1.21	10.94 ± 1.35	-	-
	Soccer	8.10 ± 0.91	9.08 ± 1.08	9.99 ± 1.09	10.67 ± 1.32	10.67 ± 1.32	11.00 ± 1.70	-	-
	Sprinters	9.68 ± 1.19$^{*\#}$	11.07 ± 1.27$^{*\#}$	12.21 ± 1.43$^{*\#}$	13.03 ± 1.37$^{*\#}$	13.66 ± 1.36$^{*\#}$	14.19 ± 1.40$^{*\#}$	14.67 ± 1.45	14.83 ± 1.71
PP$_{REL}$ (W·kg^{-1})	Rugby	16.33 ± 1.78	19.11 ± 2.14	21.30 ± 2.36	22.87 ± 2.52	24.13 ± 2.76	25.07 ± 2.47	-	-
	Soccer	17.63 ± 1.67	20.37 ± 2.13	22.40 ± 2.18	24.24 ± 2.32	25.70 ± 2.28	26.76 ± 2.42	-	-
	Sprinters	21.24 ± 2.66$^{*\#}$	24.38 ± 2.61$^{*\#}$	27.30 ± 3.06$^{*\#}$	29.38 ± 3.12$^{*\#}$	31.14 ± 3.07$^{*\#}$	32.60 ± 2.90$^{*\#}$	34.12 ± 3.34	35.35 ± 3.68

Note: MF: mean force; MPF: mean propulsive force; PF: peak force; MP: mean power; MPP: mean propulsive power; PP: peak power; REL: relative to body mass. [1]At least 78% of the subjects of the group performed the JS at this relative load. $^{*}P < 0.05$ Significant difference in relation to rugby players; $^{\#}P < 0.05$ Significant difference in relation to soccer players.

Rugby players exhibited higher values of absolute bar power and bar force than soccer players, but these differences no longer existed for relative data (Table 2). Table 2 shows the comparison of force and power variables at distinct loads relative to BM, between rugby and soccer players, and sprinters. Sprinters demonstrated significantly higher force and power values at all loads tested in comparison with rugby and soccer players ($P < 0.05$). Table 3 demonstrates the comparison of the velocity variables and JSH at distinct loads relative to BM, between rugby and soccer players, and sprinters. Sprinters showed higher velocities and JSH than rugby and soccer players at all loads tested ($P < 0.05$).

TABLE 3. Comparison of the velocity variables and estimated jump height at distinct loads relative to body mass[1], between rugby and soccer players, and sprinters.

		% Body Mass							
		40	**50**	**60**	**70**	**80**	**90**	**100**	**110**
MV ($m \cdot s^{-1}$)	Rugby	1.20 ± 0.08	1.14 ± 0.07	1.09 ± 0.07	1.04 ± 0.06	0.99 ± 0.07	0.93 ± 0.07	-	-
	Soccer	1.20 ± 0.07	1.14 ± 0.08	1.09 ± 0.06	1.05 ± 0.08	0.98 ± 0.08	0.91 ± 0.08	-	-
	Sprinters	1.31 ± 0.08*#	1.26 ± 0.08*#	1.20 ± 0.08*#	1.16 ± 0.07*#	1.10 ± 0.07*#	1.06 ± 0.06*#	1.02 ± 0.06	0.99 ± 0.07
MPV ($m \cdot s^{-1}$)	Rugby	1.28 ± 0.10	1.22 ± 0.08	1.15 ± 0.08	1.09 ± 0.07	1.03 ± 0.08	0.96 ± 0.09	-	-
	Soccer	1.27 ± 0.08	1.20 ± 0.09	1.14 ± 0.08	1.09 ± 0.09	1.01 ± 0.09	0.93 ± 0.09	-	-
	Sprinters	1.40 ± 0.11*#	1.34 ± 0.10*#	1.27 ± 0.10*#	1.21 ± 0.08*#	1.15 ± 0.07*#	1.09 ± 0.07*#	1.04 ± 0.08	1.00 ± 0.08
PV ($m \cdot s^{-1}$)	Rugby	2.51 ± 0.17	2.40 ± 0.15	2.30 ± 0.15	2.20 ± 0.12	2.12 ± 0.11	2.04 ± 0.09	-	-
	Soccer	2.56 ± 0.13	2.45 ± 0.13	2.33 ± 0.13	2.24 ± 0.13	2.15 ± 0.11	2.06 ± 0.10	-	-
	Sprinters	2.85 ± 0.16*#	2.75 ± 0.14*#	2.64 ± 0.14*#	2.53 ± 0.14*#	2.40 ± 0.12*#	2.30 ± 0.12*#	2.21 ± 0.11	2.13 ± 0.12
JSH (cm)	Rugby	25.3 ± 2.8	23.4 ± 2.5	21.7 ± 2.5	20.1 ± 2.1	18.8 ± 1.8	17.4 ± 1.5	-	-
	Soccer	26.0 ± 2.1	24.2 ± 2.2	22.3 ± 2.1	20.7 ± 2.1	19.2 ± 1.9	17.7 ± 1.7	-	-
	Sprinters	30.9 ± 2.6*#	29.3 ± 2.3*#	27.3 ± 2.3*#	25.5 ± 2.4*#	23.4 ± 2.0*#	21.8 ± 2.0*#	20.3 ± 1.9	18.9 ± 2.0

Note: MV: mean velocity; MPV: mean propulsive velocity; PV: peak velocity; JSH: jump squat height. [1]At least 78% of the subjects of the group performed the JS at this relative load. *$P < 0.05$ Significant difference in relation to rugby players; #$P < 0.05$ Significant difference in relation to soccer players.

DISCUSSION

This study provides reference values for a set of mechanical parameters collected via LVT during JS attempts in top-level athletes from three different sports. In addition to presenting a comprehensive dataset of JS outputs, we observed that: 1) relative bar power, relative bar force, bar velocity, and JSH were significantly higher in sprinters than in rugby and soccer players, for all loads tested, regardless of the variable considered (i.e., mean, mean propulsive, or peak values); 2) irrespective of the measure, rugby players had higher values of absolute bar power and bar force than soccer players across all loading conditions, but these differences disappeared when the data were adjusted for BM (i.e., relative bar power and force); 3) sprinters optimized their bar-power production at significantly greater relative loads (i.e., % BM) than rugby and soccer players; however, all groups generated their maximum bar-power outputs at similar bar velocities and jump heights. These findings may have important implications for practitioners and researchers.

Sprinters typically exhibit higher levels of relative strength and relative power than athletes from other sports (Table 2), which is consistent with the high correlations commonly observed between these measures and sprint velocity [5, 18, 32]. Nonetheless, for the first time, we demonstrated that bar velocities (and jump heights) were higher for sprinters than for team-sport players across a wide range of relative loads (Table 3). González-Badillo et al. [33] stated that the velocity at which loads are lifted "is a fundamental part of the intensity" and expresses "the real relative loading intensity at which the subject has trained" [33]. From an applied perspective, this means that, for sprinters, the BM represents a lower percentage of their maximum strength potential (as measured by, for example, the one-repetition maximum test), which allows them to jump higher and sprint faster than rugby and soccer players. These assumptions are supported by previous findings regarding sprinters and team-sport athletes and highlight an important point: higher bar velocities at similar % BM imply greater levels of relative strength and relative power [18, 29]. This approach (i.e., measuring bar velocity at fixed % BM) can be used to evaluate athletes very quickly and may be considered as a relevant indicator of athletic performance.

As expected, in line with recent reports, rugby players displayed higher levels of absolute bar power and force than soccer players [5, 29]. Rugby is a collision sport; abilities such as tackling opponents and tolerating repeated physical confrontations (e.g., scrummaging, rucking, mauling, etc.) are paramount for performance [34, 35]. In this sense, rugby union players are "naturally selected" by their physical traits (i.e., taller, and heavier) [36, 37] and usually perform higher volumes of strength-based training than soccer players [38]. Nonetheless, both sports require optimal levels of speed and relative power [39–43], as players frequently execute multiple sprints and cutting manoeuvres during the games [40, 42, 44, 45]. To some extent, these anthropometric and physical performance factors (i.e., heavier subjects generating lower relative parameters) may explain the absence of differences in relative bar power and bar force between rugby and soccer players. However, once again, these mechanical similarities (in terms of bar power and force) could have been detected by simply observing the lack of differences between bar velocities at similar % BM for both groups of athletes.

Sprinters, rugby players, and soccer players maximized bar-power production at similar bar velocities, but at distinct % BM (Table 1). Importantly, this phenomenon was shown to be independent of the variable collected (i.e., MV, MPV, or PV), thus allowing coaches to select and consider the most appropriate measure, according to personal preferences and available technology (e.g., by using LVTs, LPTs, accelerometers, or mobile apps). These data agree with previous studies demonstrating that sprinters achieve their OPL at a higher % BM than both rugby and soccer players (Table 1) but at the same (and narrow) range of bar velocities [5, 18]. As a consequence, these athletes also reach similar jump heights in the optimum power zone, which may facilitate the determination of the OPL [5]. Although in this study we did not use a specific device (e.g., contact mat or force plate) to assess vertical jump trials, we calculated these metrics using the equation provided by García-Ramos et al. [30], which enables accurate estimation of JSH from the maximum bar velocity attained during the concentric phase of the movement (when collected by an LVT). These heights (and all the heights within the wide range of assessed loads) are presented in Table 3, with the intention of providing more information about the loaded jump performance of sprinters and team-sport players. Furthermore, these data confirm previous findings concerning the OPL, revealing that top-level athletes, with distinct strength-power levels, can jump ~20 cm in the optimum power zone [5]. Of note, in the current study, the JSH was calculated from the PV (Table 1), indicating that, independent of the variable considered (i.e., MPV or PV), athletes maximize bar-power production when jumping, on average, 20 cm.

In summary, for the first time, we provided reference values for the JS exercise for three different bar-velocity outputs (i.e., MV, MPV, and PV), for sprinters, rugby players, and soccer players over a wide range of relative loads. These variables have already been shown to be reliable measures of JS performance, with the highest values of reliability detected in favour of PV (i.e., MV: 3.93%, MPV: 4.61%, and PV: 2.14%, for mean CVs across different loads) [46]. It is worth noting that during ballistic exercises (e.g., bench throws or JS) athletes are pushing with maximum effort throughout the concentric phase in order to achieve higher projection velocities and hence longer throws or higher heights [47]. Thus, in theory, ballistic actions should not involve a braking phase, as athletes do not apply force in the opposite direction to the lifting at the end of the concentric phase to, for example, avoid taking off. However, in practical terms, there are differences between MV and MPV against different loads, suggesting the existence of a brief "braking phase" (i.e., bar acceleration lower than $-9.8\ m{\cdot}s^{-2}$) during some ballistic exercises [3]. This braking phase might occur due to two different factors: 1) increases in the friction coefficient of the Smith-machine guides at higher bar velocities, or 2) increases in the tension of LVT or LPT cables when longer cable lengths or higher bar velocities are attained. Nevertheless, both MV and MPV have also been found to be appropriate for assessing the load-velocity relationship during ballistic movements, in both lower- and upper-body exercises, which supports their utilization for training and testing purposes [48, 49]. Therefore, practitioners can use the reference values provided here according to their preferences, in order to monitor their athletes and, specifically, to compare them with top-level sprinters and team-sport players.

This study is limited by its cross-sectional nature, which does not allow, for example, the evolution of these mechanical parameters to be prospectively followed through different training phases or even within each specific sport. Moreover, it is not possible to state with absolute certainty that the differences between athletes are more related to their training routines or inherent capabilities. Further studies with similar designs (i.e., different bar-velocity outputs assessed across an extensive loading range) comprising athletes from different sport disciplines (e.g., endurance runners and martial artists) should be conducted to expand our knowledge and understanding of these highly trained and specialized individuals.

CONCLUSIONS

The JS is a widely and frequently used exercise and has been shown to be very effective in improving athletic performance. Hence, providing reference values for top-level athletes from different sports using a set of mechanical parameters (i.e., MV, MPV, and PV) over a wide range of relative loads (i.e., from 40 to 110% BM) may be useful for practitioners and researchers. Coaches can use our data to make direct comparisons among athletes from distinct performance levels (e.g., elite versus non-elite), regardless of their personal preferences (i.e., using mean or peak velocities) and available technology (as both measures have been shown to be appropriate for assessing the load-velocity relationship in loaded jumps) [49]. The fact that the OPL (based on the PP output) is achieved at a JSH of ~20 cm (calculated from the PV equation) also allows coaches to use this jumping height range as an adequate reference for the optimum power zone, regardless of the mechanical measure considered to determine the load able to optimize bar-power output (i.e., MPV or PV) [5].

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