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ORIGINAL ARTICLE

Interrelationships between different loads in resisted sprints, half-squat 1 RM and kinematic variables in trained athletes

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Abstract

Resisted sprint running is a common training method for improving sprint-specific strength. It is well-known that an athlete's time to complete a sled-towing sprint increases linearly with increasing sled load. However, to our knowledge, the relationship between the maximum load in sled-towing sprint and the sprint time is unknown, The main purpose of this research was to analyze the relationship between the maximum load in sled-towing sprint, half-squat maximal dynamic strength and the velocity in the acceleration phase in 20-m sprint. A second aim was to compare sprint performance when athletes ran under different conditions: un-resisted and towing sleds. Twenty-one participants (17.86 ± 2.27 years; 1.77 ± 0.06 m and 69.24 ± 7.20 kg) completed a one repetition maximum test (1 RM) from a half-squat position (159.68 ± 22.61 kg) and a series of sled-towing sprints with loads of 0, 5, 10, 15, 20, 25, 30% body mass (Bm) and the maximum resisted sprint load. No significant correlation ($P < 0.05$) was found between half-squat 1 RM and the sprint time in different loaded conditions. Conversely, significant correlations ($P < 0.05$) were found between maximum load in resisted sprint and sprint time (20-m sprint time, $r = -0.71$; 5% Bm, $r = -0.73$; 10% Bm, $r = -0.53$; 15% Bm, $r = -0.55$; 20% Bm, $r = -0.65$; 25% Bm, $r = -0.44$; 30% Bm, $r = -0.63$; MaxLoad, $r = 0.93$). The sprinting velocity significantly decreased by 4–22% with all load increases. Stride length (SL) also decreased (17%) significantly across all resisted conditions. In addition, there were significant differences in stride frequency (SF) with loads over 15% Bm. It could be concluded thatthe knowledge of the individual maximal load in resisted sprint and the effects on the sprinting kinematic with different loads, could be interesting to determinate the optimal load to improve the acceleration phase at sprint running.

Keywords: *Sled towing, sprinting kinematics, velocity*

Introduction

The ability to achieve a high maximum sprinting velocity is an important determinant of success in sports such as athletics, soccer and other team sports (Alcaraz, Palao, Elvira, & Linthorne, 2008). Sprint running performance is the product of stride frequency (SF) and stride length (SL) with numerous components influencing this apparently simple formula (Ross, Leveritt, & Riek, 2001). Performance in sprint exercise has traditionally been thought to be largely dependent on genetic factors; however, other mechanisms of adaptation are required and this likely includes neural improvements (Ross et al., 2001).

Resisted sprint towing has become a specific strength training method for sprinters (Alcaraz et al., 2008; Delecluse, 1997; Zafeiridis et al., 2005). This training mode for athletes is believed to increase strength, SL (Alcaraz et al., 2008) and SF (Alcaraz et al., 2008; Clark, Stearne, Walts, & Miller, 2010; Zafeiridis et al., 2005).

In field sports, speed plays a pivotal role. Whether it was to escape a tackle or to get into position for a

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pass, speed and acceleration are vital for success. So, resisted sprint towing is also used in training for field sports.

Different devices are used to apply the resistance, being the most popular sled towing. Several studies have examined the effects of sled towing on sprint performance (Alcaraz et al., 2008; Alcaraz, Palao & Elvira, 2009; Cronin, Hansen, Kawamori, & McNair, 2008; Letzelter, Sauerwein, & Burger, 1995; Lockie, Murphy, & Spinks, 2003; Maulder, Bradshaw, & Keogh, 2008; Murray et al., 2005). Some studies have attempted to find the appropriate load for resisted sprinting (Alcaraz et al., 2009; Lockie et al., 2003; Spinks, Murphy, Spinks, & Lockie, 2007), but the resistance was calculated as a percent of Bm. Different studies suggest that to maintain load specificity in sprints, horizontal velocity should not fall below 90% of the athlete's maximum velocity (Alcaraz et al., 2008; Letzelter et al., 1995).

In this sense, Lockie et al. (2003) explored the effects of sled towing on acceleration sprint kinematics in field-sport athletes, and presented an equation that relates the reduction in running velocity to the weight of the sled.

Conversely individual force ability has not been considered in the mentioned studies. Strength usually increases with body mass, thus a movement follows Newton's second law of motion $F = ma$, where 'm' is mass and 'a' is acceleration. The force is proportional to the mass (inertia). As the body mass is typically selected as a parameter of a motor task, the force determines the acceleration. Murray et al. (2005) suggested assigning loads as a proportion of strength, and Letzelter et al. (1995) used maximal static strength of the leg extensors at 90° angle in knee and hip joints to ascertain whether the tempo reduction and changes in stride variables were dependent on maximal strength, finding a lack of correlations between maximal strength and sprint performance. Murray et al. (2005) suggested that the use of one-repetition maximum squat may be more appropriate and practical than an isometric test, as questions related to the selected muscle groups and speed of test would need to be resolved. The literature has focused on the use of absolute and relative resistance and the effects on sprinting kinematics, but an appropriate criterion to apply loads correctly is needed. Alcaraz et al. (2009) suggested load control is essential to ensure the specificity of resisted sprint training method.

Previous research on the maximum velocity phase supports the contention that when towing a sled with a resistance that reduces the athlete's velocity by more than 10% of unloaded sprinting maximal velocity, there are substantial changes to the athlete's sprinting mechanics (Alcaraz et al., 2008). A possible reason for the variation in performance is that some of the heavier players may not be as strong as some of the lighter players and vice versa (Murray et al., 2005), and the use of a leg strength measurement and the assigning of the loads as a proportion of strength on the test may have been better (Murray et al., 2005).

Keeping this in mind, the purpose of this research was to compare sprint performance over 20 m when athletes ran under different conditions: un-resisted and towing sleds with loads between 5 and 30% Bm. A secondary aim was to ascertain the relationship between maximal strength and resisted sprinting, to determine whether resisted sprinting loads should be applied in relation to individual's maximal dynamic strength (1 RM).

Methods

To analyze the kinematics of acceleration of field-sport athletes and runners while towing a sled of varying resistances (5–30% Bm), an experimental design was used. The variations of athlete's sprint time, SL and SF were measured in relation to their un-resisted sprint time. The loads from 5 to 30% Bm were used for the analyses with maximum resisted sprint load. This load was determined as the load that made athletes unable to increase their velocity in the last 5m-sprint. Furthermore, half-squat 1 RM was assessed to ascertain the relationship between resisted sprint velocity and the level of maximal strength in the lower limbs.

Each of the two test sessions was performed over a 5-day period, following the same order of assessments: Day 1: half-squat 1 RM and Day 2: 20 m sprint acceleration in un-resisted and resisted conditions.

Subjects

Twenty-one male volunteers were recruited for the study (17.86 ± 2.27 years; 1.77 ± 0.06 m; 69.24 ± 7.20 and 1 RM 159.68 ± 22.61 kg). Seven participants were active competitive athletes who specialised in sprint run (20.21 ± 1.80 years; 1.82 ± 0.03 m; 71.94 ± 8.38 kg and 1 RM: 176.43 ± 22.42 kg), and 14 were soccer players of national competitive level (16.53 ± 0.64 years; 1.75 ± 0.05 m; 67.97 ± 6.52 kg and 1 RM: 151.87 ± 18.58 kg). All had 3 years previous experience in their respective sports. None of the subjects had previously performed any sled towing training. Each participant gave his written informed consent to participate in this study before testing. Ethical approval was obtained for all testing procedures from the Castilla La Mancha University ethics committee.

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Procedures

The study was performed in three separated days over a 5-day period, with 48 h-rest between them. Subjects performed a familiarisation session in the first day, half squat 1 RM in second day and resisted sprint test in the third day.

Anthropometric information was collected in the familiarisation session prior to strength testing. Height and body mass (Seca 720, Vogel & Halke, Germany) were recorded. Then the subjects were familiarised with the maximal muscular strength assessment of the lower extremity muscles (half-squat 1 RM test) during several sub maximal and maximal actions. The familiarisation was performed in the same conditions that test would be carried out in second day.

During the first testing session (second day) each subject was tested for his half-squat 1 RM. Subjects completed a 5-minute warm-up on a stationary bike at a standardised resistance (50 W) and a cadence of 70 rpm (McBride, Nimphius, & Erickson, 2005). Following this, the subjects completed one set of 5–10 repetitions of the squat with light load (40–60% of predicted 1 RM) and one set of 2–3 repetitions with moderate load (60–80% of predicted 1 RM). Each set was separated by a two-minute rest period (Thomas et al., 2007).

A detailed description of the half-squat 1 RM can be found in Thomas et al. (2007). The half-squat was performed in a Smith machine (Multipower, Salter, Barcelona, Spain), with linear bearings on two vertical bars allowing only vertical movements. The subject had to descend to the point where the tops of the thighs were parallel to the floor and perform a concentric leg extension (as fast as possible), to reach 180° of leg extension against the resistance determined by the weight plates added to both ends of the bar. The shoulders were in contact with the bar. Thereafter, four to five separate single attempts were performed. The last acceptable single repetition with the highest possible load was determined as one-repetition maximum. The 1 RM half-squat in relation to body mass was calculated, dividing the maximum load between body mass. Each attempt was separated by a three-minute rest period.

During the second testing occasion (third day) the sprint time of each subject was assessed for both un-resisted and resisted conditions. The sprint time was evaluated with a 20 m sprint effort using a system of photocells (Newtest Powertimer 300, Newtest Oy, Finland) placed at 2 and 22 m to record the participants' sprint times over 20 m. Other photocells were used to measure sprint times between 2 and 7, 12, 17 and 22 m to record the participants' sprint times over 5 m (Figure 1). A high-speed camera (Casio High Speed Exilim EX-F1, Casio, Tokyo, Japan) operating at 300 fps was used to analyze the SL and SF. The camera was set at a height of 0.85 m. The placement of the camera was 5 m from the end of the recorded section of the run as shown in Figure 1. The participants were recorded for the entire run, although their strides were only counted from the moment they crossed the line at 2 m to when they crossed the line at 22 m. If the feet did not land exactly on either line, then half-strides were counted (Murray et al., 2005).

The SL and SF were determined as follows: SL = distance/stride number; SF = stride number/time.

The participants completed a 10 minute standardised running warm-up prior to the sprints consisting of 4 minutes of running with a heart rate of 140 bpm and two sub maximal sprints unloaded and two sub maximal sprints with a loaded sled (5% Bm), immediately prior to the test. The rest between sprints was 2 minutes. The participants completed two sprint efforts at their maximum speed and the best sprint was used for analysis. In the resisted sprint test the loads were applied with a weighted sled (Byomedic, Barcelona, Spain) attached to the athlete by a 2.7 m cord and waist harness. The weighted sled was comprised of a smooth surface about 0.4 m long and 0.3 wide. The sprint trials were

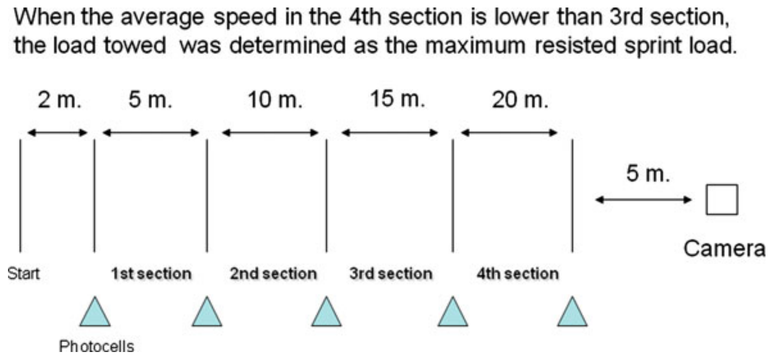

Figure 1. Scenario of the 20 m acceleration sprint.

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conducted on a Mondo athletics track in an outdoor athletics stadium.

Loads were increased by 5% Bm, until the participant was unable to keep increasing his speed, so the sprint time from the last 5 m (17–22 m) was higher than the sprint time from 12 to 17 m. The sprint time was measured in every section of 5 m during the 20 m acceleration test (Figure 1). All athletes completed the test until the 30% Bm despite their loss of speed on the previous loads, to obtain data from all towing loads. The load that made athletes unable to increase their speed in relation to the last section was determined as the maximum resisted sprint load.

To determine whether the velocity reduction and the changes in SF and SL were dependent on maximal strength, two different performance groups (high and low strength level) were compared. The distribution criterion was the maximum strength in the half-squat and participants grouped above and below the median value.

Statistical analyses

Mean and standard deviations were calculated for each of the dependent and independent measures for each condition. Normal distribution and homogeneity of the parameters were checked with Shapiro–Wilks and Levene's test. According to the result, a repeated-measures ANOVA with Bonferroni post hoc contrasts was used to determine whether there was a significant effect of sprint load on sprinting kinematics – sprint time, SF and SL.

A two factor (group × load) repeated-measures ANOVA with Bonferroni post hoc contrasts was used to determine if maximal strength affects the variables of interest across resisted loads. Pearson's correlation was used to determine the relationship between load and velocity variables in sprint, resisted sprint and half-squat. All statistical procedures were performed using SPSS for Windows 17.0 using an alpha level of 0.05.

Results

All the variables had normally distributed data. The effects of resisted sprinting on SL, SF and sprint time over 20 m are shown in Table I. Sprint time was significantly higher ($P < 0.001$) than in all the loaded conditions. The decrease in running velocity arose through decreases in both SL (~2 to ~17%) and SF (~2 to ~7%). All loads reduced SL significantly as compared to the unloaded sprinting, and between loads, except between 30% Bm and maximum resisted sprint load. SF was significantly lower to the unloaded condition at loads higher than 15% Bm. A significant decrease ($P < 0.05$) was found between 5% and loads bigger than 30% Bm.

Subject characteristics and strength values, and their distribution between a high and low strength group can be observed in Table II. Although significant differences were found between sprint time, SL and SF across loads these variables were not significantly different between the high and low strength groups. Therefore, these differences were not substantiated by the level of maximal strength in half-squat (Figure 2 and Table III).

A significant correlation was obtained between maximal load in resisted sprint and sprint time unloaded and loaded ($P < 0.05$ in 10% and 25% Bm, $P < 0.01$ in 15% and 30% Bm, $P < 0.001$ in unloaded, 5, 20% Bm and maximal load). Therefore, there was no significant correlation between half-squat variables and sprinting ability in loaded and unloaded conditions. No significant correlation was also found between half-squat 1 RM in relation to body mass and sprint ability (Table IV).

Discussion

This research has shown that the increase in loads involves a decrease in sprint performance over 20 m when athletes ran under different conditions: unresisted and towing sleds with loads between 5 and 30% Bm. Previous studies have suggested that

Table I. Mean ± SD sprinting velocity, stride length and stride frequency across different resisted loads ($n = 21$)

	Resisted sprint load							
	Unloaded	5% Bm	10% Bm	15% Bm	20% Bm	25% Bm	30% Bm	MaxLoad
Sprint time, s	2.885 ± 0.086	3.006 ± 0.115***	3.099 ± 0.130***	3.196 ± 0.110***	3.277 ± 0.136***	3.371 ± 0.133***	3.463 ± 0.153***	3.739 ± 0.390***
Stride length, m	1.58 ± 0.11	1.55 ± 0.10*	1.52 ± 0.10***	1.48 ± 0.11***	1.44 ± 0.10***	1.42 ± 0.10***	1.40 ± 0.10***	1.32 ± 0.12***
Stride frequency, Hz	4.40 ± 0.31	4.32 ± 0.27	4.26 ± 0.27	4.24 ± 0.28**	4.23 ± 0.26*	4.18 ± 0.26**	4.15 ± 0.25***	4.10 ± 0.31***

Bm = body mass

*Statistically significant difference ($P < 0.01$) from unloaded sprinting.

**Statistically significant difference ($P < 0.01$) from unloaded sprinting.

***Statistically significant difference ($P < 0.001$) from unloaded sprinting.

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Table II. Mean ± SD age, body mass. Height and 1 RM for high and low strength groups ($n = 21$)

	Age (years)	Body mass (Kg)	Height (m)	1 RM (kg)
High level ($n = 10$)	19.38 + 2.26	73.11 ± 7.07	1.77 ± 0.05	184.13 ± 13.21
Low level ($n = 11$)	17.00 ± 1.95	66.76 ± 6.70	1.76 ± 0.07	143.85 ± 10.66

resisted sprinting with sled significantly reduces sprint ability (Alcaraz et al., 2009; Letzelter et al., 1995; Lockie et al., 2003; Maulder et al., 2008, Murray et al., 2005) according to the present study.

In our study, a significant decrease was shown in SL with additional loading. These effects were found in other studies with sleds (Alcaraz et al., 2009; Corn & Knudson, 2003; Cronin et al., 2008; Lockie et al., 2003; Murray et al., 2005). A possible explanation is that working out with excessive loads in sled towing induces significant increases in centre of gravity vertical oscillation and significant reductions in SL (Alcaraz et al., 2009).

In addition, SF did not decrease significantly with loads under 15% BM; however, a significant decrease at the SF was observed with loads higher than 15% BM. Similar decreases in SF were found in other studies using loads between 12 and 32% BM (Alcaraz et al., 2008; Lockie et al., 2003). Conversely to these results, Lockie et al. (2003) reported that a higher SF is performed to compensate the effects in SL (Lockie et al., 2003).

In our study, the increase in sprint time with loads lower than 15% Bm could be a consequence of a reduction in SL; however, the increase in sprint time with loads higher than 15% Bm could be a function of reductions in SL and SF, according to the study of Lockie et al. (2003).

Additional loads may be said to increase muscular force output leading to a potential increase in SL over time (Faccioni, 1994; Lockie et al., 2003). In the current study, a non-significant correlation was found between maximal strength in half-squat and the speed recorded in towing resistances or SL and SF. This coincides with the work by Letzelter et al. (1995) where the differences found in sprint time cannot be substantiated by the level of maximal strength.

After analyzing the differences between the strongest subject's group and the less strong subject's group, non-significant differences were observed. The relationship between maximal strength in half-squat and the sprint performance seems not to be clear, as there are some studies showing contradictory results on this issue (Baker & Nance, 1999; Juárez et al., 2008; Wisloff, Castagna, Helgerud, Jones, & Hoff, 2004; Young, McLean, & Ardagna, 1995). Anyway, it is necessary to bear in mind that the relationship between the maximal strength and the sprint performance is influenced for the variables analyzed and the characteristics of the subjects (i.e. body mass). To determine if this relationship could be affected by body mass a correlation analyses was performed between half-squat 1 RM/Bm and sprint ability. The results showed no significant correlation between them. Cronin and Sleivert (2005) suggest that strength qualities such as impulse, rate of force development of explosive strength may better predict athletic performance and hence it is the development of these qualities that research and strength training should focus on, in future research these strength qualities should be used to determinate this relationship.

In this sense, the high and significant correlation found in our study between maximal load in resisted sprint and sprint velocity suggests the use of this

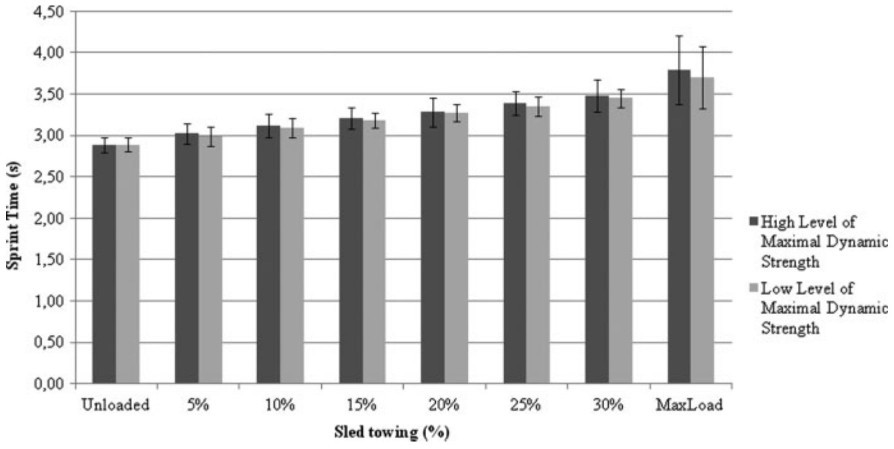

Figure 2. Mean ± SD sprint velocity depending on the sample 1 RM level: High vs. low level of maximal dynamic strength.

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Table III. Mean ± SD stride rate and stride length in the maximal strength level groups ($n = 21$)

	Stride frequency		Stride length	
	High level	Low level	High level	Low level
Unloaded	4.38 ± 0.40	4.41 ± 0.27	1.59 ± 0.12	1.58 ± 0.11
5%	4.28 ± 0.31	4.35 ± 0.25	1.54 ± 0.10	1.55 ± 0.09
10%	4.19 ± 0.28	4.31 ± 0.27	1.53 ± 0.11	1.52 ± 0.09
15%	4.18 ± 0.25	4.28 ± 0.30	1.50 ± 0.12	1.48 ± 0.11
20%	4.24 ± 0.25	4.23 ± 0.28	1.44 ± 0.11	1.46 ± 0.10
25%	4.12 ± 0.18	4.21 ± 0.30	1.43 ± 0.11	1.42 ± 0.11
30%	4.07 ± 0.20	4.19 ± 0.28	1.41 ± 0.11	1.39 ± 0.10
MaxLoad	4.11 ± 0.32	4.09 ± 0.31	1.33 ± 0.18	1.31 ± 0.08

Table IV. Correlation between maximal strength and 1 RM in half-squat test, maximal load in resisted sprint and sprinting velocity in unloaded and loaded conditions

	1 RM	1 RM/Bm	MaxLoad (Resisted sprint)	Time unloaded	T5% Bm	T10% Bm	T15% Bm	T20% Bm	T25% Bm	T30% Bm	TMax Load
1 RM	1										
1 RM/Bm	0.712***	1									
MaxLoad (Resisted sprint)	−0.027	0.711***	1								
Time unloaded	−0.054	0.041	0.706***	1							
T5%Bm	0.071	0.054	0.734***	0.876**	1						
T10%Bm	0.029	0.158	−0.528*	0.668**	0.818***	1					
T15%Bm	0.025	0.065	−0.555**	0.635***	0.723***	0.771***	1				
T20%Bm	−0.090	−0.042	−0.650***	0.712***	0.779***	0.826***	0.920***	1			
T25%Bm	−0.045	0.126	−0.440*	0.640***	0.638***	0.785***	0.858***	0.835***	1		
T30%Bm	−0.105	−0.051	−0.629**	0.649***	0.732***	0.796***	0.871***	0.910***	0.887***	1	
TMaxLoad	0.077	0.153	0.932***	−0.490*	−0.468*	−0.248	−0.336	−0.463	−0.214	−0.4371	

Bm, body mass; T, sprint time.
***Correlation is significant at the 0.001 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

measurement to assign loads as a proportion of individual strength. To our knowledge, this relationship not has been analyzed previously.

It is necessary to take into account that a research limitation of this study was the heterogeneity of participants (soccer players and sprinters). In this sense, different training adaptations in relation to their strength and velocity could be achieved.

Conclusion

The 20-m sprint performance decreased with increasing load at resisted running using sled in recreationally active athletes and national competitive level soccer players. SL decreased across all resisted conditions, while the SF increased with loads over 15% Bm.

No significant correlation was found between half-squat 1 RM and the sprint velocity. Conversely, high relationship was found between maximal load in resisted sprint and sprint velocity. The knowledge of the individual maximal load in resisted sprint and the effects on the sprinting kinematic with different loads, could be interesting to determinate the optimal load to improve the acceleration phase at sprint running. The finding supports the use of a training load of approximately 15% Bm for a running distance of 20 m, to improve acceleration phase.

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