Title

Sled-push load-velocity profiling and implications for sprint training prescription in young athletes.

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Abstract

Resisted sled pushing is a popular method of sprint-specific training; however, little evidence exists to support the prescription of resistive loads in young athletes. The purpose of this study was to determine the reliability and linearity of the force-velocity relationship during sled pushing, as well as the amount of between-athlete variation in the load required to cause a decrement in maximal velocity (Vdec) of 25, 50 and 75%. Ninety (n=90) high school, male athletes (age 16.9 ± 0.9 years) were recruited for the study. All participants performed one un-resisted and three sled-push sprints with increasing resistance. Maximal velocity was measured with a radar gun during each sprint and the load-velocity relationship established for each participant. A subset of 16 participants examined the reliability of sled pushing on three separate occasions. For all individual participants, the load-velocity relationship was highly linear ($r > 0.96$). The slope of the load-velocity relationship was found to be reliable (CV = 3.1%), with the loads that cause a decrement in velocity of 25, 50 and 75% also found to be reliable (CVs = <5%). However, there was large between-participant variation (95%CI) in the load that caused a given Vdec, with loads of 23-42% body mass (%BM) causing a Vdec of 25%, 45-85%BM causing a Vdec of 50% and 69-131%BM causing a Vdec of 75%. The Vdec method can be reliably used to prescribe sled-push loads in young athletes, but practitioners should be aware that the load required to cause a given Vdec is highly individualized.

Key Words

Resisted sprinting, acceleration, horizontal strength training.

INTRODUCTION

Sprint-specific training can be defined as training that is specific to the movement patterns and direction of sprinting. It is likely to be more successful than non-specific training such as traditional resistance training in improving speed (14, 29). Popular methods of sprint-specific training include adding a resistive stimulus to movement in a horizontal plane of motion, commonly referred to as resisted sprinting. Research has examined different forms of resisted sprinting such as weighted vests and belts (5, 7), parachutes (2) and pulley systems (18). However, sled sprinting is the most commonly researched form of resisted sprinting (3, 24) and reflects a form of sprint-specific training that has been shown to improve sprinting performance (12, 17, 22, 30). The usefulness of sled sprinting as a form of sprint-specific training is likely due to the ability to target distinct bands of horizontal force and velocity output by manipulating loading (6, 16, 20, 23).

In practice two commonly used methods of resisted sled sprinting are sled pulling and pushing. Sled pulling has been more commonly researched across various loads and distances, with a recent review by Petrakos et al. (24) identifying 11 studies that had examined sled pulling. In contrast there is very limited research available on the acute or longitudinal effects of sled pushing on sprint performance. Waller et al. (33) reported a greater increase in the blood lactate response during loaded sled push conditions over un-resisted sprints, while Seitz et al. (30) reported that resisted sled push sprints provided a post-activation potentiation response in a subsequent 20 m sprint. To the authors knowledge these are the only two published studies to examine sled pushing. However, sled pushing has not been examined in youth populations. Research has determined the reliability and the linearity of the load-velocity profile in sled pulling (8, 10) and the response of different populations to sled pulling (2, 29). Research by Rumpf et al. (27) demonstrated that mature boys benefited more than immature boys from a resisted sled pull training intervention to enhance sprint capability. However, little is known about the efficacy of resisted sled sprinting as a mode of training at heavier loads in young athletes and no such information exists for sled pushing.

In general, sled pushing is often perceived as a similar method of training to sled pulling. However, differences in force application point (i.e. ‘pushing point) and sled characteristics (size, shape, friction) could in turn lead to alterations in sprint kinematics, kinetics and desired training outcomes when comparing pushing to pulling. For example, if the aim is to train at light loads that don’t change technical markers from unloaded sprinting (1, 19), it is likely on most surfaces the base weight of a sled pushing apparatus may exceed that necessary for the aim. Additionally, the anterior position of a push sled and use of the arms would will alter sprint mechanics significantly, irrespective of loading differences in sled pulling. Lighter loads of <10% body mass have been suggested to still allow for technical training during sled pulling (19). However, the mechanics of sled pushing, specifically the arms, mean that it should not be considered a technical exercise but rather reflecting the use of sled sprinting as a specialized form of horizontal resistance training. More recently, heavier loads have been studied in both sled pushing (30) and pulling (22, 23) suggesting greater improvements in acceleration than lighter loads previously studied.

An inverse linear relationship between load and velocity has been confirmed in sled pulling, and it has been suggested that selecting load based on its decrement in velocity (Vdec) could be valuable in training prescription (3, 8). Using such an approach, Cross et al. (8) demonstrated that a Vdec of 50% corresponds to a stimulus associated with peak power production during sled pulling, and that the optimal load that causes this level of Vdec within a power zone of training varies considerably across athletes. This variability may also exist to a greater extent in young athletes due to differences in maturity, size and strength. Resisted sled sprinting has been shown to acutely impede immature boys 50% more than mature when load is prescribed as a % of body mass (26). Therefore, adopting the Vdec method could standardize the training stimulus across a group of young athletes to account for the variability that may exist and the limitations of using % body mass alone to prescribe sled loading. Building on the work of Cross et al. (8), a recent review suggested different percentages of Vdec may represent alternative training zones such as speed-strength (<35% Vdec) or strength-speed qualities (>65%Vdec) respectively (3). Given the linearity of the load-velocity relationship observed during sled pulling, it is hypothesized that the Vdec approach can also be applied to sled pushing to provide novel insight regarding training prescription during sled pushing. Therefore, the aims of the study are to examine the reliability, linearity and the amount of between-athlete variation associated with the Vdec approach to prescribe training loads during sled pushing in youth athletes.

METHODS

Experimental Approach to the Problem

To determine the load-velocity relationship of un-resisted sprinting and sled pushing, a group of young athletes (n = 90) performed one un-resisted and three resisted sprints recorded over 30 m and 20 m respectively, at increasing loads during a familiarization session and then again during a data collection session. A subset of participants (n = 16) repeated the protocol on three separate occasions separated by seven days to assess reliability of the method. Resisted sprints were completed with a range of loads to allow the load-velocity relationship to be modelled. The maximum velocity attained (Vmax) during each sprint was measured via radar gun. Using Vmax, individual load-velocity relationships were then established for each subject and used to identify the loads that corresponded to a decrement in velocity of 25, 50 and 75% within speed-strength, power and strength-speed zones respectively.

Subjects

Ninety male high school team sport athletes (16.9 ± 0.9 years; height, 1.77 ± 7.5 cm; weight, 75.7 ± 12.3 kg; and Vmax; 7.71 ± 0.57 m/s) from three sports; rugby, baseball and lacrosse, were recruited to participate in this study. All subjects biological maturity was established as post peak height velocity (PHV) using a non-invasive method of calculating the age at PHV according to Mirwald et al. (21). All subjects had a minimum of one-year resistance training experience and were healthy and injury free at the time of testing. Written consent was obtained from a parent/guardian and assent from each subject before participation. All risks and benefits of the study were explained prior to data collection. Experimental procedures were approved by West Chester University institutional ethics committee.

Procedures

All subjects reported one week prior to the first data collection, where they were familiarized with the equipment and sprint protocol. Testing procedures were completed in dry conditions on an outdoor 4G artificial turf field with sprint lanes set-up at a cross wind. A randomized counter balance design was implemented on each test day. Subjects were required to abstain from high intensity training in the 24 hours prior to the testing session. Subjects wore running shoes and comfortable clothing. A radar device (Model: Stalker ATS II, Applied Concepts, Dallas, TX, USA) was positioned 10 m directly behind the starting position and at a vertical height of 1 m to approximately align with the subject's center of mass as per the recommendation of Simperingham et al. (31). The radar gun has been validated in human subjects against photocell timing gates at each 10m split within a 100m sprint trial (r^2=0.99) (11).

Subjects started from a standing split stance position and sprinted in a straight line for 30 m with maximal effort for un-resisted efforts and 20 m for resisted efforts. Distances were estimated from pilot testing to ensure Vmax was achieved without inducing additional fatigue. In all sessions, subjects performed a standardized dynamic warm up and two submaximal effort sprints (70% and 90% of self-determined maximal intensity) before maximal effort. A minimum of four minutes of passive recovery was given between each trial (un-resisted and resisted). Maximum velocity was gathered from the radar gun for all sprints. Software provided by the radar device manufacturer (STATs software, Stalker ATS II Version 5.0.2.1, Applied Concepts Dallas, TX, USA) was used to collect raw velocity data throughout each trial.

Un-resisted sprinting protocol. Subjects were instructed to approach the start line and stand in a split stance with their preferred foot to jump off in front and kicking dominant foot behind.

Subjects were instructed to sprint through a set of cones placed at 32 m to ensure maximal effort and achievement of maximal velocity during recorded 30m sprint.

Insert figure 1 near here

Resisted sled pushing protocol. Subjects received the same set up and instructions as per the un-resisted sprints. A custom-made push sled was placed in front of the start line, between the 0-1 m marks. Subjects were instructed to place their hands at hip height on the vertical poles and lean in towards the sled with elbows bent to a minimum of 90 degrees. Starting stance did not change from un-resisted sprints but subjects were reminded to push off the front foot and not to lift the sled base off the ground. Subjects were instructed to sprint through a set of cones placed at 22 m to ensure maximal effort during the 20m recorded resisted sprints. The first resisted trial used was the 27 kg weight of the unloaded push-sled. Two additional loads increasing in increments of 20% body mass were then performed. Pilot testing was carried out to determine the range of loads that reduced an athlete's velocity by values above and below 50% of un-resisted Vmax and would allow individual load-velocity relationships to be calculated.

Load-velocity relationship and load optimization

Vmax was obtained for each un-resisted and resisted trial. The individual load-velocity (LV) relationship was established for each participant and checked for linearity. The linear regression of the load-velocity relationship was then used to establish the load that corresponded to a velocity decrement of 25% (L_{25}), 50% (L_{50}) and 75% (L_{75}), with the slope of the line explaining the relationship between load and velocity. An example of this is illustrated in figure 2.

Insert figure 2 near here

Statistical Analysis

Raw data was filtered through custom made LabVIEW software to determine the maximum velocity of each trial. Means and standard deviations (SD) for Vmax, were used to represent the centrality and spread of the data. In the smaller subset of participants ($n = 16$), reliability of Vmax, L_{25}, L_{50} and L_{75} were examined by calculating the change in the mean to examine systematic bias. Random variation was then investigated by establishing the relative reliability using an intraclass correlation coefficient (ICC(2,1)) and absolute reliability using the coefficient of variation. Between-day pairwise analysis of reliability was assessed using an online excel spreadsheet (13). Simperingham et al. (31) have suggested acceptable thresholds for establishing the reliability of a radar to measure sprints as a CV < 10% and ICC > 0.70. The load-velocity relationship of young athletes was described using statistics from the larger sample ($n = 90$). The strength of linearity of the load-velocity relationship was assessed for each participant and a repeated measures ANOVA with Bonferroni post-hoc test used to confirm whether significant differences in Vmax occurred with increased loading. The alpha level was set as $p < 0.05$ with analysis performed in SPSS (version 23.0). The mean load across all participants at each Vdec was calculated and between subject-variability expressed using 95% confidence intervals. To examine factors that contributed to variability in the load that caused a given decrement in velocity, individual %BM loads at L_{50} were correlated against body mass, maturity, strength (deadlift 1RM), sport played and Vmax, F_0 and Pmax from an unresisted sprint. To further portion out the effect of body mass relationships were also examined with load at L_{50} allometrically scaled using an exponent of 0.67 (15).

RESULTS

Reliability

The reliability of the variables of interest for the sled push in a subset of sixteen participants can be observed in Table 1. No consistent pattern of change in the mean was evident across Vmax, L_{25}, L_{50} and L_{75} or the slope of the LV relationship across the different trials. The CV for Vmax and the slope of the LV relationship was consistently < 10%, while for L_{25}, L_{50} and L_{75} it was always ≤ 5%. The majority of ICCs were within acceptable ranges for Vmax, L_{25}, L_{50} and L_{75} and the slope of the LV, with relationships ranging from 0.68 to 0.91. When L_{25}, L_{50} and L_{75} was expressed in absolute load (kg), extremely high relative reliability (ICC ≥0.99) was observed.

Insert Table 1 near here

Load-velocity profiling

Load velocity profiles ware established on all participants within the study (n=90). In the large population of young athletes, the average Vmax achieved in un-resisted sprinting and with mean loads of 37 ± 4 %BM, 57 ± 7 %BM, and 77 ± 11 %BM of body mass were 7.7 ± 1.05 m/s, 5.06 ± 0.76 m/s, 4.30 ± 0.65 m/s and 3.53 ± 0.57 m/s respectively. Analysis revealed that Vmax significantly decreased with each incremental increase in load ($p < 0.001$). For all subjects the load-velocity relationship was highly linear (r > 0.96), as was the case for the mean data across the group ($r = 0.99$). The mean load-velocity profile together with loads that correspond to a Vdec of 25, 50 and 75% for the entire group can be observed in Figure 3. Based on the individual load-velocity relationships the load that corresponded to a Vdec of 25, 50 and 75% (95% CI) were 33 (23-42) %BM, 66 (45-85) %BM and 100 (69-131) %BM.

Significant relationships (all p < 0.05) were found between the %BM load at L_{50} and body mass (r = -0.60), maturity (r = -0.49), F_0 (r = -0.36), Pmax (r = -0.30), sport played (r = -0.30) and the deadlift 1RM (r = -0.24), leaving only Vmax as a non-significant predictor (r = 0.10, p > 0.05). However, when load was allometrically scaled only sport played (r = -0.27, p < 0.05) and maturity (r = -0.23, p< 0.05) remained as significant predictors, with all other variables reporting correlations of r ≤ 0.09 (p>0.05).

Insert Figure 3 near here

DISCUSSION

This is the first study to examine load velocity profiles in sled pushing in any population. The underlying rationale for the study was to confirm the linearity of the load-velocity profile and examine the reliability and between-athlete variation associated with prescribing loads for specific training zones. The load velocity relationship was found to be reliable and highly linear for all participants, and loads could be reliably optimized at a given decrement in velocity to target specific training zones. The current study found a large degree of variability between young athletes performing a sled push; a Vdec of 50% (L_{50}) resulted in a confidence interval for load ranging 45-85 % body mass. This suggests the load required to provide a consistent power training stimulus almost doubles between participants who tolerate load the least to those who tolerate load the most in a youth population, a finding that was consistent across all training zones. This highlights the need for individual prescription based off Vdec rather than % body mass for all individuals.

Multiple studies have found un-resisted sprinting using a radar gun to be valid and reliable in adult and youth populations (4, 11, 31). However, there is limited research examining the reliability measurements of the radar gun during resisted sprinting, especially in youth populations. This is the first study to assess the reliability of the load velocity profile of sprint performance in a youth population. The current study found all variables of interest, for both un-resisted and resisted conditions, in young athletes to be reliable. There was no systematic change over time, given the low percent changes in the mean between testing occasions across the loads assessed. High reliability was demonstrated for Vmax, L_{25}, L_{50} and L_{75}. The high degree of reliability expressed for loading prescription within specific zones and the consistency of the LV profile in this study are underpinned by the reliability found in the slope of the individual load velocity relationships, which agrees with previous research on resisted sled pulling (8, 25). All CVs were found to be within an acceptable range of <10% for the three outcome variables of interest across all loads indicating acceptable reliability. L_{25}, L_{50} and L_{75} the variables of most interest for prescription of loads corresponding to different zones of training, was found to be the most reliable variable with CVs <5%. ICC values for Vmax, L_{25}, L_{50}, L_{75} and the slope of the LV relationship were all within acceptable ranges of >0.70 except for one (0.68). Consequently, practitioners can reliably identify specific decrements in velocity to suit the needs of each athlete. A recent study by (9) concluded that the response to resisted sled pulling may be dependent on pre-training force-velocity characteristics. Therefore, prescription of training loads could be individualized to cater for force or velocity dominant athletes which could result in better sprint training results compared to assigning the same resistive load to the group. Several studies (26, 27, 29) have demonstrated the benefits of resisted sprinting to young athletes but also highlighted the variability and limitations that exist when using prescription of load based of % body mass. Although the Vdec method can standardize the load across a group, further research is needed to determine the effect sled loading has on the maturation status of young athletes. This will allow coaches and practitioners to better determine how loads can be optimized to ensure enhanced sprint performance throughout adolescence.

While the linear L-V relationship has been confirmed for sled pulling (8, 10), this is the first study to confirm that the same is the case for sled pushing. The loads used in the present study of 33, 66 and 100 % body mass are far greater than the majority of the research available in resisted sled pulling (3, 24). However, the validity of the method used within the current study is supported by the reliability and linearity of the load velocity relationship; all participants demonstrated a highly linear profile ($r \geq 0.96$). Adopting the Vdec method will allow practitioners to identify different training zones during resisted sled pushing, such as speed-strength (L_{25}), power (L_{50}) and strength-speed (L_{75}) (3). Matching the training zone to the athlete's force-velocity characteristic could potentially yield better training results than simply applying the same resistive load for all athletes (9). For example, examining adult participants, Cross. et al. (8) reported that a load of 69-96% body mass was required to cause a Vdec of 50% and optimize power production. Those findings suggest the amount of load required to cause the same training stimulus increases by ~50% from athletes who tolerate load the least to those who tolerate load the best. What the results also highlight is that the common practice of simply prescribing all athletes the same relative training load (i.e. a set %BM) could potentially induce different training stimuli across a cohort of athletes, with some athletes only slowed a little and others slowed substantially more. Adopting the approach of using the linear load-velocity relationship to prescribe load based on a target Vdec allows the coach to choose a specific load to ensure all athletes are exposed to a specific training stimulus.

Expressing load at L_{50} at a %BM resulted in a number of significant correlations, however, these relationships were largely driven by the effects of body mass. Expressing load as %BM uses a ratio scale method, and during forceful or powerful methods such an approach will likely advantage lighter individuals (15, 32). This was demonstrated in the present study by the negative relationship between body mass and load, with a significant relationship demonstrating that using a ratio scale did not meet the assumption of producing a performance measure independent of body mass (32). When load at L_{50} was allometrically scaled the relationship with body mass became non-significant, as did relationships with strength, force and power, variables all influenced by mass. Only sport played and maturity remained as significant, but weak predictors of load. Sport played may reflect either a selection or training effect, with participants from some sports better able to tolerate load during resisted sprinting. The fact maturity still had a negative relationship with allometrically scaled load is surprising but may reflect the need to account for other maturity and size related factors, such as fat free mass. Currently, little is known about the individual factors that determine the ability of young athletes to tolerate load during sled pushing, with more research needed.

Given the lack of empirical evidence on sled pushing and flaws within prescription of load as % body mass alone, it is hard to draw comparison to other studies. Caution must be used when comparing sled pushing and sled pulling, as although both are forms of resisted sprinting, they may offer different training stimuli. Push sleds are typically bigger in size, have a larger surface area and are likely to increase the athletes Vdec more due to the increased coefficient of friction between the sled base and surface from the placement of the arms onto the vertically aligned poles. The anterior and posterior orientation of the sled may also influence the activation of specific muscle groups. Also given the limited research available on resisted sprinting in youth athletes, it is important to factor in the participant's maturity, mass and strength as they have been shown to impact the extent of variation within a population (28). Utilizing the same Vdec approach as Cross et al. (8), the current study demonstrated between athlete variability in sled pushing is approximately two-fold higher compared to sled pulling in adult populations although it is important to note various differences in training history, sled apparatus' and experience exist. Therefore, more research is needed to examine the acute and chronic effects of sled pushing on sprint performance in young athletes.

In conclusion, the findings of the current study confirm our hypothesis that the load-velocity relationship is linear during sled pushing in young athlete's. The slope and Vdec approach to sled pushing load prescription were found to be reliable also. However, the load associated with a given Vdec varies considerably across young athletes.

PRACTICAL APPLICATIONS

Given the high linearity and reliability across all variables of interest, practitioners should establish individual load velocity profiles to prescribe sled push loads for young athletes using the Vdec method. Loads corresponding to Vdec thresholds of 25, 50 and 75% can reliably identify and reflect speed, power and strength training zones to specifically target desired adaptations or cater for individual athlete characteristics. Large between athlete variations exist, thus practitioners must be aware that young athletes can vary considerably in the amount of loading required to cause a given Vdec. This reinforces the need to utilize the load-velocity method to individualize the training stimulus across young athletes during sled pushing.

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Figure Legend

Figure 1. An example of an athletes starting stance using a custom-made sled push during resisted trials.

Figure 2. An example of the load-velocity relationship for one subject. The raw data (▲) shows the Vmax collected during resisted and un-resisted sprints. Using the linear relationship between load and velocity the plotted Vdec (■) shows the calculated loads to cause a 25, 50, and 75% decrement in velocity.

Figure 3. The linear mean load-velocity relationship of a group of n = 90 youth athletes with the loads corresponding to a Vdec of 25, 50 and 75% representing speed-strength, power and strength-speed training zones.

Table Legend

Table 1. The reliability of maximal velocity (Vmax), the loads corresponding to velocity decrements of 25, 50 and 75% and the slope of the load – velocity relationship during resisted sled pushing for a subset of sixteen participants. Results are shown as mean ± sd and reliability statistics (95% CI).