HUMAN MOVEMENT
2014, vol. 15 (1), 36–44

THE EFFECTS OF A POSTACTIVATION POTENTIATION WARM-UP ON SUBSEQUENT SPRINT PERFORMANCE

doi: 10.2478/humo-2013-0050

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ABSTRACT
Purpose. Many strength and conditioning professionals propose that postactivation potentiation (PAP) warm-ups enhance power performance although there are few studies conducted in this regard on sprinting. Therefore, the purpose of this study was to determine the effects of a PAP warm-up on sprint performance. **Methods.** Twenty-four men and women completed a 40-yard (yd) sprint pretest on four nonconsecutive days followed by a PAP warm-up that included a sled resistance sprint at either 0%, 10%, 20%, or 30% of their body mass and concluded with a 40-yd dash posttest. Each resistance sprint was recorded for kinematic analysis. **Results.** A 2 × 2 × 4 factorial mixed ANOVA revealed a statistically significant difference between sexes in 40-yd dash times ($p < 0.001$). A significant main effect was found in pre- and post-40-yd dash measures regardless of sex ($p < 0.001$). The results indicated no significant differences in the post-40-yd dash times between sled loads and the load by time interaction. The participants' 40-yd dash times improved 1.2% on average after the 10% load. Improvements in dash time for the 0%, 20%, and 30% loads were greater than 2%. Sprint kinematics analysis demonstrated statistically significant differences between lighter and heavier loads. **Conclusions.** Regardless of the significant disruptions in sprint mechanics, there appears to be a potential for heavier sled resistances to affect acute improvements in 40-yd sprint performance. However, it is unclear whether heavier sleds loads may provide greater benefit than warming up with 0% resistance.

Key words: postactivation potentiation, warm-up, resistance sprint

Introduction

Although the effects of various warm-up protocols in a variety of sports have been studied, additional research is needed to meet the specific warm-up needs for power athletes if optimal performance is to be achieved [1–8]. For example, several studies have suggested that stretching warm-ups, which have traditionally been used with endurance activities, may inhibit the execution of power activities [9–13]. The observation that warm-up strategies utilized for endurance activities do not have a positive effect on performance in power activities has led to speculation that the ability to release large amounts of energy in a relatively short period of time may rely on different physiological warm-up mechanisms. Therefore, there is growing interest in developing warm-up strategies specific to power activities. Warm-ups aimed at eliciting postactivation potentiation (PAP) have been suggested as the key to improved power performance.

A PAP warm-up protocol has been a topic of discussion in recent studies and is defined as an enhanced neuromuscular state observed after the execution of high intensity exercise [14]. The derivation of the PAP definition reflects the observation that an increase in muscle twitch contraction force follows a maximal or near maximal voluntary contraction.

Although some researchers have demonstrated that PAP warm-ups result in improved muscle performance, others have failed to demonstrate this relationship [15–18]. A number of factors have been proposed to account for the inconsistency in the PAP warm-up literature including variability in the conditioning background of the individuals performing the exercises, varied muscle fiber composition of the studied individuals, the intensity of the PAP warm-up, and the rest period between the warm-up and power activity.

A common PAP warm-up described in the literature is a moderate intensity dynamic warm-up including 4 min of cycling and/or 1 set of squats, followed by a 1 repetition maximum or near 1 repetition maximum squat (PAP movement), then, after a short rest period allowing for phosphocreatine resynthesis, the power activity is executed [e.g., vertical jump; 3, 4, 7, 8]. Although several researchers have examined the PAP warm-up concept, many of the studies involved exercises such as squats and vertical jumps rather than focusing on competitive events like sprinting. The studies that did examine a PAP warm-up and sprinting examined a variety of sprinting activities [3, 7, 8, 18–20]. The studies that demonstrated a significant effect of a PAP warm-up on sprint

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performance (a) used a rest period of 4–10 min, (b) used heavy weight squats as a warm-up activity to elicit PAP, and (c) used either well-trained or physically fit participants [3, 7, 8, 19, 20].

One of the abovementioned studies is very unique, in that it demonstrated the effects of a sled-resisted sprint warm-up on subsequent sprints [8], with significant improvements in 25 m sprint times. However, the study was conducted with ice-hockey players using an ice rink as a testing surface. The use of a resistance sprinting warm-up with other populations on other surfaces such as a track has not been found in the literature. If using a resistance sled as part of a PAP warm-up for track sprinters can result in faster sprint times, the resistance sled may serve as a feasible and accessible PAP warm-up for sprinting. Such a warm-up also may provide a training method using a device (resistance sled) that is more biomechanically similar to sprinting than a squat.

Therefore, the purpose of this study was to examine the influence of a PAP warm-up protocol using a resistance sled on subsequent sprint performance in a group of well-trained, anaerobically fit individuals. This study aimed to determine the effects of a 20-yard (yd) sled resistance sprint at different loads on subsequent 40-yd sprint performance without resistance. It was hypothesized that the resistance sprinting warm-up protocols would elicit a PAP effect and have a statistically and practically significant impact on subsequent sprint performance. For this study, practical significance was defined as a 1.65% improvement. It was also hypothesized that men would have faster 40-yd sprint times than women and there would be no interaction effect between sex and sled load. Finally, it was hypothesized that a warm-up with a sled load of 10% body mass would represent the best balance between a PAP effect and fatigue recovery and therefore result in the greatest improvement in sprint performance when compared with other sled loads. The hypothesis that 10% body mass may be the most optimal sled load was based on the assertion that loads heavier than 10–15% may cause significant disruptions in sprint technique.

Material and methods

Participants

University institutional review board approval was obtained before the study was initiated. An a priori power analysis indicated that approximately 24 participants were needed [8]. The literature on PAP suggests that this phenomenon is observed in humans regardless of sex [21–23]. Studies also suggest that anaerobically well-trained individuals may be more likely than untrained participants to exhibit a PAP response when challenged with high intensity exercise [4, 15, 24, 25]. On the basis of the above, this study sampled 24 anaerobically trained men and women (12 men and 12 women), aged 18–28 years from a university in the southwestern United States. For the purposes of this study, anaerobically trained was defined as having participated in physical activity 4–6 days per week in the preceding 6 months, with each session lasting at least 60 min and where 75% of the performed exercise required muscular power.

Procedures

The first four sessions of study consisted of preliminary screening and familiarizing the participants with the study procedures and equipment (see Fig. 1). The first session began by obtaining informed written consent and administering a screening questionnaire. The first portion of the questionnaire included questions on the physical activity readiness (PAR-Q) of the individual to participate in the study and the second portion asked for information regarding nutrition and supplement intake. All participants needed to be free of injury during the preceding 6 months and commit to abstain from additional lower-body resistance training during the study period. Participants were excluded if they had taken ergogenic aids (e.g., anabolic steroids, growth hormone, or any performance-enhancing drugs). Participants were allowed to participate in the study if they were taking or had previously taken vitamins or mineral supplements.

During the first session the participants also had their body composition measured and took part in the first of two surrogate methods to test for type II muscle fibers. The first was a vertical jump measurement, which has been found to have a strong correlation with muscle biopsy testing ($r = 0.79$) [26]. The second indirect measure of type II muscle fibers was am inertial load cycling test, which is also highly correlated with lean thigh volume ($r = 0.86$) [27, 28]. The inertial

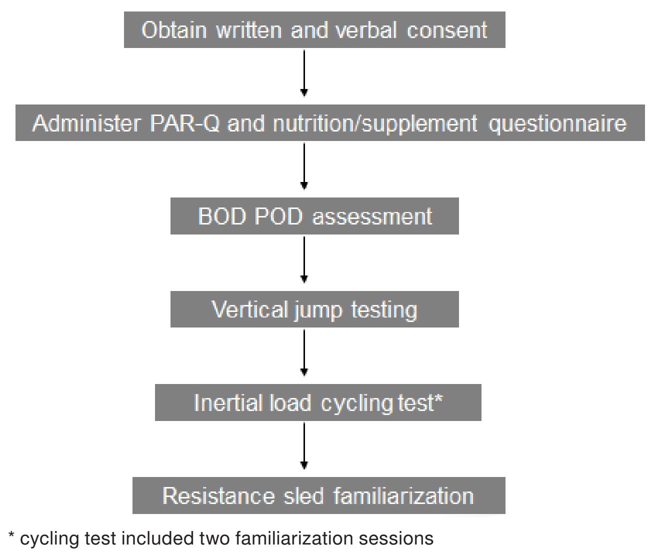


Figure 1. Preliminary screening and testing procedure (sessions 1–4)

load cycling test included two familiarization trials and one data collection trial. Inertial load testing scores from the final test trial were averaged for statistical analysis.

Both the vertical jump and inertial load cycling tests were chosen as they are noninvasive measures of lean mass and muscle fiber type, which are important factors in speed development. Participants who obtained low scores on these tests were not excluded from the study. The results of these tests were intended to provide greater insight as to whether or not lean mass and muscle fiber type played a role in responses to a PAP warm-up protocol.

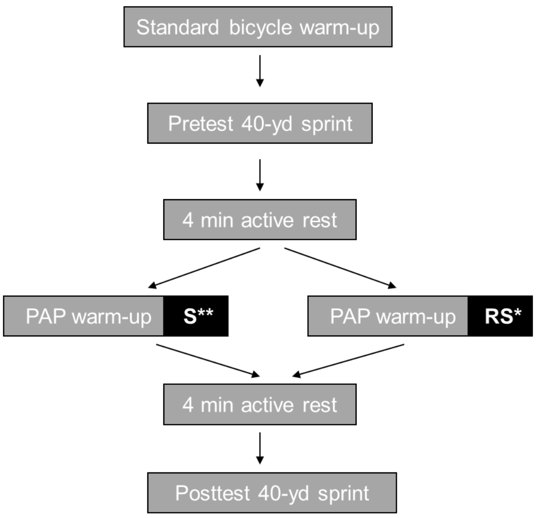
The last session of preliminary testing involved familiarizing the participants with the sled resistance training device. The participants had the opportunity to perform 20-yd sprints using 10%, 20%, and 30% of their respective body mass as resistance.

The next four sessions (sessions 5–8) were performed on separate nonconsecutive days consisting of one control trial and three randomized experimental trials of the study protocol (Fig. 2). There were 24 permutations, without repetition, of the four loads (0%, 10%, 20%, and 30%), and each participant was randomly assigned to a different order.

The control trial involved having participants engage in a standardized warm-up consisting of 4 min of pedaling on a stationary bicycle at 70 rpm at a self-selected resistance [7, 29, 30]. Exercise intensity was maintained between 50–70% of each participant's maximal heart rate monitored by a Polar E600 heart rate monitor (Polar Electro, USA). This warm-up was followed by 4 min of active rest [6, 7, 31], where the participants walked slowly around a sprint track so as to eliminate the possible effects of fatigue [7, 32, 33]. During the active rest period, the Borg Rating of Perceived Exertion (RPE) was used to determine intensity level of the active rest [34]. The goal was for participants to score a rating of 11 or below (≤ light intensity) during the active rest period. After the active rest period the participants performed a control pretest which consisted of a 40-yd sprint. Participants wore spikeless running shoes as opposed to track and field spikes during testing. The 40-yd sprint was followed by another 4-min period of active rest, after which participants were required to sprint 20 yd without resistance. This sprint was again followed by 4-min active rest. After the third active rest, the participants were tested in a final 40-yd sprint (see Fig. 2).

The three experimental trials examined the influence of different levels of 20-yd resistance sled sprinting on 40-yd sprint time. The protocol for the three experimental trials appears in Figure 2 and is based on Matthews et al. [8]. Each experimental trial began with the same standardized bicycle warm-up used in the control trial and was followed by the 4-min active rest period of a slowly walking around the track [7, 32, 33]. Although the optimal rest period may be highly dependent on individual needs, the rest period between exercises chosen for this study appears to be a favorable balance between fatigue and potentiation and is supported in similar studies [3, 19, 24, 35–37].

The experimental trials were conducted in a manner similar to the control trial. The exception was that the 20-yd sprint portion of the warm-up involved pulling a sled. The sled and harness weighed 13.2 kg (6 lbs) and additional weights were added to the sled so that 10%, 20%, or 30% of each participant's respective body mass served as the sled resistance. The order of the sled resistance loads was randomized and the 24 permutations of order meant that each participant had a unique sequence of experimental trials as an attempt to lessen any order effect.



* RS – 20-yd resisted sprint with 10, 20 ora 30% of participant's body mass
** S – 2-yd un-resisted sprint with 0% load

Figure 2. Test protocol for the control and experimental trials (sessions 5–8)

Kinematic analysis

Each 20-yd resisted sprint was filmed using a Sony HandyCam to analyze the kinematic effects of the different loads (Sony Electronics, USA) and provide information on how each sled load influenced the sprint technique of the participants. Kinematic analysis was

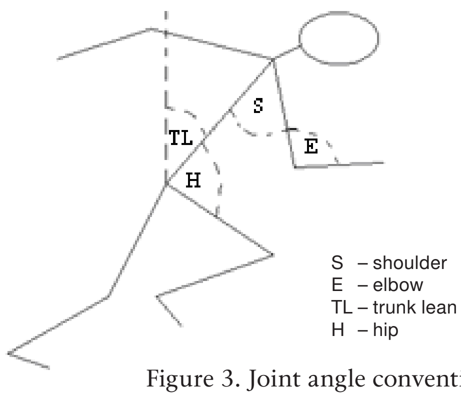


Figure 3. Joint angle conventions

conducted from the sagittal plane of each participant at 10 yd ± 1 stride of each 20-yd resisted sprint. Body angles for trunk lean, hip flexion, shoulder flexion/extension, and elbow flexion/extension were determined using Dartfish Video Analysis Software (Dartfish, Switzerland). Anatomical landmarks comprised the acromion (shoulder), lateral epicondyle of the ulna (elbow), midpoint between the styloid processes of the radius and ulna (wrist), anterior superior iliac spine, greater trochanter of the femur, and lateral condyle of the tibia (knee) [38]. The measured joint angles are shown in Figure 3. Hip, shoulder, and elbow angles were measured at maximum extension and flexion, and trunk lean (forward lean) was determined at touchdown of the first stride nearest to 10 yd.

Although the results of previous studies have indicated that sled resistance greater than 10–15% body mass negatively affects sprinting kinematics, research on PAP states that the warm-up exercises need only be biomechanically similar and not identical to the performance exercise (e.g., back squat followed by vertical jumps, or sled sprints followed by un-resisted sprints, see [38–40]). Therefore, sled loads heavier than 10-15% body mass may still have a PAP effect and improve subsequent sprint performance despite disruptions in sprint technique during the sled resistance sprints. Part of the reasoning for using different sled resistance loads was to determine an optimal load for PAP effect [4].

Instrumentation

Sprint testing was performed on a Mondo indoor track (Mondo, USA). Sprint times were measured by a multifunction infrared timing system (Lafayette Instrument Co., USA). Photo cells were set up to record times at 10, 20, 30, and 40 yd. The weighted sled was attached to the participant by dual 3.17 m (10 feet [ft] 5 inches [in]) leads connected to a waist harness (Titan Global Trading, USA). A waist harness was used as opposed to a shoulder harness to avoid excessive forward lean by the participants [39, 41]. The sled consisted of two metal parallel metal tubes that were approximately 59.7 cm (23.5 in) long and 2.5 cm (1 in) in diameter. Connecting the runners was a 25.4 × 31.8 cm (10 × 12.5 in) metal plate on which a 15.2 cm (6 in) long 2.5 cm (1 in) diameter metal post which was secured in the vertical position. The mass of the sled and harness was 2.45 kg (5.4 lbs) and 0.27 kg (0.6 lbs), respectively.

Sled towing was adopted to simulate resisted sprint training as it has the benefit of being unaffected by wind as is the case with other resistive devices such as parachutes [38]. Its design also allows for weights to be easily secured or removed in order to adjust the resistance load and is a popular training method to improve stride length and power [38, 39, 42, 43].

Body composition was assessed using the BOD POD air displacement plethysmography system (Cosmed, Italy) [44] at the University's Human Performance Lab. First, body height was measured to the nearest 0.1 cm and body mass was measured to the nearest 0.01 kg on a calibrated electric scale with the participant wearing only a tight fitting swimsuit. Next, the participant sat comfortably inside the BOD POD where the chamber's computerized pressure sensors determined the amount of displaced air to calculate body density. Body fat percentage was calculated using Siri's equation [45]. For each participant, three measurements were completed and averaged to determine body composition. Previous research has found the BOD POD device to have high test-retest reliability (rtt = 0.91–0.96) and is a valid alternative to hydrostatic weighing ($r^2 > 0.80$) [46–49]. The Bod Pod was used to provide information on lean body mass, which is a factor relating to speed development [50].

The inertial load cycling test was performed using a Model 818 ergometer (Monark, Sweden). As was mentioned previously, this test has a very strong correlation with lean thigh volume and provides an indirect measure of type II muscle fiber [27, 28]. The test involved completing four bouts of maximal acceleration cycling. Each bout lasted 3–4 s with 2 min of rest provided between cycling bouts. Two familiarization sessions were first performed before the test was performed. The inertial load cycling test has been found to be an internally consistent, reliable tool (ICC = 0.99; $r^2 = 0.999$) [28].

The VERTEC measurement apparatus (Senoh, Japan) was used for vertical jump assessment. Standing reach was subtracted from the highest of three vertical jumps to determine vertical jump height. No approach steps were permitted, but a countermovement jump was used prior to takeoff [26]. A 3-min recovery was provided between jumps [51]. Similar to the inertial load cycling test, the vertical jump test provided information on participants' muscle fiber composition. Previous research has indicated a strong correlation between vertical jump measures and muscle fiber type ($r = 0.79$) [26].

Statistical analysis

Statistical analysis was conducted using SPSS software ver. 20.0 (IBM, USA). Descriptive statistics were calculated to characterize body composition and muscle fiber type of the two subject populations (men/women). All data were subjected to standard data screening procedures for missing values and outliers and normality tests were performed both overall and within each group. Given the fairly small sample size, standard imputation and accommodation methods were used and small departures from normality were tolerated. All multiple trial measures (e.g., vertical jump) were assessed for precision, stability, and repeatability. The surrogate measures for fiber type were correlated using Pearson's product-moment correlation. Practical significance was set at 1.65%. Primary analysis was conducted using a 2 × 2 × 4 (sex × time × load) mixed factorial ANOVA with repeated measures. Statistical significance was defined at $p < 5.00\%$.

Results

Descriptive Statistics

The mean age of the participants was 23 ± 5 years and mean body fat percentage was 19.93% (females = 24.53%, males = 15.32%). Twenty-two of the 24 participants fulfilled all the requirements of the study. One female and one male participant were unable to complete the study due to muscle injuries.

Initial analysis included screening for outliers using box and whisker plots and modified Z-scores. One outlier was found, in which case multiple regression was used as an accommodation procedure. There were also missing values due to equipment malfunctions with the timing system, and in such cases multiple imputation regression was used to determine approximate data for the missing values. The results indicated that no assumptions were violated for the data in the study. Initial analyses for the data collected in this study also indicated that the vertical jump (α = 0.992), inertial load cycling (α = 0.995), and 40-yd baseline times (α = 0.983) measures were all reliable with a Cronbach's above 0.9.

Inferential Statistics

The 2 × 2 × 4 factorial ANOVA revealed a significant difference between sexes in 40-yd sprint times ($F = 34.41$, $p < 0.001$; females = 6.04 ± 0.092 s; males = 5.30 ± 0.088 s). The results also indicated that there was a statistically significant main effect difference in pre-and post-40 yd dash times ($F = 29.73$, $p < 0.001$; pretest mean = 5.720 ± 0.321 s; posttest mean = 5.615 ± 0.293 s). As indicated in Table 1, the participants' 40-yd dash times improved approximately 2.14% on average after the 0% load, 1.21% on average after the 10% load, 2.11% on average after the 20% load, and 2.24% on average after the 30% load. However, the four resistance levels for the PAP warm-ups (0%, 10%, 20%, 30%) were not statistically different. Additionally, none of the interaction effects were statistically different.

Although 40-yd sprint times did not differ across loads, running kinematics were checked as possible confounding factors (Tab. 2). Analyses of sprint kinematics demonstrated a statistically significant difference in forward lean after comparing the 0% and 10% loads to the 20% and 30% loads ($p < 0.01$). When the 20% and 30% comparison was made, no significant difference was found ($p = 0.695$). For hip flexion, there was a statistically significant difference when 30% was compared with 0% and 10%, as well as when comparing the 20% load to the 0% load ($p = 0.001$, $p = 0.023$, $p = 0.034$, respectively). For shoulder flexion, a significant difference was found when comparing the 30% and 20% loads to 0% ($p < 0.017$ and $p < 0.027$, respectively).

Discussion

The primary aim of this study was to examine the influence of a PAP warm-up protocol on subsequent sprint performance in well-trained, anaerobically fit individuals. PAP effect was elicited by performing 20-yd sprints while pulling a resistance sled following a 4-minute traditional warm-up. Three sled loads were used as well as one control 20-yd sprint without resistance, constituting four different warm-up protocols. The results indicated a significant difference in pre- to post-40-yd sprint times regardless of sex or sled load. The finding that the PAP warm-up benefitted both sexes is consistent with previous research [21–23]. There was also a statistically significant difference between sexes.

The significant difference in pre- and post-40-yd dash times also supports the notion that resistance sprinting warm-ups can result in acute improvements in sprint times [8]. However, there were no significant differences found between the warm-up protocols. Therefore, it remains somewhat unclear which load is optimal for improving 40-yd dash performance. From a practical standpoint, it was hypothesized that the PAP warm-ups would have a practically significant impact on subsequent sprint performance (1.65% improvement). On average the results of the 10% load were less preferable than those of 0%, 20%, and 30% body mass. The percent of improvement in 40-yd sprint times for the 10% load was just above 1%, whereas for the 0%, 20%, and 30% loads the improvements were greater than 2%. In comparison with other studies, the percent improvements are similar and in some cases greater than those reported. Chatzopoulos et al. [3] found a 1.7% improvement in 30-m times as a result of a PAP warm-up (pretest mean = 4.51 s vs. posttest mean = 4.43 s). Linder et al. [7] saw a 1.11% improvement in 100-m sprint times after a PAP warm-up (pretest mean = 17.14 s vs. posttest mean = 16.948 s). Matthews, Matthews, and Snook [20] found 3.3% improvements in 20-m times (pretest mean = 2.963 seconds vs. posttest mean = 2.865 seconds). The resistance sprint PAP warm-up study conducted by Matthews et al. [8] resulted in a 2.6% improvement in 25-m sprint times (pretest mean = 3.95 seconds vs. posttest mean = 3.859 seconds).

The finding that the 10% load produced less favorable improvements than the other loads is somewhat interesting, especially when considering that previous literature has recommended that a 10–15% load to be the most optimal when training with a resistance sled [38]. This assertion is based on the effects of resistance on an individual's sprint kinematics and provided the basis for the hypothesis that a 10% load would be op-

Table 1. Descriptive statistics for mean times, % improvement, and time differences

Sled load	Pre warm-up (s)	Post warm-up (s)	% improvement	Time difference (s)
0%	5.70 ± 0.541[a]	5.58 ± 0.502[b]	2.14	0.12
10%	5.72 ± 0.507	5.65 ± 0.527	1.21	0.07
20%	5.70 ± 0.464	5.57 ± 0.480	2.11	0.12
30%	5.71 ± 0.497	5.58 ± 0.465	2.24	0.13

[a] average 40-yd times in seconds prior to PAP warm-up, [b] average 40-yd times in seconds after PAP warm-up

Table 2. Kinematic variables for sled towing

Sled load	0%	10%	20%	30%	Avg.
Forward lean	15.69	20.99	26.66[b]	28.83[b]	23.04 ± 5.91
Hip flexion	106.43	103.03	98.46[a]	94.73[b]	100.7 ± 5.13
Elbow flexion	45.52	46.5	46.73	46.32	46.27 ± 0.53
Elbow extension	122.03	117.45	117.18	117.40	118.51 ± 2.35
Shoulder flexion	38.88	44.22	48.69[a]	49.28[a]	45.27 ± 4.82
Shoulder extension	68.65	65.32	65.12	62.52	65.4 ± 2.51

[a] significantly ($p < 0.05$) different from 0% load, [b] significantly ($p < 0.05$) different from 0% and 10% load; all values in degrees

timal for improving sprint performance. However, 10% of body mass would not be 75% of maximal voluntary contraction. Although the load of 30% body mass was difficult for several participants, even that condition may not have been 75% of maximal voluntary contraction

The video analysis of the sprints was in agreement with the idea that heavier loads disrupt sprint technique more than lighter loads [38]. The effects were particularly evident when addressing forward lean, hip flexion, and shoulder flexion. However, a limitation of the video analysis was that the different areas of the participants' bodies used to determine the body position angles were not marked. Although the reliability for all of the measures in the study was high, accuracy may have been improved had these areas been marked. Nonetheless, although the 20% and 30% loads had statistically more forward lean than un-resisted sprinting, the 40-yd times were not statistically different. Given that the video analysis was conducted at approximately 10 yd, an additional analysis was performed on these 10 yd times rather than 40 yd times. A Helmert contrast post-hoc analysis indicated that at 10 yd, the 10% load warm-up produced statistically slower times than the 20% and 30% loads ($p = 0.047$). It is possible that pulling heavier loads, as a more intense activity, can cause a greater PAP effect. However, why the 10% load brought the least improvement remains unclear and requires further study.

A limitation to the study that may have impacted the results is the recovery time between the warm-up and sprint tests. As was mentioned previously, the recovery time needed by each participant can be highly individual. The variability of recovery time makes it difficult to determine an ideal time. Additionally, as this is the first study using a resistance sled as part of a PAP warm-up, the recovery time needed to see a significant difference between sled loads may be different from other studies. Future research should address the issue of recovery time when using a resistance sled in a PAP warm-up.

It appears that muscle fiber type did not play a significant role in the results. The mean vertical jump score for males in this study was 28.92 in, where vertical jump scores for active, healthy adult males is between 21 and 22 inches [52]. For the females, the mean vertical jump score was 20.79 inches, where the average vertical jump score for active, healthy adult females is approximately 14 inches [52]. The comparisons between vertical jump scores obtained by the participants in this study and the average scores for active, healthy adults suggest that the study participants had a higher amount of type II muscle fiber than the norm. The participants' inertial load scores for max power (W) were lower than the norm for males and females of a similar conditioning background [27, 53]. However, the average optimal velocity (rpm) produced by the participants in this study was higher than participants in previous research who had predominant type II muscle fibers [27].

It is possible that there were no significant differences between the different warm-ups as they were so similar in nature that no statistically significant effects may be found or that the sled did not create a PAP effect. Future research might include another form of intervention such as a passive warm-up or a true control condition. A common question in research on warm-ups is whether performance improvements are primarily due to increased body temperature or a combination of PAP, body temperature increase, and other factors [54]. The inclusion of a passive warm-up or a true control may help improve understanding in this area. It is also possible that the pre warm-up 40-yd sprint may have had a PAP effect for all four conditions.

Another aspect that may require consideration is whether the resistance sprints were long enough in duration to produce a desirable effect. Matthews et al. [8] used a 10-s resisted sprint and found a 2.6% decrease in sprint times. In the current study, participants pulled a sled for 20 yd at approximately half the time of the resisted sprints in Matthews et al., and the greatest improvements in sprint times were slightly above 2%. The Matthews et al. [8] study also had participants in the comparison group rest between pre- and post-sprint tests, whereas in the current study participants ran a 20-yd sprint with 0% body mass as resistance. The inclusion of a sprint with 0% body mass may be more typical of a warm-up for sprint testing. Researchers may wish to consider the duration of sled sprints, and, as mentioned previously, include a passive warm-up or a rest period without any sprints between pre- and post-sprint tests for future studies. Additionally, the introduction of a squat warm-up, as has been used in other studies to enhance sprint performance, should also be considered as an additional intervention.

Another limitation that requires mention was the low statistical power (0.24). Although the a priori power analysis estimated that 24 participants would be satisfactory, due to the uniqueness of this study and the methods used it was not possible to know the exact number of participants needed beforehand. The Matthews et al. [8] study, which this study's a priori power analysis was based on, had differences with respect to participants (only male and less total participants) and the type of PAP warm-up. Based on the results of Matthews et al. [8] an effect size of 1.2 was estimated, whereas the interaction effect size in this study for time by load was only 0.65. However, almost twice as many participants were used, compared with the study by Matthews et al. [8], for this study to detect an effect of 0.65. Whether or not statistical significance may be reached with a greater number of participants is unclear.

As this is one of the first studies to examine the effects of PAP on sprint performance using a modality (sled sprint) different from the more conventional warm-up devices (e.g., squat) in other PAP studies, there are many questions that remain unanswered. Overall, this study does indicate a potential for heavier sled resistances to affect acute decreases in 40-yd sprint times when used in a warm-up. However, the benefit may not be greater than un-resisted sprinting. Fitness trainers and coaches should use caution when considering to include heavier sled loads as part of a training program. Further study is needed to determine whether or not chronic adaptations to training with heavier sled loads can negatively affect sprint kinematics and sprint performance [38].

It is recommended that future researchers consider the following aspects in respect to the present study: replicate a similar protocol and design although with a greater number of participants and an additional intervention (e.g., passive warm-up, squat PAP warm-up, or a rest period in place of a sled pull between pre- and post-40-yd time tests); employ body markings for sprint kinematics analysis; analyze sprint mechanics from the sagittal plane of the first and second stride of sled pull as opposed to the 10-yd mark; analyze a different recovery time to determine if there is an optimal balance between recovery from fatigue and PAP effect; conduct a study with participants with different conditioning backgrounds (e.g., elite track sprinters, football players) to further understand the effects of such warm-up protocols on specific populations; test the chronic effects of training with different sled loads on 40-yd dash performance; select a different recovery time for the warm-up to test its effects; test the effects of pulling sled loads at different durations, distances, and intensities (e.g., heavier sled loads); and test other ways to enhance the intensity of a PAP warm-up such as weighted vests.

Conclusions

Although more research is needed, the findings of this study suggest that athletes may benefit from using heavier sled loads as part of a PAP warm-up to enhance sprint performance. Lighter sled loads may be less desirable and may potentially bring less favorable improvements for athletes if used prior to testing or competition. Although using heavier sled loads to improve acute power performance may be appropriate, using heavier loads as part of a regular training program may potentially be harmful to an athlete's sprint technique and therefore not recommended at this point in time until additional study is performed. It is also not entirely clear whether using a resistance sled is more advantageous than using un-resisted sprints as part of a PAP warm-up strategy for improving sprint performance. This study did not investigate the effects of a heavy weight back squat as a means for enhancing sprint performance, however, sled pulls are biomechanically more similar to sprinting than squats in relation to the line of force application. Additionally, sled towing may be a more feasible method of warming up than squats due to the minimal equipment needed.

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Paper received by the Editors: January 2, 2014
Paper accepted for publication: February 6, 2014

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