Original Article

Effect of strength-to-weight ratio on the time taken to perform a sled-towing exercise

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ABSTRACT

Sled-towing exercisesare effective at developing sprint acceleration in sports. In a sled-towingexercise the time taken by an athlete to tow the sled over a given distance isaffected by the weight of the sled, the frictional properties of the runningsurface, and the physiological capacities of the athlete. To accurately set thetraining intensity for an athlete, the coach needs a detailed understanding ofthe relationships between these factors. Our study investigated therelationship between the athlete's strength-to-weight ratioand the rate of increase in sled-towing time with increasing sled weight. Twenty-two male athletes performed aone-repetition maximum (1RM) half-squat and sled-towing exercises over 20 mwith sleds of various weights. The strength of the correlation between 1RM half-squat performance (normalized to bodyweight)and the rate of increase in sled-towing time with increasing sled weight was interpreted using the Pearson product-moment correlationcoefficient. As expected, we found substantialinter-athlete differences in the rate of increase in time with increasing sledweight, with a coefficient of variation of about 21% and 17% for sled-towingtimes over 10 and 20 m, respectively. However, the rate of increase in sled-towing time showed nocorrelation with normalized 1RM half-squat performance ($r = -0.11$, 90% confidence interval = –0.45 to 0.26; and $r = -0.02$, 90% confidence interval =–0.38 to 0.34, for sled-towing times over 10 and 20 m, respectively). Theseresults indicate thatinter-athlete differences in the rate of increase in sled-towingtime with increasing sled weight are not likely to be due to differences instrength-to-weight ratio. Instead,we recommend the weight of the sled be

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scaled according to the athlete'spower-to-weight ratio. **Key words:** ATHLETICS, BIOMECHANICS, KINEMATICS, SPRINTING

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INTRODUCTION

The ability to accelerate rapidly is important in sprinting and hurdling and in field sports such as soccer, rugby, American football, Australian football, and field hockey (Baker & Nance, 1999; Dawson et al., 2004; Duthie et al., 2006; Murphy et al., 2003; Spinks et al., 2007; Varley & Aughey, 2013; Young et al., 1995). Athletes can improve their sprint acceleration capabilities through using overload exercises to increase strength and power. Typical training modalities include weightlifting, plyometrics, and resisted sprinting exercises (Bentley et al., 2014). The resisted sprinting modality includes sled-towing exercises, and these can be very effective in improving sprint acceleration because they closely replicate the movement patterns and range of motion of unloaded sprinting and so have high specificity (Alcaraz et al., 2009; Clark et al., 2010; Cronin & Hansen, 2006; Harrison & Bourke, 2009; Lockie et al., 2012; Makaruk et al., 2013; Spinks et al., 2007; West et al., 2013; Zafeiridis et al., 2005).

Most towing sleds are designed to slide along the ground on runners or a flat base, and have a post on which to stack weights. A cord connects the sled to the athlete via a waist harness or shoulder harness. In a typical sled-towing exercise the athlete starts from a crouched or standing position and then sprints with maximum effort over a short distance (10–50 m). The coach will often record the time taken for the athlete to cover a set distance, and the increase in the athlete's time relative to the time in unloaded sprinting is an indicator of the intensity of the exercise (Linthorne, 2013; Linthorne & Cooper, 2013; Martínez-Valencia et al., 2013). Knowledge of the intensity of the exercise is very useful to the coach as it is the intensity that determines the training stimulus experienced by the athlete. Unfortunately, setting of the sled weight so that the athlete achieves the desired increase in time is not straight-forward. The time taken by the athlete depends not only on the weight of the sled, but also on the coefficient of friction of the running surface, the athlete's body mass, and the athlete's physiological capacities (e.g., lower body power) (Cronin et al., 2008; Linthorne, 2013; Linthorne & Cooper, 2013; Martínez-Valencia et al., 2013; Maulder et al., 2008; Murray et al. 2005). Experimental studies and modelling studies have shown that the time an athlete takes to tow a weighted sled over a given distance increases linearly with increasing sled weight and coefficient of friction (Linthorne, 2013; Linthorne & Cooper, 2013; Martínez-Valencia et al., 2013; Murray et al. 2005). The weight of the sled needs to be increased in proportion to the athlete's body weight so as to account for the fact that larger athletes tend to generate greater muscular power. Also, athletes with a greater power-to-weight ratio need to be set a greater relative sled weight in order to experience the same exercise intensity because the time taken to tow a weighted sled over a given distance decreases exponentially with increasing power-to-weight ratio (Linthorne, 2013).

Despite our substantial understanding of how to set the sled weight for an athlete, Martínez-Valencia et al. (2013) found that only about 50% of the observed variance in sled-towing time (on a given surface) was explained by differences in sled weight, body mass, and power-to-weight ratio (as measured by performance in a countermovement jump). The aim of the present study was to investigate other physiological factors that might be affecting an athlete's performance in a sled-towing exercise.

Many studies have shown that muscular power is strongly correlated with muscular strength (Cronin & Sleivert, 2005), and many studies of sprinting have found a strong negative relationship between an athlete's sprint time and their strength-to-weight ratio (Dowson et al., 1998; McBride et al., 2005). Therefore, we suggest that the time an athlete takes to tow a weighted sled over a given distance might be determined by the athlete's strength-to-weight ratio (in addition to the athlete's power-to-weight ratio). We suggest that when the sled weight is normalized for body weight, athletes who possess a greater than average strength-to-weight ratio have a lower relative stress placed on their sprint capabilities and so produce a faster time than would otherwise be expected. This time advantage is expected to be even greater at higher normalized sled loads, and therefore the athlete's rate of increase in time with increasing sled weight should be lower than for an average athlete. That is, among a group of athletes we expect to see differences in their rate of increase in time with increasing sled weight, with the lowest rates produced by athletes with a high strength-to-weight ratio and the highest rates produced by athletes with a low strength-to-weight ratio. However, as yet the effect of the athlete's strength-to-weight ratio on the time to perform a sled-towing exercise has not been investigated.

With regards to sled-towing exercises, the best indicators of an athlete's strength-to-weight ratio are likely to be measures of lower body strength, such as the maximum force in an isometric squat, the weight lifted in a one-repetition maximum (1RM) full-squat, and the weight lifted in a 1RM half-squat (Baker & Nance, 1999; McBride et al., 2009; Sleivert & Taingahue, 2004; Wisløff et al., 2004; Young et al., 2005). For these isometric and isotonic measures of muscular strength, the most appropriate method of normalizing for body size is to divide the strength score by body mass to the power of two-thirds (Åstrand et al., 2003; Jaric et al., 2005).

The purpose of the present study was to investigate the relationship between strength-to-weight ratio and the time taken to tow a weighted sled over a given distance. To determine this relationship, a correlational approach was used. Twenty-two male athletes performed a 1RM half-squat and sprints over 20 m while towing sleds of various weights. Our hypothesis was that there would be a strong negative correlation between normalized 1RM half-squat performance and the rate of increase in sled-towing time with increasing sled weight.

MATERIALS AND METHODS

Participants

Twenty two male athletes volunteered to participate in the study (age 18.7 ± 3.9 years; height 1.78 ± 0.06 m; body mass 68.7 ± 6.1 kg; mean ± *SD*). Eight participants were track and field athletes who specialized in sprinting (22.6 ± 4.3 years; 1.84 ± 0.04 m; 70.2 ± 4.9 kg), and fourteen participants were young national-level soccer players (16.5 ± 0.7 years; 1.75 ± 0.05 m; 67.8 ± 6.7 kg). The study adhered to the tenets of the Declaration of Helsinki and was conducted in accordance with procedures approved by the Human Ethics Committee of Castilla La Mancha University. The participants were informed of the procedures and inherent risks prior to their involvement, and written consent to participate was obtained from the participant or their legal guardian.

Measures

Sled-towing performance was assessed with the time taken to tow a weighted sled over distances of 10 m and 20 m. A series of sled weights of up to 30% of the participant's body mass was used. Strength-to-weight ratio was assessed with the weight lifted in a 1RM half-squat exercise (and normalized to body mass).

Procedures

This study was performed during three sessions over a 5-day period, with a 48-hr rest between each session. Each participant performed half-squat familiarization exercises in the first session, a 1RM half-squat test in the second session, and a sled-towing test in the third session. During the familiarization session the participants performed several submaximal and maximal half-squats in a Smith machine that had linear bearings on two vertical bars which allowed only vertical movement (Multipower; Salter, Barcelona, Spain). The participants had to descend to the point where the tops of their thighs were parallel to the floor, and then ascend as fast as possible so as to reach full knee and hip extension.

During the second session the participant completed a five minute warm-up on a stationary bike at a standardized resistance (50 W) and a cadence of 70 rpm (McBride et al., 2005). They then performed one set of 5–10 repetitions of the half-squat with a light load (about 40–60% of their expected 1RM) and one set of 2–3 repetitions with a moderate load (about 60–80% of their expected 1RM). For the 1RM test the participant performed 4–5 separate half-squat attempts with increasing weight, with each attempt separated by a three minute rest period to reduce the effects of fatigue on performance (Thomas et al., 2007). The greatest successful performance was taken as the participant's one-repetition maximum and this value was normalized for body size by dividing by the participant's body mass to the power of two-thirds (Åstrand et al., 2003; Jaric et al., 2005). The participant's body mass was measured using electronic weighing scales and recorded to the nearest 0.1 kg.

The sprint trials and sled-towing trials during the third session were 20-m sprints at maximum intensity from a standing start. Three timing gates (Newtest Powertimer 300; Newtest, Tyrnävä, Finland) with a time resolution of 0.001 s were placed at 0 m, 10 m, and 20 m. The participants commenced from a line 2 m behind the first gate so as to avoid early breaking of the beam of the first gate. The participant's 10-m and 20-m sprint times were taken as the elapsed time obtained from the relevant gates. The sprint trials and sled-towing trials were conducted on a Mondo Sportflex Impronta athletics track (Mondo, Alba, Italy) in still air conditions in an outdoor athletics stadium. For the sled-towing trials a weighted sled (Byomedic, Barcelona, Spain) was attached to the participant by a 2.7 m cord and waist harness. The 2.6 kg sled travelled on a flat base about 0.4 m long and 0.3 m wide, and the coefficient of friction of the sled when sliding on the running surface was 0.29.

Before performing the sprint and sled-towing tests the participants completed a standardized warm-up routine consisting of four minutes of running with a heart rate of 140 bpm, six minutes of active stretching and running technique exercises, two submaximal short sprints, and two submaximal sprints when towing a sled loaded to 5% of the participant's body weight. The participants then performed seven 20-m sprints (one unloaded sprint and six sled-towing sprints). For the loaded sled-towing trials, weights were added to the sled to give a total weight as a desired percentage of the participant's body weight (about 5%, 10%, 15%, 20%, 25%, and 30% body weight). The participants performed one trial at each condition. A rest period of about five minutes was given between trials to minimize the effects of fatigue on sprint performance (Harris et al., 1976).

Analysis

For the sprint and sled-towing tests the participant's unloaded and loaded times were plotted against the weight of the sled (expressed as a fraction of the participant's body weight), and the gradient of the line of best fit was taken as the rate of increase in sled-towing time (in seconds per body weight) for the participant. The participant's 10- and 20-m times were analyzed separately, thus giving two values for the rate of increase in sled-towing time for each participant. For the 10-m and 20-m times by the 22 participants, the magnitude of the inter-athlete variation in the rate of increase in time was quantified by calculating the coefficient of variation of the mean rate of increase in time.

This study examined the correlations between selected strength, sprinting, sled-towing, and athlete variables. All variables were screened for homogeneity of variance, multivariate and univariate outliers, and normality. To address the main aim of the study, we examined the correlation between the rate of increase in sled-towing time (over 10 m and 20 m) and normalized 1RM half-squat performance. In addition, we compared our participants to those used in previous correlation studies of sprinting and squatting by examining the correlations between: a) absolute 1RM half-squat performance and body weight (we expected a strong positive correlation); b) unloaded 20-m sprint time and absolute 1RM half-squat performance (we expected a strong negative correlation); and c) unloaded 20-m sprint time and normalized 1RM half-squat performance (we expected a strong negative correlation) (Dooman & Vanderburgh, 2000; Jaric et al., 2005; Markovic & Jaric, 2004; Wisløff et al., 2004).

The direction and strength of the linear dependence between two variables was calculated using the Pearson product-moment correlation coefficient (*r*). According to Cohen (1988) an *r* value that is close to zero is a 'negligible' correlation and the threshold *r* values for 'weak', 'moderate', 'strong', and 'very strong' correlations are ±0.1, 0.3, 0.5, and 0.7, respectively. The 90% confidence limits of the correlation coefficient were calculated using the Fisher *z* transformation. We used 90% confidence limits because the chances that the true value of the correlation coefficient lies below the lower limit or above the upper limit are both 5%, which can be interpreted as very unlikely (Batterham & Hopkins, 2006). However, with a sample size of 22 the 90% confidence interval of a correlation coefficient is about ±0.35. That is, in the present study we were not able to reliably distinguish between the divisions in the correlation coefficient that were proposed by Cohen. Instead, we designated the correlation coefficient as 'unclear' if the 90% confidence limits of the correlation coefficient spanned both weak negative and weak positive values, and otherwise the magnitude of the correlation coefficient was taken as the observed value (Fisher, 1921; Harris et al., 2008). Therefore, in this study a correlation coefficient was only considered to be 'clear' if it was less than –0.27 or greater than +0.27.

RESULTS

All variables exhibited homogeneity of variance. There were no multivariate outliers or univariate outliers and none of the variables exhibited excessive skewness or kurtosis. The mean 1RM half-squat performance of the participants was 160 ± 22 kg (mean ± *SD*) and the mean 10-m and 20-m unloaded sprint times were 1.62 ± 0.05 s and 2.87 ± 0.09 s, respectively. There were substantial differences between the participants in the rate of increase in sled-towing time with increasing sled weight (Figure 1). The coefficients of variation for the rate of increase in time were 21% and 17% for the 10-m and 20-m times respectively.

We did not observe a strong negative correlation between the rate of increase in sled-towing time and normalized 1RM half-squat performance (Figure 2). The correlation was unclear for sled-towing times over both 10 m (*r* = –0.11; 90% confidence interval –0.45 to 0.26) and 20 m (*r* = –0.02; –0.38 to 0.34).

(a)

(b)

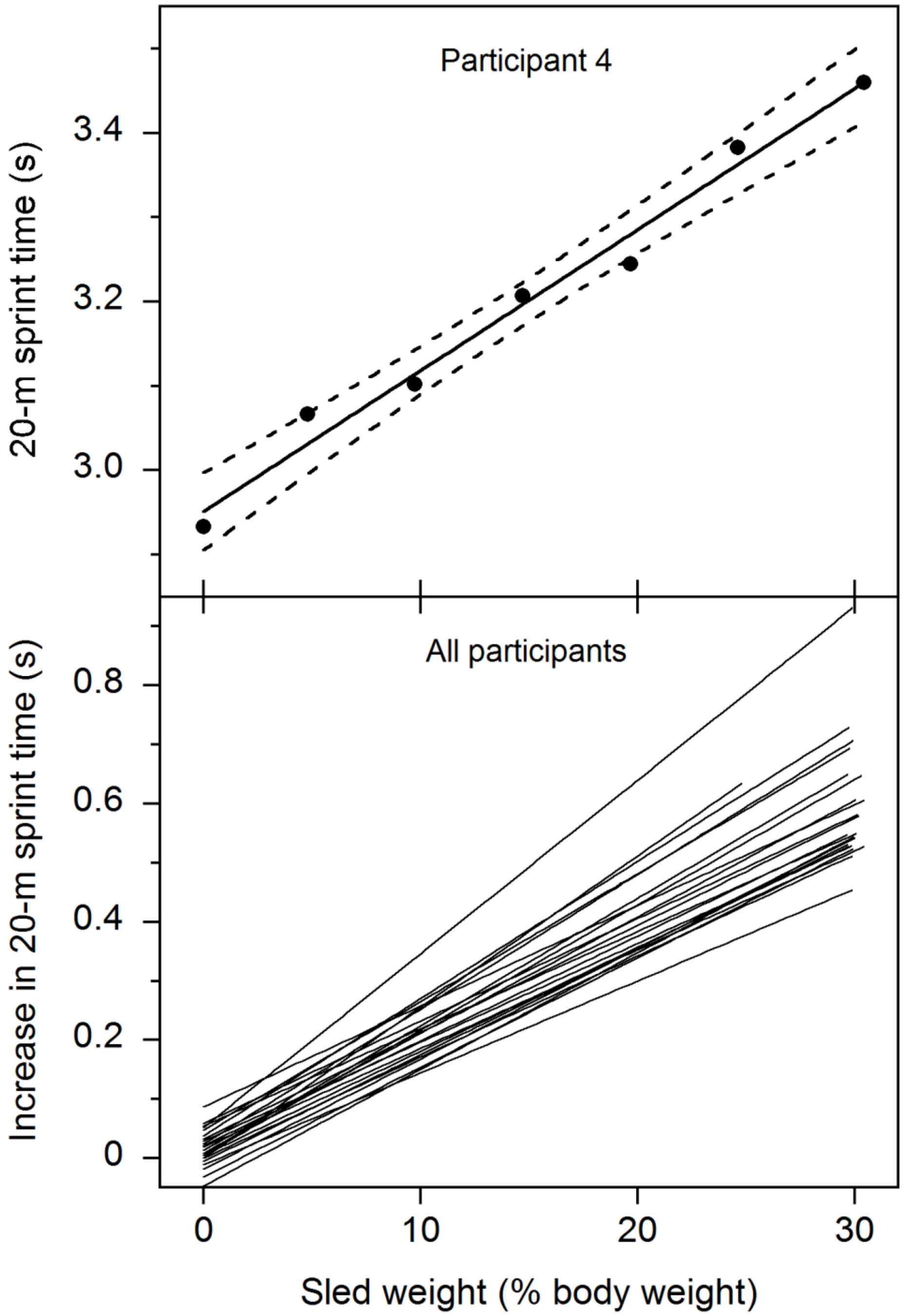

Figure 1. Plot (a) shows the linear increase in 20-m sled-towing time with increasing sled weight for a male athlete (Participant 4). The solid line is a regression curve and the dashed lines indicate the 95% confidence limits. The gradient of the line of best fit gives the rate of increase in time for this athlete. Plot (b) shows that there were substantial differences in the rate of increase in 20-m sled-towing time with increasing sled weight within this group of male athletes. Only the regression curves for each of the 22 athletes are shown; data points have been omitted for clarity.

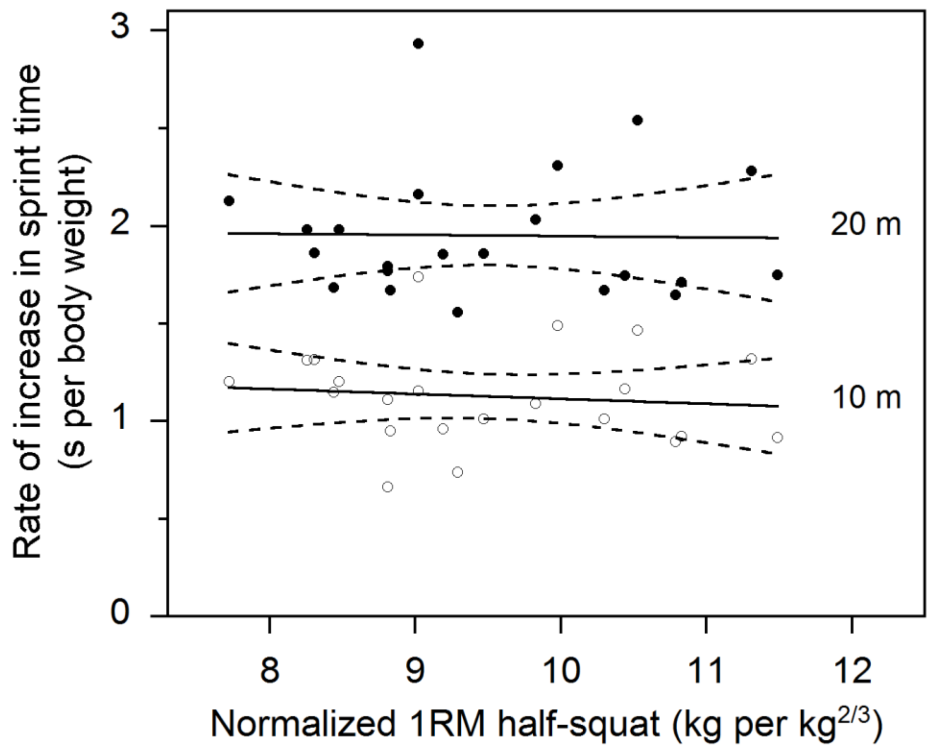

Figure 2. This plot shows the lack of relationship between the rate of increase in 10-m and 20-m sled-towing time with increasing sled weight and normalized 1RM half-squat performance. Data for 22 male athletes. The solid line is a linear regression curve and the dashed lines indicate the 95% confidence limits.

We observed a clear strong positive correlation between absolute 1RM half-squat performance and body weight (r = 0.57; 0.27 to 0.77), and a clear moderate negative correlation between unloaded 20-m sprint time and absolute 1RM half-squat performance (r = –0.37; –0.65 to –0.02). However, we observed a weak negative correlation between unloaded 20-m sprint time and normalized 1RM half-squat performance (r = –0.28; –0.58 to 0.09).

Similar results were obtained when the track and field athletes and soccer players were analyzed as separate groups, although the confidence intervals in the correlation coefficients were greater due to the reduced number of participants in the groups.

DISCUSSION

As expected, we found substantial inter-athlete differences in the rate of increase in sled-towing time with increasing sled weight among a group of male track and field athletes and soccer players. However, for this group there was no clear correlation between the rate of increase in sled-towing time with increasing sled weight and normalized 1RM half-squat performance. This result indicates that inter-athlete differences in the rate of increase in sled-towing time with increasing sled weight are not likely to be due to differences in strength-to-weight ratio.

The athlete's 1RM half-squat performances and unloaded 10-m and 20-m sprint times in the present study were similar to those in other studies of male athletes (Baker & Nance, 1999; Martínez-Valencia et al., 2013; Sleivert & Taingahue, 2004; Wisløff et al., 2004). Likewise, the strength of the correlations between half-squat performance, unloaded sprint time, and body weight in this study were mostly similar to those in other studies of male athletes (Jaric et al., 2005; Markovic & Jaric, 2004; Sleivert & Taingahue, 2004). These similarities suggest that the result from the present study regarding the lack of a relationship between the rate of increase in time in a sled-towing exercise and normalized 1RM half-squat performance would also be observed in other groups of trained male athletes.

For this study, our initial assumption was that when sled weight is normalized for body weight, athletes who possess a greater than average strength-to-weight ratio will have a lower relative stress placed on their sprint capabilities and so produce a faster sled-towing time than would otherwise be expected. Therefore, athletes with a greater strength-to-weight ratio were expected to have a lesser rate of increase in sled-towing time with increasing (normalized) sled weight. This argument assumes that there is a strong negative relationship between an athlete's sprint time and their strength-to-weight ratio. Such a relationship has been found in many previous studies of sprinting. For example, Dowson et al. (1998) found a strong negative correlation between sprint time and normalized isokinetic knee extension and flexion torque, and McBride et al. (2009) found a strong negative correlation between sprint time and normalized full-squat performance. However, for the athletes in our study there was only a weak negative correlation between unloaded 20-m sprint time and normalized 1RM half-squat performance. That is, our data suggest that an athlete's time in a short sprint is not strongly determined by their strength-to-weight ratio. The lack of correlation that we observed between the rate of increase in sled-towing time and normalized 1RM half-squat performance (Figure 2) is consistent with the weak correlation that we observed between unloaded sprint time and normalized 1RM half-squat performance.

CONCLUSIONS

Within the group of male athletes examined in the present study, the athlete's time in a sled-towing exercise increased in proportion to the weight of the sled and the athletes had substantial differences in their rate of increase in sled-towing time. The athlete's rate of increase in time with increasing sled weight was not correlated with their normalized 1RM half-squat performance. These results indicate that inter-athlete differences in the rate of increase in time in a sled-towing exercise are not due to differences in the athlete's strength-to-weight ratio. However, a previous study found a strong correlation between power-to-weight ratio and the rate of increase in time in a sled-towing exercise (Martínez-Valencia et al., 2013). Presumably, in the present study the observed differences in the rate of increase in time were mostly due to inter-athlete differences in power-to-weight ratio. Therefore, when setting the intensity of the exercise for an athlete, the weight of the sled should be scaled according to the athlete's power-to-weight ratio (using measures such as jump height in a countermovement jump), rather than scaled according to the athlete's body weight or strength-to-weight ratio.

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