The Acute Effects of Heavy Sled Towing on Subsequent Sprint Acceleration Performance

AUTHORS:
Paul Jarvis [1], Anthony Turner [1], Shyam Chavda [1], and Chris Bishop [1]

AUTHOR AFFILIATIONS:
[1] School of Science and Technology, Middlesex University, London Sport Institute, UK

CORRESPONDING AUTHOR:
Paul Jarvis
Middlesex University, London Sport Institute
Allianz Park, Greenlands Lane, London, NW4 1RL
Email: P.Jarvis@mdx.ac.uk
Phone: +44 (0) 20 8411 4775

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ABSTRACT

OBJECTIVES:

The purpose of this study was to assess the practical use of heavy sled towing and its acute implications on subsequent sprint acceleration performance.

DESIGN AND METHODS:

Eight healthy male varsity team sport athletes (age: 21.8±1.8years, height: 185.5±5.0cm, weight: 88.8±15.7kg, 15m sprint time: 2.66±0.13s) performed sprints under three separate weighted sled towing conditions in a randomised order. Each condition consisted of one baseline unweighted sprint (4-min pre), the sled towing sprint protocol: (*1*) 1x50% body mass, (*2*) 2x50% body mass, (*3*) 3x50% body mass (multiple sprints interspersed with 90s recovery), and 3 post-testing unweighted sprints thereafter (4, 8, 12-min post). All sprints were conducted over a 15m distance.

RESULTS:

Significantly faster sprint times for the 3x sled towing protocol were identified following 8-min of rest (*p*=0.025, *d*=0.46, 2.64±0.15s to 2.57±0.17s). When individual best sprint times were analysed against baseline data, significantly faster sprint times were identified following both 1x (*p*=0.007, *d*=0.69, 2.69±0.07s to 2.64±0.07s) and 3x (*p*=0.001, *d*=0.62, 2.64±0.15s to 2.55±0.14s) sled towing protocols. Within the 3x condition, all athletes achieved fastest sprint times following 8–12 min of rest.

CONCLUSIONS:

The findings from the present study indicate that a repeated bout of sled towing (3x50% body mass) leads to the enhancement in subsequent sprint acceleration performance, following adequate, and individualised recovery periods.

KEY WORDS: Post Activation Potentiation, Sprint Kinematics, Warm-Up, Speed, Power

INTRODUCTION

Success within sprinting events relies heavily on both the ability to accelerate rapidly, and following this, through achieving and maintaining high running velocities. The acceleration phase of sprinting is generally referred to as the initial 0–30m [1], with the progression into maximal velocity running and subsequently the maintenance of top speed thereafter (30–60m+) [1]. Research has found that increases in sprint acceleration performance are primarily achieved through optimising the resultant ground reaction force (GRF) vector to facilitate a horizontal (propulsive) orientation [2,3]. As such, literature reports propulsive forces within acceleration to be 46% greater than those observed within maximal velocity running [4-6]. Fundamentally therefore, a large training consideration should be noted for training modalities which provide overload to the propulsive nature of GRF application within the acceleration phase of sprint running.

Sled towing is a form of resisted sprinting which provides mechanical overload to the horizontal component of GRF application; thus, postulated to bring about a mechanically more efficient force orientation per stride [7]. Given its low cost and high level of practicality, sled towing can be easily exploited by athletes where extensive gym equipment may not be accessible. Kinematically, increased stance time, shank angle (i.e. shin angle relative to the ground) and trunk angle (i.e. torso lean relative to the ground), and increased hip extension angles can all be observed [8-12]. From a kinetic standpoint, literature reports sled towing to lead to a reduction in normalized mean vertical GRF ($3.0\pm1.6N.kg^{-1}$ to $1.7\pm1.16N.kg^{-1}$), with concomitant increases in net horizontal impulse ($0.75\pm0.28m.s^{-1}$ to $0.97\pm0.17m.s^{-1}$) and peak propulsive forces ($8.8\pm2.5N.kg^{-1}$ to $9.3\pm0.9N.kg^{-1}$) when towing sled loads of as little as 30% body mass (BM) [13]. As such, a shift in ratio of forces applied into the ground can be noted, with research by Kawamori, Newton & Nosaka [13] reporting a mean shift in ratio of GRF application (vertical to horizontal) of ~11%, thus bringing about a mechanically more efficient force application throughout ground contact [2]. Further to this, a review by Petrakos, Morin, and Egan [7] examining longitudinal training implications indicates how sled towing with “light” loads (<10% body mass [BM]) may infact lead to decrements in sprint acceleration performance (–1.5%, ES=0.50). On the contrary, “moderate to very heavy” loads (10–19.9% BM to >30% BM) appear superior in lending itself to improvements in sprint acceleration performance (0.5–9.1%, ES=0.14–4.00). This data is somewhat not surprising, given how recent findings by Cross et al. [14] noted mean sled loads to maximise peak power within the sled towing exercise to range from 69–96% BM (resistive force of 3.5 ± 0.34 $N.kg^{-1}$ at a velocity of 4.58 ± 0.40 $m.s^{-1}$).

Whilst training interventions have been shown to aid mechanical effectiveness and thus enhance sprint performance [15], limited evidence of its use within the acute stages prior to performance as a means of harnessing post activation potentiation (PAP) are noted. PAP is a phenomenon often referred to as a strength-power-potentiation complex [16], with substantial evidence within the literature apparent for tasks such as jumping, sprinting, throwing, and upper body ballistic style exercises (see review by Seitz and Haff [17]). This said however, little is understood as to the efficacy of utilizing sled towing as a conditioning activity (CA) to aid in harnessing PAP. To the authors knowledge, three studies to date have investigated resisted sprinting through use of a weighted sled as a PAP mechanism [10-12]; however, a variety of sled loads (10% BM – 150% BM) and frequency of sprints (x1 – x3) utilised emphasizes the absence of both an optimal load and frequency of sprints understood to maximise any PAP effect. Smith et al. [10] identified enhancements 4-min post the resisted sprinting (> 2% increase mean sprint performance) following sled loads of 30% BM. In contrast, Winwood et al. [12] acknowledged strongest effect sizes for percent change in sprint time at 12-min post (d=0.64; p<0.05), this following sled loads of 75% BM. It could be argued however that both studies indicate the magnitude of CA as falling outside of optimal, given how peak increases in muscular power have previously been suggested to be realised following approximately 7–10 minutes of rest [18]. Whelan et al. [11] undertook a repeated sprint intervention, whereby participants completed multiple sprints (x3) against the sled resistance of ~25-30% BM, however no evidence of PAP was discovered, with the data attained highly unsystematic in nature.

Whilst limited evidence is apparent to substantiate the use of resisted sprinting as a PAP mechanism, data supports the use of sled loads at each of 30% and 75% BM to facilitate kinematic parameters of sprint performance, whilst enhancing sprint time [10,12]. Furthermore, it is widely understood that heavier loads impose greater neuromuscular stress upon an individual [19], leading to the potential increase in muscle fibre recruitment of motor units specific to sprinting. Therefore, the aim of this investigation was to bridge the gap between sled loads currently investigated within the literature, and observe from both a performance and kinematic standpoint the dose response and thus performance change identified following the resisted sprinting protocol. It was hypothesised that all dependent variables would see enhancements following the sled towing interventions, with a greater dose response and thus potentiation in sprint performance postulated following the 3x sled towing protocol.

METHODS

SUBJECTS

A total of eight healthy male varsity team sport athletes volunteered to participate in this study (age: 21.8±1.8years, height: 185.5±5.0cm, weight: 88.8±15.7kg, 15m sprint time: 2.66±0.13s). All participants were free from injury, with participants excluded from the study if they had suffered any form of injury within the three months leading up to testing. All testing was completed throughout the off-season, with participants asked to refrain from strenuous exercise within a 48h period leading up to testing sessions. Participants were untrained concerning the use of weighted sleds, although a familiarisation session exposing each participant to resisted sprinting with 50% BM was completed. Full ethical approval was granted from the Middlesex University London Sport Institute ethics committee, and all participants provided written consent.

PROCEDURES

A repeated measures study design was completed over a 14-day period, whereby all participants completed all testing procedures, allowing a minimum of 72 hours rest dividing each respective testing session. All testing sessions took place on an outdoor natural grass surface throughout the months July and August, whereby no rain within a 48hr window leading up to testing sessions was permitted, thus limiting interference by virtue of weather and altered coefficient of friction from the running surface [5]. Prior to any data collection, all health screening questionnaires and informed consent forms were completed additional to basic anthropometrics (height, weight). Participants were then familiarised to the experimental conditions, this compromising of detailed verbal instructions on the experimental protocol and acclimation to all testing procedures (5x15m maximal sprints and 5x15m sled resisted sprints at 50% BM) [20]. Testing commenced 72 hours following familiarisation, with all conditions randomised in order and separated by a minimum of 72 hours of rest. Participants were instructed through a standardised warm up (see Table 1) compromising of dynamic exercises of a progressive nature in specificity to the kinematics of sprint running. Upon completion of this, a baseline unweighted maximal sprint was conducted (4-min pre), with this acting as each participants control for the respective protocol and thus comparable measure to post testing sprints. After a period of 4-min, the resisted sprint protocol was completed (either 1x, 2x, or 3x sled towing), with 90s rest between resisted sprints permitted for the multiple sprint protocols. Following this, post-testing unweighted sprints were completed at

4, 8 and 12-min. All sprints were conducted from a staggered standing stance, with participants advised to sit between trials to limit fatigue. Throughout the full testing process the same strip of turf was used for each respective individual's trials, and all participants were instructed to wear the same footwear (spikeless running shoes) for each testing session.

*** Insert Table 1 about here ***

SPRINT TIME:

Sprint time was measured through use of an electronic timing system (*Brower Timing Systems, Draper, Utah, USA*), with data obtained over a 15m distance. Pilot testing concluded that timing gates as a requirement must be situated above waist height relative to each individual to ensure no interference from the trailing cord attached to the weighted sled, with this respective height for each individual measured within the familiarisation session. Participants were instructed to start 50cm behind the initial set of timing gates in a staggered stance with their left foot leading, this to ensure they did not trigger the gates ahead of time. Following confirmation from the instructor that all technical aspects of data collection were set up and ready to record, participants were approved to start each trial, with initiation of movement self-selected thereafter. Participants were strictly instructed to limit any rocking (countermovement) prior to starting each trial. Average sprint velocity was subsequently equated to provide information on velocity decrement within each of the resisted sprints, utilising the following formula:

$$\text{Velocity (V)} = \text{Distance (D)} / \text{Time (T)}$$

SLED TOWING:

For the resisted sprinting, participants were attached via a waist harness and a trailing 3.9m cord to the weighted sled (*ATREQ Speed Sled, 2.88kg, length 660mm, width 430mm, ATREQ Fitness, UK*), this to limit any catching from the heel throughout the recovery phase of sprinting. Participants were instructed to maximally accelerate the 50% BM sled over a distance of 15m. In line with the methodology of Whelan et al. [11], a 90s recovery period was permitted between sprints for the trials requiring multiple sled tows, whereby the instructor would tow the weighted sled back to the start point for the participant. Load and frequency of sprints were determined from each of; Smith et al. [10], Winwood et al. [12], and Whelan et al. [11] studies, with the present study aiming to bridge the gap between sprints at high relative loads (1x75% BM) and lighter relative loads (1x~25-30% BM; 3x30% BM).

VIDEO ANALYSIS:

Kinematic analysis was recorded and measured through use of a High Speed Video Camera (iPhone 6, Apple Inc., USA) placed on a secure tripod at a height of 1m recording 1280 pixels x 720 pixels at a frame rate of 240 frames per second. In line with methodological suggestions from Bartlett [21], the camera was located 2.5m forwards from the start line and 9m back perpendicular to the running lane, with the field of view from the camera zoomed so that video capture acquired data solely for the first 5m of the 15m sprint (See Figure 1), thus limiting potential for perspective (parallax) error within subsequent third step kinematic analysis. Two pointed cones placed 5m apart on the running lane were also situated in shot throughout each sprint for both vertical and horizontal calibration throughout subsequent video analysis.

*** Insert Figure 1 about here ***

A total of five reflective markers placed on the right side of the body were situated on palpable anatomical landmarks located at the acromion, greater trochanter of the femur, lateral condyle of the tibia, lateral malleolus, and lateral region of 5th metatarsal, to enable subsequent kinematic analysis (see both Figure 2 & Table 2). The instance of touchdown and push off were determined from visual identification through frame by frame analysis. Zero vertical and horizontal marker velocity from the landmark located at the lateral region of 5th metatarsal (i.e. remained stationary for multiple frames) was the precursor for the instance of touchdown, and push off was determined from a change in either vertical or horizontal marker velocity (i.e. acceleration of the marker) from the static position of ground contact. All movement analysis was conducted on biomechanical motion analysis software Kinovea (*Kinovea Software V0.8.15, France*), which produced high levels of test retest reliability when three pilot testing trials were analysed five times each for each of the dependent variables (ICC = 0.995 – 0.998).

*** Insert Table 2 about here ***

*** Insert Figure 2 about here ***

STATISTICAL ANALYSIS

A Shapiro-Wilk test was used to assess the normality of all dependent variables recorded at baseline. To assess for both within and between trial reliability, coefficient of variation (CV) and intraclass correlation coefficient ($ICC_{2,1}$) were used. To examine for changes in sprint performance for each dependent variable, a (3x4) repeated measures ANOVA was conducted. Bonferroni post hoc analysis was run where necessary to determine which measures significantly differed, with this measuring both between time points within groups, and between groups within time points. Magnitude of change (effect size) for main and interaction effects were reported using partial eta squared (η^2), with follow up pairwise comparisons reported using Cohen's *d* [22]. All magnitude based effect size data was interpreted in line with Cohen's [22] suggestions: 0.2 (small), 0.5 (moderate), 0.8 (large). Paired samples T-Tests were used to compare baseline data with post testing individual best sprint times. Significance was accepted at a confidence interval of 95% ($p<0.05$). All data analysis was conducted using statistical software SPSS (*version 20.0; SPSS, Chicago, IL*).

RESULTS

A representation of all mean data reported for baseline and post sled towing is presented within Table 3. All dependent variables were identified as normally distributed for baseline data scores ($p>0.05$). Low levels of reliability were identified for both trunk angle (CV=14.6%; ICC=0.126) and shank angle (CV=18.1%; ICC=0.366). As a result of this, no further analysis was conducted for these specific variables.

*** Insert Table 3 about here ***

SPRINT TIME:

Sprint time reported moderate to high levels of within and between trial reliability (CV=2.7%; ICC=0.664). ANOVA identified a significant main effect for time [$F_{(3,21)}=3.317$, $p=0.04$, $\eta^2=0.322$]. Bonferroni post hoc analysis identified for the 3x sled towing condition significance between baseline and 8-min post ($p=0.025$, $d=0.46$, 2.64±0.15s to 2.57±0.17s). No significant group effect [$F_{(2,14)}=1.253$, $p=0.316$, $\eta^2=0.152$] or interaction effect for group and time was identified [$F_{(2.14,14.982)}=1.825$, $p=0.194$, $\eta^2=0.207$].

Analysis of individual best post-test sprint times following the sled towing protocols identified, for the 1x sled towing condition, significantly faster post testing sprints compared to baseline (p=0.007, d=0.69, 2.69±0.07s to 2.64±0.07s) (See Figure 3). Within this, 37.5% of participants achieved their best score 4-min post, 37.5% at 8-min post, and 12.5% at 12-min post. For the 2x sled towing group, no significance between baseline scores and best post-test sprint time scores were apparent (p=0.129, d=0.38, 2.64±0.16s to 2.58±0.15s). For the 3x sled towing group, significantly faster post testing sprints compared to baseline were identified (p=0.001, d=0.62, 2.64±0.15s to 2.55±0.14s). Within this, 75% achieved their best post-test sprint time at 8-min post, and 25% at 12-min post.

*** Insert Figure 3 about here ***

STEP LENGTH:

Step length reported high levels of within and between trial reliability (CV=4.1%; ICC=0.75). ANOVA identified no significant effect for group [$F_{(2,14)}$=0.535, p=0.597, η^2=0.071], time [$F_{(1.73,12.11)}$=2.05, p=0.174, η^2=0.227], or group and time interaction [$F_{(6,42)}$=1.58, p=0.177, η^2=0.184].

STEP FREQUENCY:

Step frequency reported moderate to high levels of within and between trial reliability (CV=6.7%; ICC=0.516). ANOVA identified no significant effect for group [$F_{(2,14)}$=0.819, p=0.461, η^2=0.105] or time [$F_{(3,21)}$=0.269, p=0.847, η^2=0.037]. A significant interaction effect of group and time was noted however [$F_{(2.828,19.798)}$=8.02, p=0.001, η^2=0.534]. Bonferroni post hoc analysis identified at the baseline time point significance between the 2x and 3x sled towing groups (p=0.016, d=0.87, 4.09±0.48Hz vs. 3.74±0.31Hz). Additionally, at the 4-min post time point significance between the 1x and 3x sled towing groups was noted (p=0.02, d=0.62, 3.95±0.25Hz vs. 3.76±0.35Hz). For the 3x sled towing group, significance was noted between the 4-min post and 12-min post time points (p=0.043, d=0.53, 3.76±0.35Hz vs. 3.93±0.31Hz).

HIP EXTENSION ANGLE:

Hip extension angle reported high levels of within trial reliability (CV=2.2%), although low levels of agreement were identified between conditions (ICC=0.334). ANOVA identified no significant effect for group [$F_{(2,14)}$=1.267,

p=0.312, η^2=0.153] or any interaction between group and time [$F_{(2.374,16.619)}$=1.127, p=0.356, η^2=0.139]. A significant main effect of time was noted however [$F_{(1.338,9.363)}$=8.164, p=0.014, η^2=0.538]. Bonferroni post hoc analysis identified for the 1x sled towing group significance between time points at baseline and 8-min post (p=0.001, d=0.62, 168.6±5.9° vs. 172±5.2°).

SPRINT VELOCITY:

When comparing unweighted baseline sprints to sled resisted sprints, the 1x sled towing condition reduced baseline average sprint velocity by 44±4%. The 2x sled towing condition reduced baseline average sprint velocity by 44±3%, and 40±4%. The 3x sled towing condition reduced baseline average sprint velocity by 42±4%, 43±4%, and 43±4%. All sled towing conditions were significantly slower than baseline sprint times (p<0.05, d>1).

DISCUSSION

Strength and conditioning practitioners are continually searching for ways to enhance an athlete's capability to accelerate, given its implications on sporting performance. Since the use of heavy sled towing in an attempt to enhance sprint acceleration performance is still a relatively new concept within the applied field, it is important to obtain data to bring to light changes in sprinting performance following use of such apparatus. The main findings of the present study fall in line with the initial hypotheses, with the 3x sled towing group identifying significant improvements in sprint performance following 8-min of recovery. These findings support the work from previous PAP research [23-25], which has highlighted the requirement of at least 8-min of recovery from a heavy CA to enhance subsequent strength or power performance in biomechanically similar movements. Further to these findings, when individualised time periods of recovery are permitted, significant increases in sprint performance were realized, with participants within the 3x sled towing group all achieving their best sprint times following 8–12 minutes of recovery (8-min post, 75%; 12-min post, 25%). These findings support the window of opportunity proposed by Seitz and Haff [17], who identified strongest effect sizes for recovery time when duration exceeded 8-min, and Wilson et al. [18], who identified optimal performance to be realised within a 7–10 minute window following a prior CA.

This was the first study to the authors' knowledge which assessed sprint kinematics following an acute bout of heavy sled towing. Previous research has solely examined sprint performance and stride variables (step rate, step length, ground contact time, running speed over first 6 steps of maximum effort sprint) within the post-testing sprints [10-12]. For kinematic parameters of the shank and trunk upon touchdown, the present study identified low levels of both within and between trial reliability (CV=18.1%, 14.6%; ICC=0.366, 0.126). Further to this, low levels of between trial reliability were noted for hip extension angle (ICC=0.334). This highlights the large variability within sprint technique of the sample of athletes recruited, illustrating similar outcomes (represented through sprint performance) achieved though varied processes (represented through change in kinematic variables). Research by Whelan et al. [11] also recruited a sample of untrained athletes regarding sprint training, with their results matching those of the present study, identifying high levels of typical error analysis both within and between variables. While inter day reliability was noted as low for hip extension angle, strong levels of within session reliability were noted (CV=2.2%), and results illustrate moderate effects following the 1x sled towing condition (baseline to 8-min post: d=0.62, 12-min post: d=0.52), and the 3x sled towing condition (baseline to 8-min post: d=0.64). Concomitantly, following the 3x sled towing condition, moderate effects for both step length (d=0.51) and step frequency (d=0.76) were noted following 8-min recovery, indicating a link within the present study between the magnitude to which an athlete enters hip extension throughout the push off phase of ground contact and subsequent step length. As such, it may be prudent to suggest that possible facilitation to the effectiveness of force application within subsequent sprints was noted, given how increases in hip extension angle and step length variables were both noted simultaneously. Without concurrent GRF data however to substantiate this theory, further research is warranted, and it appears therefore, that whilst the high levels of variation may potentially have been a by-product of the individualized nature of PAP [18], the appropriateness of kinematic data within an untrained sample of athletes appears impractical. As such, level of technical training experience should be considered, and further research is warranted to greater understand this.

The present study identified how decrements in average sprint velocity of between 40% to 44% can be an effective CA to augment subsequent sprint acceleration performance. Interestingly, this figure is marginally higher than findings from both Winwood et al. [12] (34% to 37% following 75% BM sled tow), and research by Kawamori et al. [26] (planned 30% decrement over 8week training period). Both the present study and research by Kawamori et al. [26] recruited samples of physically active team sports athletes with varying performance standards, this in contrast to Winwood et al. [12] who recruited a sample of resistance-trained rugby athletes. Interestingly, the present study identified greater decrements in comparison to Winwood et al. [12], this noteworthy due to greater loads undertaken within Winwood et al. [12] protocol in comparison to the present study (34–37% [75% BM] vs. 40–44% [50% BM]). It should be noted however that varying track surfaces were utilised between studies (synthetic track surface [10-12] vs. natural grass surface). With this comes constraints by virtue of weather, with factors such as wind and grass length all affecting the coefficient of friction and thus training overload [27]. Given the discrepancy that is apparent therefore as to optimising velocity decrement (by virtue of load), it appears, whilst inconclusive to date, how heavier loads which lead to decrements in sprint velocity of between ~30-44% may aid in optimising sprint acceleration performance, highlighting the potential benefits for athletes of a variety of performance standards. With this in mind however, further research into understanding optimal decrements in sprint velocity relative to athlete training state and sprinting surface is necessary, and practitioners should be advised therefore to take caution and consider these variables when exploiting sled towing interventions on a variety of training surfaces.

Within the present study, a sled load of 50% BM was used to bridge the gap, both from a volume and intensity standpoint, between research by Winwood et al. [12] (1x 75% BM) and Smith et al. [10] (3x 30% BM). Unsurprisingly, the time course of recovery from CA to potentiation was relative to sled load; with Smith et al. [10] identifying peak performance following 4-min rest (3x 30% BM), the present study following 8-min rest (3x 50% BM), and Winwood et al. [12] following 12-min of rest (1x 75% BM), this in line with previous research (see review by Seitz & Haff [17]). Research into PAP following the back squat exercise as a CA reports intensities exceeding 60% of 1 repetition maximum as optimal [18], however a transferable value to sled towing is yet to be derived. It should be noted however, as indicated by Seitz & Haff [17], how stronger effects are evident for repetition maximal loads (ES=0.51) in comparison to sub-maximal loads (ES=0.34), indicating how heavier sled loads hypothetically should be more optimal in eliciting a PAP effect. The findings from both the present study and those of Winwood et al. [12] corroborate with this, with optimal sled loads identified at between 50–75% BM. This can further be explained by the ground contact phase; when sled loads recruited are significantly lower in relative intensity, shorter ground contact times are required, leading to a reduced “time under tension” phase. As alluded to by Murray et al. [28], this phase is where force application occurs, leading to greater levels of neuromuscular stress and thus increased potential recruitment in motor units specific to sprinting [19]. Although the authors in the present study standardised variables such as the warm-up to limit variability between trials [29], it appears plausible to suggest that if sled loads are not heavy enough (as proposed by Morin et al. [15]), any true change in sprint performance may be attributable to solely warm-up effects, as opposed to factors modulating PAP, i.e. recruitment of higher order motor units [30]. Further to this, it should be noted that whilst the sample of athletes within the present study were homogeneous in nature, solely eight participants were measured. With this in mind, and with no information pertaining to physical characteristics (i.e. strength levels), a greater depth of research within this subject area is warranted, highlighting direction for future investigations.

PRACTICAL APPLICATIONS

The findings from the present study have practical applications for team sports athletes. Our findings suggest that incorporating a repeated bout of sled towing (3x 50% BM) within a warm up, leading to decrements in sprint velocity of between 40–44%, can bring about enhancement in subsequent sprint performance. It should be noted however, that optimal responses are attained when participants are permitted adequate, and individualised recovery periods (~8–12 mins). Practitioners should be aware of the individualised nature of PAP, and preliminary testing to understand individual responses would be advised to optimise timing of peak sprint performance. Future research should look to expand upon this study with sprint trained athletes, as this may bring to light any acute kinematic adaptions to heavy sled towing within subsequent sprints. Additionally, further research is warranted around optimal sled induced sprint velocity decrements to facilitate subsequent sprint acceleration performance, as this will aid with clarity around sled training prescription.

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Table 1: Standardized Warm-Up Protocol.

Warm-Up Phase	**Exercise**	**Sets x Reps**
General Prep	Light Jog	5-min
	SL RDL	2 x 6 ES
	Spiderman: Internal Rotation	2 x 6 ES
	Inchworm	2 x 6
	Squat	2 x 10
Stiffness / Force Production Prep	Bilateral Ankling	2 x 10
	SL Broad Jump: Bilateral Landing	2 x 6 ES
Sprint Specific Prep	A-Skip	2 x 8 ES
	B-Skip	2 x 8 ES
	50% Max. Linear Sprint	2 x 15m
	75% Max. Linear Sprint	2 x 15m
	100% Max. Linear Sprint	2 x 15m

Notes: *Prep* = Preparation, *min* = minutes, *SL* = Single leg, *RDL* = Romanian deadlift, *ES* = Each side, *Max.* = Maximal effort

Table 2. Classification of phases of the gait cycle and joint kinematics. See Figure 2 for visual illustration.

Phase / Measure	**Metric**	**Classification**
Touchdown	–	The first frame whereby the foot gains contact with the ground following the swing phase
Push Off	–	The first frame whereby the foot leaves contact with the ground following ground contact phase
Trunk Angle	°	Measured at touchdown of third step as: acromion – greater trochanter of the femur – vertical, whereby a positive value is indicative of the acromion leading ahead of the greater trochanter of the femur relative to the direction of movement
Shank Angle	°	Measured at touchdown of third step as: lateral condyle of the tibia – lateral malleolus – vertical, whereby a positive value is indicative of the lateral condyle of the tibia leading ahead of the lateral malleolus relative to the direction of movement
Hip Extension Angle	°	Measured at push off on third step as: acromion – greater trochanter of the femur – lateral condyle of the tibia, whereby 180° would be indicative of a straight line through each of the three landmarks, with this value lowering through reduced hip extension
Step Length	cm	Measured as horizontal distance between the lateral region of 5th metatarsal upon third step touchdown and the next respective touchdown on the opposing foot
Step Frequency	Hz	Measured as time elapsed through third step touchdown at lateral region of 5th metatarsal to the next respective touchdown on the opposing foot, and expressed as an inverse of time from each of the consecutive foot strikes (Hz)

Notes: ° = degrees, cm = centimeters, s = seconds

Table 3: Group Mean ± SD and Magnitude Based Effect Size Data.

	1x Sled Tow		**2x Sled Tow**		**3x Sled Tow**	
	Mean ± SD	***d***	**Mean ± SD**	***d***	**Mean ± SD**	***d***
Sprint Time (s)						
4-min Pre	2.69 ± 0.07	-	2.64 ± 0.16	-	2.64 ± 0.15	-
Sled Tow 1	4.8 ± 0.4	7.42	4.68 ± 0.36	7.4	4.59 ± 0.4	6.39
Sled Tow 2	-	-	4.41 ± 0.36	6.27	4.66 ± 0.26	9.44
Sled Tow 3	-	-	-	-	4.66 ± 0.3	8.37
4-min Post	2.68 ± 0.08	0.08	2.61 ± 0.15	0.18	2.64 ± 0.1	0
8-min Post	2.65 ± 0.09	0.38	2.65 ± 0.17	0.07	2.57 ± 0.17 ***	0.46
12-min Post	2.67 ± 0.07	0.28	2.6 ± 0.2	0.22	2.62 ± 0.09	0.16
Step Length (cm)						
4-min Pre	109.7 ± 7.97	-	107.48 ± 10.4	-	105.38 ± 11.74	-
Sled Tow 1	71.69 ± 8.16	4.71	78.54 ± 9.25	2.94	70.74 ± 7.65	3.5
Sled Tow 2	-	-	76.43 ± 6.5	3.58	73.27 ± 8.34	3.15
Sled Tow 3	-	-	-	-	73.67 ± 7.56	3.21
4-min Post	109.69 ± 6.55	0	106.91 ± 8.8	0.06	110.29 ± 5.42	0.54
8-min Post	109.01 ± 8.18	0.09	108.21 ± 8.39	0.08	109.76 ± 3.31	0.51
12-min Post	111.72 ± 6.83	0.27	112.55 ± 8.69	0.53	108.49 ± 3.85	0.36
Step Frequency (Hz)						
4-min Pre	3.79 ± 0.24	-	4.09 ± 0.48	-	3.74 ± 0.31	-
Sled Tow 1	3.38 ± 0.33	1.41	3.34 ± 0.15	2.07	3.12 ± 0.22	2.3
Sled Tow 2	-	-	3.38 ± 0.46	1.5	3.11 ± 0.25	2.23
Sled Tow 3	-	-	-	-	3.22 ± 0.13	2.15
4-min Post	3.95 ± 0.28	0.61	4.05 ± 0.52	0.08	3.76 ± 0.35	0.06
8-min Post	3.86 ± 0.2	0.31	3.89 ± 0.47	0.42	3.96 ± 0.27	0.76
12-min Post	3.86 ± 0.28	0.25	3.93 ± 0.43	0.36	3.93 ± 0.31	0.63
Hip Extension Angle (°)						
4-min Pre	168.6 ± 5.9	-	167.4 ± 4.7	-	168.1 ± 5.3	-
Sled Tow 1	161.6 ± 4.9	1.28	160.7 ± 6.7	1.16	161.1 ± 7.4	1.08
Sled Tow 2	-	-	163.6 ± 5.9	0.7	160.5 ± 8.8	1.05
Sled Tow 3	-	-	-	-	163.9 ± 5.9	0.73
4-min Post	170.9 ± 5	0.42	168.6 ± 3.9	0.3	168 ± 6.4	0.01
8-min Post	172 ± 5.2 ***	0.62	168.5 ± 4.7	0.24	171.2 ± 4.4	0.64
12-min Post	171.4 ± 5.1	0.52	168.8 ± 5.2	0.29	169.4 ± 4.8	0.27

Notes: *SD* = Standard deviation, *d* = Cohen's *d* effect size (In relation to baseline measure of respective variable), *** = significantly different ($p < 0.05$) from respective 4-min pre baseline value (post testing values only)

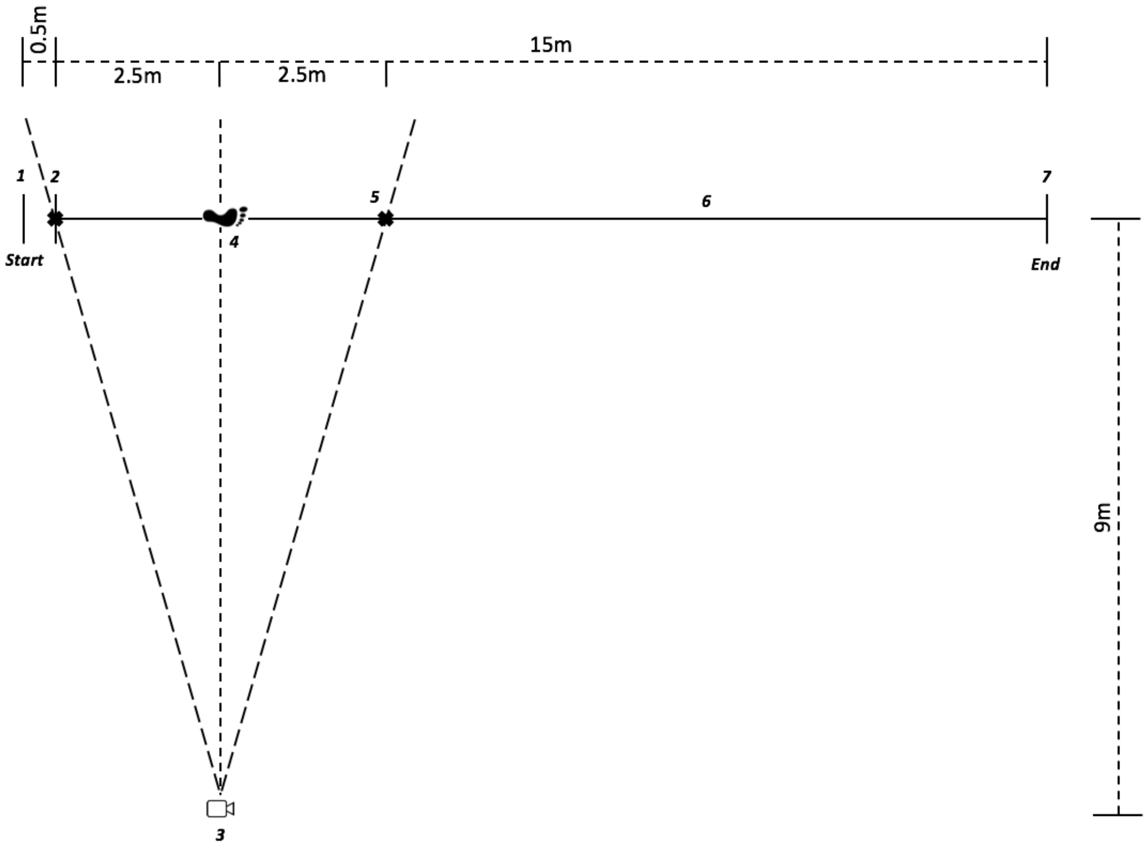

Figure 1: Schematic representation of full testing set up, whereby participants would start 50cm behind the initial set of timing beams (point "*1*") and sprint throughout the 15m running lane (point "*6*": between point "*2*" and point "*7*"), with kinematic data acquired throughout participants third step (point "*4*"). Note: *1* = line 50cm from start of 15m running lane which participants start behind, *2* = placement of first set of timing beams & first cone for calibration, *3* = camera placement, *4* = capture area of third stride, *5* = placement of second cone for vertical and horizontal calibration, *6* = 15m running lane, *7* = end of 15m running lane & placement of second set of timing beams.

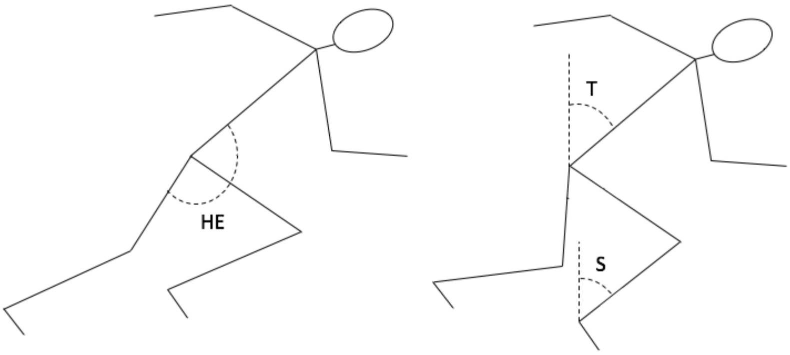

Figure 2: Schematic of all joint angles measured.

Note: *HE* – Hip Extension (Measured at push off), *T* – Trunk (Measured at touchdown), *S* – Shank (Measured at touchdown).

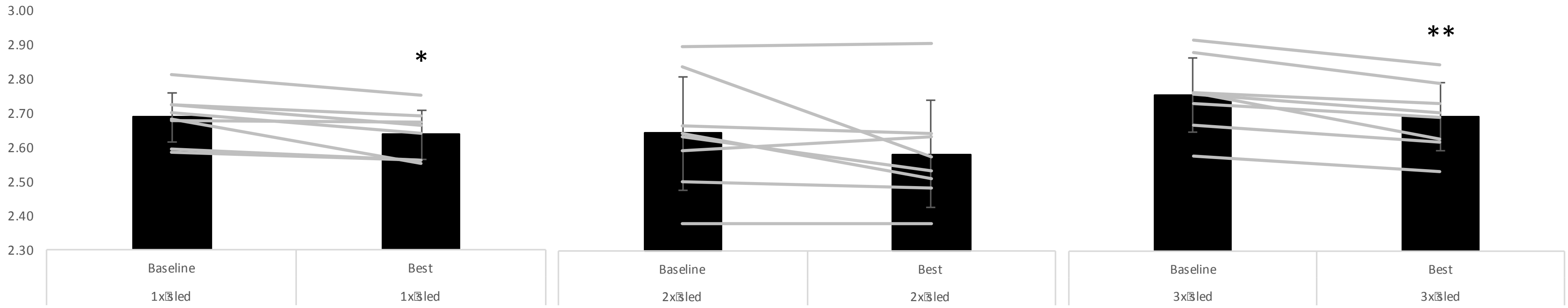

Figure 3: Group mean data with standard deviation error bars and individual data overlaid to represent baseline and individual fastest sprint times following the sled towing interventions.

Note: * = *p*<0.05, ** = *p*<0.01