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THE EFFECTS OF REPEATED PUSH SLED SPRINTS ON BLOOD LACTATE, HEART RATE RECOVERY AND SPRINT TIMES

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ABSTRACT
Resisted sprinting devices have been examined for their effect on sprinting but there is limited research on sled pushing thus leaving a gap in the literature related to this topic. The current study examined the effects of varied push sled loads during repeated sprinting on blood lactate levels, heart rate recovery, and sprint times. Division II female power athletes (softball n = 5, volleyball n = 9), age 19.93 ± .83 years, body mass 70.71 ± 5.39 kg, height 170.29 ± 6.41 cm, and body fat 17.47 ± .04 %, participated in a randomized, repeated measures study. Subjects were randomly assigned to a traditional sprint condition (SPR), sprints pushing an unloaded sled (SLED), along with the following loads of 10 kg, 15 kg, 20 kg, 35 kg, 50 kg and completed each condition over a 7 week period with testing occurring once a week at the same time of day. For each condition, subjects performed 6 sprints over 20 yds with a 35 second passive recovery between each sprint with split times and total times measured. Blood lactate was obtained by a finger prick and was analyzed by a portable lactate analyzer (Accutrend® Lactate) at rest prior to the repeat sprint trials, 3 minutes and 5 minutes post intervals. The results demonstrated statistically significant differences in all mean sprint times and in peak sprint times except in 10 kg and 15 kg conditions. Statistically significant differences were observed in BLA3MIN and BLA5MIN in sprint conditions ≥ 15 kg. The results suggest that repeated push sled sprints ≥ 15 kg load may be beneficial to adapting the fast glycolytic system.

Keywords: Lactate, On-set blood lactate accumulation, Heart rate, Sprint, Recovery.

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Contribution/ Originality

This study is one of very few studies which have investigated the acute effects of sprinting with pushing a sled of varying loads in female athletes.

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1. INTRODUCTION

Training with sleds has been utilized and recommended for the improvement of skill execution, energy systems and sprinting performance for sports (Hoffman and Hamilton, 2002; Pollitt, 2003.; Cronin and Hansen, 2006; Behrens and Simonson, 2011). There are a number of variables that influence sled towing which has been discussed in previous literature such as load application, sprinting kinematics, sled pulling kinetics, and sports performance (Lockie *et al.*, 2003; Alcaraz *et al.*, 2008; Alcaraz *et al.*, 2009; Andre *et al.*, 2013).

Sleds and other resisted sprinting devices have been examined for their effect on sprinting kinetics and kinematics, but there is limited research on sled pushing thus leaving a gap in the literature related to this topic. Sled pushing drills have been promoted for their use in strength and conditioning (SC) plans to potentially improve sprinting or fast glycolysis performance. However, the only study to examine pushing an object is by Berning *et al.* (2007) which utilized a motor vehicle similar to what may be seen in a strongman competition. Berning *et al.* (2007) demonstrated blood lactate accumulation (BLA) levels of 15.0 ± 2.0 mmol·L^{-1} at 5 min post vehicle pushing with an accumulative distance of 400 m. The BLA levels are indicative of the fast glycolytic system being dominant during vehicle pushing events. The load of the vehicle however is problematic in SC as it far exceeds the loads suggested by Alcaraz *et al.* (2009) that have a positive impact on sprint performance. In regards to applying sled pulling data to the loads of the push sled used in the current study the majority are far less than those used by Berning *et al.* (2007) which would alter the sprint kinematics. Although sprint kinematics may be negatively impacted from pulling loads greater than 30% of body mass, the use of a push sled needs further investigation in the alterations pushing a sled has on sprint kinematics. The type of resisted pulling device that is used can effect sprint kinematics at different phases of a sprint (Alcaraz *et al.*, 2008). Pushing a sled may further alter sprint kinematics by changing the application of force to the handles instead of a towing ring specific to pulling. Alcaraz *et al.* (2008) demonstrated a decrease in sprinting velocity (14 ± 2%) pulling a sled while the use of a parachute or weight belt caused no statistical difference to traditional sprint performance. The SC coach should not randomly choose a sled load as it applies to pulling a sled as a range from 10 to 16% of body mass is necessary to maintain sprint kinematics (Lockie *et al.*, 2003; Alcaraz *et al.*, 2008). This load, however may vary depending on the training level of the athlete, if sprint kinematics need to be maintained, if increasing leg strength is the goal or if energy system adaptation is the desired adaptation. Kinematic characteristics of heavy sled pulling to loads greater than 18% of body mass (total sled load of 171.2 kg) suggest the possible inclusion heavy sled pulls in strength and conditioning programs (Keogh *et al.*, 2010). These potential kinetic neuromuscular adaptations may further be complimented with the lighter loads for providing an overload to the bioenergetic systems. From a perspective of providing a stimulus to create adaptations to a specific bioenergetic system the pulling or pushing a loaded/unloaded sled may be an effective training method. For example, sports that require a high anaerobic demand to be successful during competition (e.g. soccer) may benefit from sled pushing drills that illicit similar blood lactate responses to that respective sport. The paucity of information that currently exists for sled pushing guidelines and the respective physiological responses require investigation for comparative use to its sled pulling counterpart. Therefore, the purpose of the current study is to examine the effects of repeated sled push sprinting of varying loads (weight) on blood lactate levels, heart rate recovery, and sprint times. It is hypothesized that the heaviest load on the push sled will have the highest blood lactate levels, highest heart rate recovery, and the greatest amount of time to complete the sprints. The results from the study may provide SC coaches with evidence based methodologies for utilizing the push sled in athletic preparation.

2. METHODS

Division II female power athletes (softball n = 5, volleyball n = 9), age 19.93 ± .83 years, body mass 70.71 ± 5.39 kg, height 170.29 ± 6.41 cm, and body fat 17.47 ± .04 %, participated in a randomized, repeated measures study. Each subject signed consent forms and provided verbal consent prior to participation in the study. These subjects were all engaged in a SC program for their respective sports and had experience utilizing a push sled for sprint or metabolic training of the lower extremities. Subjects were given a randomly designated number for assignment to a sprint condition order. The study was approved by the site university's institutional review board prior to data collection.

2.1. Procedures

Subjects were randomly assigned to a traditional sprint condition (SPR), sprints pushing a 29.5 kg sled (SLED), sprints pushing a sled with an additional 10 kg load (10KG), sprints pushing a sled with an additional 15 kg load (15KG), sprints pushing a sled with an additional 20 kg load (20KG), sprints pushing a sled with an additional 35 kg load (35KG), sprints pushing a sled with an additional 50 kg load (50KG). Subjects scheduled a weekly testing time that each attended at the same time for 7 consecutive weeks. Subjects performed their standard sport dynamic warm-up prior to each testing condition, which included walking lunges, locomotive drills (e.g. A-skips), and active range of motion drills which took approximately 10 minutes to complete. Prior to the dynamic warm-up, each of the subject's resting HR and BLA were obtained and recorded. All sprint times were measured by hand held electronic stop watch by the same tester throughout the study. The shortest time to complete the 20 yds sprint was retained as the peak sprint time while all sprints times were used to determine mean sprint time for all conditions. For each condition, subjects performed 6 sprints over 20 yds with a 35-second passive recovery between each sprint. Blood lactate was obtained by a finger prick via lancet, where a drop of blood was analyzed by a portable lactate analyzer (Accutrend® Lactate) while the subject was at rest prior to the repeat sprint trials, and at 3 minutes and 5 minutes post repeat sprint intervals. Heart rate was obtained using Polar™ heart rate telemetry at the same time intervals as blood lactate. All sprinting sessions were separated by 1 week to avoid neural and anaerobic fatiguing effects while controlling the testing sessions. See Table 1 for an outline of the procedures.

2.2. Statistical Analysis

A descriptive analysis and a 1-way repeated measures analysis of variance (ANOVA) was used followed by a Bonferroni post-hoc for all significant results. The independent variable was sprint condition (7 levels of sprinting with 6 utilizing a sled load) while the dependent variables were mean and peak sprint times, blood lactate accumulation and heart rate. Statistical significance was set at 0.05 and intraclass correlation coefficient (ICC) was used for assessment of consistency of the dependent variables between test trials. All statistical analysis was completed using a Statistical Package for Social Sciences (SPSS v20.0, IBM, Chicago IL).

3. RESULTS

Peak sprint times demonstrated a statistically significant differences between all trials with the exception of 10KG and 15KG sprint conditions, while mean sprint times demonstrated statistical significant differences between all trials (See Table 2). Table 3 shows there were statistical significant differences in BLA3MIN and BLA5MIN compared to baseline between sprint conditions 15KG and greater. Table 4 demonstrates that sprints performed while pushing a loaded sled have higher HR after the cessation of activity in comparison to SPR and SLED conditions.

4. DISCUSSION

This is the first study to examine the influence of varying loads on repeated sled push sprinting performance in female power dominant sports athletes. The heaviest sled load (total of 79.5 kg) demonstrated the highest blood lactate and heart rate levels at the 3 and 5 minutes post recovery supporting the research hypothesis that heaviest load on the push sled will create the highest values and the greatest amount of time to complete the sprints. Furthermore, the increased external loads via the sled had the greatest effect on the repeat sprint times but interestingly only demonstrated statistical significance on OBLA once loads were greater than 15KG condition. The results of the current study contributes to the literature on resisted sprint training that may be incorporated into a SC plan to potentially improve overall bioenergetic performance in female power athletes. A review by Cronin and Hansen (2006) on resisted sprint training suggests possible benefits to the acceleration phase in a linear sprint, but unfortunately there was an absence of discussion on pushing a sled for sprint training. Furthermore, other articles have only examined resisted pulling devices for improving peak sprint velocity or their impact on sprinting kinematics (Alcaraz *et al.*, 2008; Keogh *et al.*, 2010; Andre *et al.*, 2013; Kawamori *et al.*, 2014). Alcaraz *et al.* (2008) demonstrated resisted sprinting with a sled, parachute, and weighted belt altered average sprinting velocity, but only minor effects on joint angle velocity during sprinting. The current study observed an increase in sprint times as loads increased but in the absence of video recording a kinematic analysis of joint and segment angles is not possible. Future studies on pushing a sled should investigate further linear and joint angle kinematics for comparison to sled pulling sprints

A comparison to sled pulling would provide the SC coach with an increased clarity of why and when pushing a sled would be an effective SC method. Furthermore, SC coaches may assume that increasing loads on a push sled require the leg musculature to generate greater force to push a loaded sled while repeated sprints will result in higher lactate production to sustain muscular actions. The effects of the varying loads mimic a force-velocity curve demonstrating that as the load increases the velocity decreases as evident by the increased sprinting times (Figure 1). The increased sprint times and the greater muscular force required to push the loaded sled are the possible reason to the linear relationship observed between BLA and increasing sled loads in the current study. The authors make an assumption that the muscular actions of the leg musculature were under tension for a greater amount of time, had a greater amount of repeated muscular actions, and short interval rest periods, which placed an emphasis on the fast glycolytic system for continued muscular actions. Berning *et al.* (2007) observed that pushing vehicles as performed in strongman competitions reached BLA levels of 15.0 ± 2.0 mmol·L^{-1} after pushing a 1,960 kg vehicle 400 m in 6 strength trained subjects. In contrast to the current study that observed female power athletes reaching the highest BLA levels (11.89 ± 2.72 mmol·L^{-1}) at 3 min post with sled loads of 50KG and a total distance covered of 120 yds. This contrast is specific to the loads pushed that can allow the SC practitioner to use lighter loads, higher muscular action velocities, and less distance that may be conducive to overall SC planning. The increase in BLA from loads greater than 15KG may provide an ideal training stimulus for athletes who may benefit from enhancing their time to on-set of blood lactate accumulation (OBLA). However, the loads added to the sleds should not be arbitrarily determined but rather should consider the athletes' body mass and leg strength when determining the most effective load. Although further research is needed on assigning a more accurate load for sled pushing, athletes would benefit from being put into either groups of similar body masses and/or strength levels. A uniform load for an entire team would be less effective in a SC plan as some athletes would be able to move the sled easier than the others. While the size of the athlete would affect strength and speed adaptations in a training plan, there is potential influence that oxygen consumption (VO_2) may be enhanced from repeated sled sprints. Future research should investigate acute VO_2 response during push sled sprints to develop a greater understanding of the relationship between VO_2 and OBLA related to this training method. Although the exact point of where VO_2 and OBLA will occur varies because of genetics and training but a value $> 87\%$ VO_{2max} is not an unacceptable starting point (Seiler and Kjerland, 2006). Further investigation into repeated push sled sprints is needed to observe if a point for a VO_2 and OBLA relationship occurs along with the potential chronic adaptations (> 6 weeks of continuous training).

The rest interval time of 35 s between sprints in the current study may be an ideal rest time for chronic adaptations to the lactate energy system (Ross and Leveritt, 2001) while increasing the inter-sprint rest times or manipulation to sprint distance may influence improvements in sprint velocity. Moreover, the acute responses during repeated push sled sprints may require adjustments to sled load, inter-sprint rest times, distance or technique to create the most effective stimulus. Phosphagen dominant sports, such as volleyball and softball in the current study, should have different SC plans in comparison to sports that require greater contribution from the lactate energy system (i.e. lacrosse, ice hockey, mixed martial arts). This difference may explain the BLA levels from the repeated sprints in the athletes in the current study. Future studies need to examine the effects of varying rest times on BLA, athlete types, and the effects of an repeated push-sled training program may have on BLA and time to OBLA.

Besides BLA responses in the current study, HR elevated in a linear fashion with increasing loads while 3 min post sprinting had the highest values and remained elevated at 5 min post (Table 4). All participants were in a seated position for the entirety of the post-sprint time recovery, which may have caused a steep declination in HR in comparison if an active recovery was utilized. However, these elevated HR levels are most likely needed to aid in the clearance of lactate to return levels below 4.0 mmol. Whether an active recovery following repeated sled pushing sprints would have a dramatic effect on the recovery HR and BLA needs further investigation. The current study demonstrates that HR remains elevated following repeated sprints suggesting the sustained increase is in response to the high BLA. This HR response can provide guidance to the SC coach utilizing HR monitoring during their conditioning programs. Monitoring an athlete's HR can allow for the most effective training stimulus, exercise selection and adequate recovery to obtain the desired cardiovascular and bioenergetic adaptations. Future studies that examine the timing of longer rests, and active versus passive rests would provide further clarity to programming. SC coaches would benefit from timing athletes rest periods for determining the ideal amount of inter-set rest time for the individual or team's recovery. A limitation in the current study is the use of a hand held stop watch for timing of sprint times, which allows for "real life" application but contributes to a reliability acknowledgement. Although the same person did all timing during testing sessions it would be advantageous to use electronic timing gates in future studies to increase the accuracy of sprint times. Furthermore, along with timing it may be prudent to test sled pushes on different surfaces as the coefficient of friction may significantly alter the results (Hall, 2012). The current study was conducted on a rubberized floor, but these types of drills may also be conducted on grass, dirt, asphalt, and artificial turf. To ascertain how much sprint time, BLA, or HR variation may result from sled push sprints on different surfaces needs further investigation. SC coaches need to consider the effects of the surface being used based on the sports of the athletes along with the possible alterations to sprint technique. The athlete's sport also influences the type of shoe used for each or the sport's respective surface as this may assist or hinder the force production of the leg muscles. The subjects in the current study wore the shoes they used in their SC training throughout the study. Researchers in future studies may see different results if they standardize the shoes worn during the testing conditions or if they are specific to the testing surface. Surface may prove critical on testing, especially if the athletes tested participate on ice. Modifications to the push sled may be necessary so testing can be conducted on ice or the acquisition of a bobsled may be warranted. The bobsled is the only sport where a push sled has absolute sport specificity but the long term impact of using a push sled on sprinting kinematics and kinetics on other sport athletes needs further investigation. The current study only examined the acute effects push sleds had on female athletes and results may differ from training with push sled or with male athletes of similar sports. Expanding sports and skill level (e.g. High School versus Professional) may provide further information on the most appropriate use of push sleds in a strength and conditioning program.

The purpose of using push sleds in a SC plan may be to enhance muscle morphological adaptations over long application (≥ 8 weeks) or neurological adaptations in a shorter time period. Regardless whether a push or pull sled is used, the objective of adapting the neural system may be related the H-reflex, muscle spindles, and motor unit recruitment (Ross *et al.*, 2001). Improvement in motor recruitment can increase muscle contraction velocity and force production, resulting in decreased sprint times. The addition of sleds to a SC plan in advanced level athletes may provide the necessary stimulus to invoke a neurological adaptation. Behrens and Simonson (2011) outlined various methods that may enhance sprinting along with strength and plyometric training recommendations, but excluded a discussion on sled pushing. As noted by Alcaraz *et al.* (2008) that the type of resisted pulling sprints (e.g. parachute) may decrease sprint velocity and alter sprint mechanics, which may also apply to push sled sprints. One noticeable difference using a push sled is that the arms are not involved in the sprint as they are when towing a sled. Lack or arm movement may provide the SC coach with a method of assessing leg power in absence of contribution from arm movements. The results of assessing leg power may further assist in developing SC plans to address deficiencies in lower body development. The angle of an athlete's body may also be different to a traditional sprint or a pull sled sprint, which could influence the desired neurological adaptations. Future training studies and video should also consider observing stride length and frequency when performing push sled sprints along with consultation of SC or sport coaches on what information is desired by them to improve the performance of the athletes. Stride length (SL) and frequency (SF) have been attributed to sprint performance (Ross *et al.*, 2001; Lockie *et al.*, 2003; Alcaraz *et al.*, 2008; Behrens and Simonson, 2011) and if one of these qualities could be enhanced through push sled sprints then this would validate their use as an training method. Muscular force and contraction velocity, SL and SF increases would have a linear improvement on sprint velocity. The use of any sled added to sprinting becomes problematic if an inappropriate load is used that can increase sprint times transitioning the push sled sprint to a strength exercise. Alcaraz *et al.* (2009) used a percent of $velocity_{max}$ to determine an optimal load used based on an athlete's body mass for pull sled sprinting. This optimal load may also apply to the push sled load and the SC coach should start with loads that do not drops the athlete's ability to maintain a sprint velocity greater than 90% $velocity_{max}$. The incorporation of push sleds for sprinting and for strength may both prove to be beneficial to a SC plan and a balance between the two may have greater impact than either used in isolation. The combination of strength training, plyometrics, and sprinting methods suggest to have the best effect on improving sprint speed (Behrens and Simonson, 2011).

5. CONCLUSION

The current study examined the effects of push sled sprints on BLA and HR for application of push sled sprint training for bioenergetic and cardiovascular adaptations. The results suggest that repeated push sled sprints with loads of 15KG or greater would be more conducive to causing an increase to blood lactate than repeated sprints alone. Higher BLA may illicit adaptations to fast glycolysis benefitting athletes by increasing time to anaerobic threshold, OBLA, and minimizing a rapid onset of muscular fatigue. Additionally, loads of 35 kg would be ideal for higher HR in comparison to lower loads allowing for SC coaches to monitor the cardiovascular effects of push sled sprints. Acute effects demonstrate that the greater loads increase sprint time emphasizing force production with a decrease in sprinting velocity and representing a shift in a force velocity curve. SC coaches should prioritize when using a push sled if the objective is improving sprinting performance, leg strength or the fast glycolysis energy system.

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Table-1. Procedures outline

Session	Sprint Load / Distance	Bouts / Recovery
Initial	Body mass, body fat %, resting values and consent form completed	
1	0 / 20 yd	6 / 35 seconds
2	Sled only / 20 yd	6 / 35 seconds
3	Sled +10 kg / 20 yd	6 / 35 seconds
4	Sled +15 kg / 20 yd	6 / 35 seconds
5	Sled +20 kg / 20 yd	6 / 35 seconds
6	Sled +35 kg / 20 yd	6 / 35 seconds
7	Sled +50 kg / 20 yd	6 / 35 seconds

Table-2. Sprint times for each condition

Condition	Peak Sprint Time (sec) Mean ± SD	Mean Sprint Time (sec) Mean ± SD
SPR	$3.22 \pm .10^{**,***,\dagger,\dagger\dagger,\dagger\dagger\dagger,@}$	$3.34 \pm .11^{**,***,\dagger,\dagger\dagger,\dagger\dagger\dagger,@}$
SLED	$4.36 \pm .28^{*,***,\dagger,\dagger\dagger,\dagger\dagger\dagger,@}$	$4.53 \pm .27^{*,***,\dagger,\dagger\dagger,\dagger\dagger\dagger,@}$
10KG	$4.73 \pm .54^{*,**,\dagger\dagger,\dagger\dagger\dagger,@}$	$5.02 \pm .37^{*,**,\dagger,\dagger\dagger,\dagger\dagger\dagger,@}$
15KG	$5.10 \pm .46^{*,**,\dagger\dagger,\dagger\dagger\dagger,@}$	$5.33 \pm .41^{*,**,***,\dagger\dagger,\dagger\dagger\dagger,@}$
20KG	$5.37 \pm .47^{*,**,***,\dagger,\dagger\dagger\dagger,@}$	$5.63 \pm .51^{*,**,***,\dagger,\dagger\dagger\dagger,@}$
35KG	$6.25 \pm .67^{*,**,***,\dagger,\dagger\dagger,@}$	$6.89 \pm .92^{*,**,***,\dagger,\dagger\dagger,@}$
50KG	$7.72 \pm 1.15^{*,**,***,\dagger,\dagger\dagger,\dagger\dagger\dagger}$	$9.01 \pm 1.80^{*,**,***,\dagger,\dagger\dagger,\dagger\dagger\dagger}$

(*significantly different to Sprint; **significantly different to Sled; ***significantly different to 10kg; †significantly different to 15kg; ††significantly different to 20kg; †††significantly different to 35kg; $^{@}$significantly different to 50kg)

Table-3. Blood lactate accumulation (BLA) at 3 min and 5 min post repeated sprints

Condition	BLA3MIN	BLA5MIN
SPR	$5.81 \pm .81^{\dagger,\dagger\dagger,\dagger\dagger\dagger,@}$	$5.57 \pm 1.01^{\dagger,\dagger\dagger\dagger,@}$
SLED	$7.01 \pm 1.55^{@}$	$6.83 \pm 1.84^{\dagger\dagger\dagger,@}$
10KG	7.69 ± 2.12	8.20 ± 3.63
15KG	$8.22 \pm 1.35^{*,@}$	$8.24 \pm 1.27^{*}$
20KG	$8.99 \pm 1.64^{*}$	$7.71 \pm 1.78^{@}$
35KG	$9.86 \pm 2.06^{*}$	$10.30 \pm 2.37^{*,**}$
50KG	$11.89 \pm 2.72^{*,**,\dagger}$	$11.31 \pm 2.02^{*,**,\dagger\dagger}$

(*significantly different to Sprint; **significantly different to Sled; ***significantly different to 10kg; †significantly different to 15kg; ††significantly different to 20kg; †††significantly different to 35kg; $^{@}$significantly different to 50kg)

Table-4. Heart rate at 3 min and 5 min post repeated sprints

Condition	Resting HR Mean ± SD	HR3MIN (bpm) Mean ± SD	HR5MIN(bpm) Mean ± SD
SPR	79.64 ± 15.11	$99.91 \pm 14.03^{\dagger,\dagger\dagger,\dagger\dagger\dagger,@}$	$94.07 \pm 12.93^{\dagger,\dagger\dagger\dagger,@}$
SLED	74.57 ± 12.68	$97.00 \pm 21.04@$	$97.64 \pm 15.14^{\dagger\dagger\dagger,@}$
10KG	73.86 ± 20.22	107.93 ± 12.20	101.57 ± 9.86
15KG	76.79 ± 8.99	$104.43 \pm 9.22^{*,@}$	$100.07 \pm 10.75^{*}$
20KG	75.14 ± 8.25	$105.21 \pm 9.78^{*}$	$100.29 \pm 12.03^{@}$
35KG	74.71 ± 10.35	$111.64 \pm 9.34^{*}$	$105.71 \pm 9.52^{*,**}$
50KG	74.21 ± 9.41	$120.64 \pm 12.02^{*,**,\dagger,\dagger\dagger}$	$111.36 \pm 11.84^{*}$

(*significantly different to Sprint; **significantly different to Sled; ***significantly different to 10kg; †significantly different to 15kg; ††significantly different to 20kg; †††significantly different to 35kg; $^{@}$significantly different to 50kg)