CAN BACKWARD SLED TOWING POTENTIATE FIVE METRE SPRINT PERFORMANCE?

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Daniel John Monaghan

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Abstract

Post-activation potentiation (PAP) describes an augmentation within muscle properties, with the ability to enhance muscular performance. Due to the complexity of this highly individualised phenomenon, PAP has the greatest effect in well-trained populations. Back squat, sled towing, and sled pushing protocols have shown to acutely improve 20 m sprint performance. Potentiating activities that reflect the specific movement profiles of the performance activity are proposed as most effective, suggesting a possible relationship between muscle specific potentiation and augmented sprint performance. Therefore, the use of a quadriceps dominant sprint related exercise (i.e., backward sled towing) may acutely enhance sprint performance.

The objectives of this study were to determine whether backward sled towing can elicit a PAP response to enhance 5 m sprint performance, and to determine if sled loading via a reduction in velocity can elicit an improvement in 5 m sprint performance. A randomised design was used to examine the effects of forward and backward sled tow loading of 35% and 55% reduction of individual's maximal velocity ($rVel_{mean}$) on 5 m sprint performance. Eighteen participants performed one familiarisation session, followed by four intervention sessions (55% $rVel_{mean}$ backward; 55% $rVel_{mean}$ forward; 35% $rVel_{mean}$ backward; 35% $rVel_{mean}$ forward) separated by a minimum of 24-hours. Intervention sessions included baseline un-resisted 5 m sprints, and the collection of maximum voluntary contractions of lower limb musculature via surface electromyography (EMG), followed by three loaded sled tows over a distance of 3.2 m or 5 m for heavy and light loads, respectively. An un-resisted 5 m sprint was then completed following 6 and 12 min rest. Mean sprint velocity, EMG, and sprint kinematic and temporal data were collected during each session. EMG was used to determine if a potentiated effect was due to changes in neural excitation.

Sled towing, irrespective of load or rest period, produced no significant change in 5 m sprint velocity ($p > 0.05$). Significant difference was found between both 35% and 55% backwards calculated velocity reduction and actual velocities during towing ($p < 0.01$). There was no significant change in EMG across sessions. Kinetic and temporal data suggested no significant changes in baseline measures; however, current findings highlight the importance of vertical force production during sprint acceleration.

Sled towing to potentiate sprint performance using a reduction of velocity requires further investigation. The author acknowledges that greater time under tension during conditioning activities may result in greater sprint related potentiation. However, further research is required to assess the legitimacy of this speculation.

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Abbreviations

ADP	Adenosine diphosphate
ATP	Adenosine triphosphate
BF	Biceps femoris
BM	Body mass
BR	Backward running
Ca^{2+}	Calcium
CaM	Calmodulin
CMJ	Counter movement jump
EMG	Electromyography
FR	Forward running
GM	Gluteus maximus
GN	Gastrocnemius
HR	Heart rate
HR_{max}	Heart rate maximum
m	Metre
min	Minutes
MLC	Myosin light chain
MLCK	Myosin light chain kinase
MLCP	Myosin light chain phosphorylation
MVC	Maximal voluntary contraction
ms^{-1}	Metres per second
N	Newton

Nm	Newton metre
Nkg^{-1}	Newton's per kilogram
$Ns^{-1}kg^{-1}$	Newton per second per kilogram
$Nkg^{-1}s^{-1}$	Newton per kilogram per second
PAP	Post activation potentiation
P	Phosphate
Pi	Inorganic phosphate
RM	Repetition maximum
rev min^{-1}	Revolutions per minute
sec	Seconds
SR	Sarcoplasmic reticulum
TA	Tibialis anterior
$rVel_{mean}$	Mean velocity reduction
VL	Vastus lateralis
SD	Standard deviation

Chapter One: Introduction

Post-activation potentiation (PAP) is a phenomenon characterised by an acute muscular augmentation as a result of a maximal or near maximal pre-conditioning muscular contraction (Seitz, Mina, & Haff, 2017). Following a conditioning activity the muscle is left in a co-existing state of fatigue and potentiation until the point of equilibrium where potentiation is at its greatest (Sale, 2004). Deciphering the balance of fatigue and potentiation has proven somewhat elusive to previous authors (Bevan et al., 2010; Crewther et al., 2011; Whelan, O'Regan, & Harrison, 2014; Wyland, Van Dorin, & Reyes, 2015). Additionally, parameters such as initial muscular strength, rest intervals, individual fibre distribution, training status, and power-strength ratio are recognised as limiting factors of PAP (Tillin & Bishop, 2009).

Various PAP strategies have been utilised to improve acute sprint performance (Byrne, Kenny, & O’Rourke, 2014; Chatzopoulos et al., 2007; Healy & Comyns, 2017; McBride, Nimphius, & Erickson, 2005; Turner, Bellhouse, Kilduff, & Russell, 2015; Winwood, Posthumus, Cronin, & Keogh, 2016). As a chronic training mode forward sled towing is commonly used to increase ground reaction forces (Behrens & Simonson, 2011). However, acutely, a sled load of 20% body mass (BM) has been shown to increase ground reaction forces in the lead leg (Cottle, Carlson, & Lawrence, 2014) while a 75% BM sled load has been reported to improve 15 m sprint performance (Winwood et al., 2016). Contrary, previous research has failed to show that acute sled towing can enhance sprint performance (Whelan et al., 2014).

Contemporary research has indicated the importance of horizontal force production during sprint acceleration (Morin et al., 2012), identifying the significance of eccentric hamstring activation during late stance and late swing phases of sprinting (Morin, Gimenez, et al., 2015;

Yu et al., 2008). Other authors have emphasised the role of quadriceps activation in eliciting high levels of knee torque during sprinting (Handsfield et al., 2017; Tottori et al., 2018). Although hamstring activation is proposed as the most active muscle during sprinting (Morin, Gimenez, et al., 2015), quadriceps dominant exercises have shown significant acute performance improvements. For example, back squats are a common conditioning activity of sprint related PAP investigations where ~90% of one repetition maximum (1RM) improved 5-40 m sprint time and maximal sprint velocity (Chatzopoulos et al., 2007; McBride et al., 2005; Seitz, Trajano, & Haff, 2014). This suggests if potentiation is directed at knee extensors it can initiate a PAP response to improve sprint performance. In contrast, some authors advocate the conditioning activity should be movement specific to maximise the PAP response of the subsequent performance (Dello Iacono, Padulo, & Seitz, 2018; Seitz et al., 2017). It remains equivocal whether resistance load or movement specificity is more important. Current literature indicates that both forward sled towing and back squats can acutely enhance sprint performance, indicating that both resistance load and movement specificity are important.

Another popular exercise that is often prescribed as an effective stressor for multiple systems (i.e., cardiorespiratory, strength endurance, hormonal), is backward resisted sprinting (West et al., 2014). It has the ability to utilise less elastically stored energy (West et al., 2014), implying that force generation is mainly concentric, which is capable of reducing muscle soreness, damage, fatigue, and inflammation compared to eccentric exercise (West et al., 2014). The aforementioned benefits would be a welcome addition if backward resisted towing was able to potentiate acute sprint performance. However, its use as a PAP approach to enhance sprint performance is currently unknown. Electromyography (EMG) may indicate the effect of contraction specificity on sprint PAP. Surface EMG is a non-invasive method of assessing the neuromuscular effects of resisted sled towing (Yu et al., 2008). It can provide an indirect method for assessing muscle recruitment and frequency of firing to determine the acute response of sprinting performance (Yu et al., 2008), which is one theory of PAP. Performance measures such as this may further quantify the relationship between movement specificity and PAP.

Further, body mass is widely regarded as the standard means of sled loading (Jarvis, Turner, Chavda, & Bishop, 2017; Whelan et al., 2014), but due to its large individual variability in sprint performance, it may not be an appropriate method. Alternatively, mean sprint velocity reduction may provide a better approach to determining an individual's sprint load (Winwood et al., 2016).

Sprint related PAP is a contemporary mode of performance enhancement. This thesis will examine the acute effect of backward and forward sled towing on 5 metre sprint performance. As an acute method of training, the potential to enhance sprint performance and training outcomes are substantially significant. To date, sled related sprint PAP literature has only examined forward sled movement. To the author's knowledge, this is the first study to investigate the effect of acute backward sled towing on sprint performance. This thesis will provide a significant opportunity to increase the current body of sprint related PAP literature, allowing for the application of such modalities in practical training and performance situations.

The aim of this thesis is to provide an extensive review of contemporary sprint biomechanics and sprint related PAP literature from which a hypothesis will be tested to investigate the effect of heavy sled loads and movement specificity on 5 m sprint performance. The literature review (**Chapter Two**) will commence by explaining the concepts surrounding sprint locomotion, specific sprint kinetics and kinematics, and the acute differences between forward and backward sprinting. The review will then focus on PAP, its mechanisms, the parameters of its application, and previous sprint related PAP literature. The aim of the literature review will be to summarise the main concepts of sprint locomotion, PAP physiology, and the current knowledge of its application. From this knowledge, the aims and hypothesis will be presented in **Chapter Three**. The methodology, equipment, and testing procedures will be documented in **Chapter Four**, followed by an analysis of findings in **Chapter Five**. **Chapter Six** will provide an in-depth discussion of the findings that culminate in conclusions and possible future research directions (**Chapter Seven**).

Chapter Two: Literature Review

2.1 Sprint Locomotion

Elite sprint performance is characterised by a high level of explosiveness over a short period of time (Mero, Komi, & Gregor, 1992), typically seen within the early acceleration phase (i.e. 5-10 m) (Murphy, Lockie, & Coutts, 2003). It is from this perspective acceleration will be defined for the current study. Sprint acceleration is regarded as a key characteristic when attaining elite sprint status (Morin, Slawinski, et al., 2015). However, during sprint performance, the most powerful and/or athletic individual is not always the most successful. An individual's success is often determined by directional velocity and the ability to control the body's centre of mass. **Section 2.1** will aim to quantify the desired ground reaction force profiles of sprint acceleration. Additionally, this section will discuss forward and backward locomotion, changes in movement patterns, postural changes, and motor recruitment patterns.

2.1.1 Sprint Kinetics and Kinematics

The ability to accelerate the centre of mass is a key determinant of sprint performance. The success of sprint acceleration is determined by gravitational force, air resistance, and ground reactive forces (GRF) (Morin, Gimenez, et al., 2015). However, the most athlete-influential force during sprint performance is GRF (Kawamori, Nosaka, & Newton, 2013), suggesting that an augmentation of GRF will generate an enhanced sprint performance. Sprint GRF are measured in three planes: vertical, anterior-posterior, and medial-lateral (Samozino et al., 2016). Within the sagittal plane, horizontal and vertical force impulses are the key elements of sprint motion and mass displacement. Although vertical force production is highlighted as a key modulator of sprint performance, horizontal force production is pivotal during early acceleration (Morin, Gimenez, et al., 2015). The most favourable acceleration profile is one in which vertical impulse is sufficient to overcome gravity, generating a separation time great enough to reposition lower limbs, allowing all other strength reserves to generate horizontal force (Hunter, Marshall, & McNair, 2005). The importance of vertical force has been shown during first stance for the need to reposition the lower limbs beneath the centre of mass and create a more erect position. Graham-Smith, Brandner, Ryu, and Gallagher (2017) analysed the first two steps of 19 international level athletes for kinetic variables. They reported a peak vertical acceleration of 9.9 ms^{-2} during the first stance while peak horizontal acceleration was measured at 11.3 ms^{-2}. This highlights the importance of horizontal force production during acceleration, and the requirement of vertical force to accommodate such action. Vertical force production has been shown to increase until the 14th stance (Plamondon & Roy, 1984). Thereafter, vertical force is maintained during maximal speed whilst maximal horizontal impulse is achieved (Nagahara, Mizutani, Matsuo, Kanehisa, & Fukunaga, 2017).

The subcomponents of anterior-posterior GRF, identified as braking and propulsive forces are of additional interest. Braking force describes the force generated in a posterior direction, occurring early within the stance phase; whereas propulsion occurs late within the stance phase, and describes anterior force production (Ciacci, Di Michele, & Merni, 2010). From the analysis of 18 male elite sprinters, Nagahara et al. (2017) reported the importance of a smaller braking impulse at speeds greater than 75% of maximal sprint velocity. Reductions in braking force and increases in propulsive GRF have been identified as key components for successful sprint performance (Ciacci et al., 2010). A highly active touchdown has been hypothesised to reduce braking force (Hunter et al., 2005). This is related to the horizontal velocity of the foot, which is minimised prior to foot contact, potentially initiating force propulsion earlier in the stance phase. Propulsion can be maximised by the full triple extension of ankle, knee, and hip during stance phase take off (Hunter et al., 2005).

Contact time and its ratio between braking and propulsive force have been identified as a major characteristic of successful sprint acceleration (Morin, Slawinski, et al., 2015). It defines the duration of one full stance phase, beginning with the ground contact of the foot and ending with toe off (Lockie, Jalilvand, Callaghan, Jeffriess, & Murphy, 2015). Duration of the braking phase is reported to be shorter during initial acceleration when compared to maximal velocity braking (Lockie et al., 2015). Previous literature suggests that contact time during maximal sprinting does not significantly change (McMahon & Cheng, 1990). However, Weyand, Sternlight, Bellizzi, and Wright (2000) found significant changes in sprint speed were achieved through greater ground force production during smaller contact times as opposed to increased leg movements. Multiple authors have also linked lower contact times to more efficient sprint accelerations (Lockie et al., 2015; Murphy et al., 2003; Weyand et al., 2000).

2.1.2 Acute Differences between Forwards and Backwards Running

Backwards running (BR) (labelled retro running) is often prescribed as a clinical rehabilitation exercise which offers a dynamic lower body movement to reduce ligament stress (Dufek, House, Mangus, Melcher, & Mercer, 2011; Threlkeld, Horn, Wojtowicz, Rooney, & Shapiro, 1989). Backwards locomotion as a dynamic movement profile is seen mainly within a sporting environment, often used to improve dynamic balance, endurance, and reduce joint loading (Threlkeld et al., 1989). However, the efficacy of its application is relatively unknown. BR is suggested to utilise different central nervous patterns (Eilam & Shefer, 1992), along with an obstructed directional awareness (Hoogkamer, Meyns, & Duysens, 2014), and significantly different muscle activation patterns in comparison to FR (Threlkeld et al., 1989). The following headings will further investigate the acute differences between BR and FR.

2.1.2.1 Central Neural Pattern

Backward running is a form of locomotion often seen in various sporting environments (Uthoff, Oliver, Cronin, Harrison, & Winwood, 2018). The application and coordination of BR are suggested to be controlled via an intrinsic property within the spinal neural circuitry (Eilam & Shefer, 1992). Many authors suggest the central neuron pattern is inversely identical during backward and forward running (Mehdizadeh, Arshi, & Davids, 2015; Meyns, Desloovere, Molenaers, Swinnen, & Duysens, 2013). Studies of young infants support the conclusion of a central pattern generator, with infants able to seamlessly alternate between forward and backward walking irrespective of mature corticospinal projections (Lamb & Yang, 2000). However, a common central pattern generator is purported as opposed to a completely identical pattern generator (Hoogkamer et al., 2014).

2.1.2.2 Directional Awareness

A fundamental difference between forward and backward locomotion is the availability of visual sensory information. During FR an athlete can utilise visual information to convey attributes of the surrounding environment, resulting in directional awareness (Hoogkamer et al., 2014). However, during BR alternative sensory mechanisms must be utilised to ensure locomotion occurs in the desired direction (Hoogkamer et al., 2014). Many athletes, especially those competing in team sports, utilise backward locomotion whilst performing fine motor skills. Elite rugby backs spend ~3.5% of a match running backward, while completing game-specific skills (G. Duthie, Pyne, & Hooper, 2003). Likewise, elite touch rugby player's complete 30 backward running repetitions lasting 3.13 sec in a single 30 min game, accounting for 5% of total game time (O'Connor, 2001). However, the intensity of these efforts and the incorporation of BR within team training environments may benefit athlete performance.

2.1.2.3 Muscular Activation

Although BR is mainly limited to rehabilitation, balance, and strengthening protocols (Dufek et al., 2011; Flynn & Soutas-Little, 1993; Hoogkamer et al., 2014; Rose, DeMark, Fox, Clark, & Wludyka, 2018), it has also been shown to enhance FR performance (Threlkeld et al., 1989). BR has been shown to increase quadriceps strength via the increase activation of knee extensors (Flynn & Soutas-Little, 1993; Threlkeld et al., 1989). Threlkeld et al. (1989) found a decreased vertical loading force whilst running backward compared to forwards. Therefore, the reduction in joint loading may, in theory, increase the activation of quadriceps and therefore alter the firing frequency of such motor patterns. Flynn and Soutas-Little (1993) combined EMG and kinetic parameters to examine the differences in BR and FR. Significant decreases in eccentric and concentric peak muscle and mechanical power at the knee were found when comparing BR (concentric: 404W; eccentric: -176W) and FR (concentric: 475W; eccentric: -817W). However, significantly different muscle firing patterns occurred between trials. Vastus lateralis and vastus medialis motor patterns were largely concentric and isometric during backward running when compared to FR conditions. Flynn and Soutas-Little (1993) also suggest a significant difference in motor firing patterns between running modes. FR initiated rectus femoris, vastus laterlalis, vastus medialis, gastrocnemius, and tibialis anterior upon heel strike, whilst biceps femoris was activated at 8% completion of the stance phase. During BR, rectus femoris, vastus lateralis, vastus medialis, and lateral gastrocnemius were activated at toe strike. Activation of biceps femoris and tibialis anterior onset occurred at 10% and 20% through stance phase respectively.

Force power curves suggest an increased concentric activation of quadriceps during the last 50% of stance phase during backward running. This suggests that while less work is generated across the knee joint BR may in fact activate quadriceps more than FR. Contemporary research has proposed an increased anterior muscular chain activation during BR in contrast to FR (Sterzing, Frommhold, & Rosenbaum, 2016). Irrespective of running velocity, Sterzing et al. (2016) reported a leg extensor/hip flexor range of 53.3% and 186.6% activation increase in BR compared to FR. Complimentary to an increased muscular activation, a significant increase in average muscle force per ground force unit (14%) has been shown in BR compared to FR (Wright & Weyand, 2001), which may be due to increased ankle force during BR. The aforementioned study also reported a significantly shorter muscle length at the ankle (4%) during BR, suggesting that these muscles spent 4% longer concentrically contracted during a single stride cycle during BR. These shorter fibres are suggested to increase active muscle volume ~10% during BR in comparison to FR. The speed at which these contractile units develop force is a key variable when determining explosive potential (Slawinski et al., 2010). BR has been shown to significantly increase force development rates by up to 22%, with an increased rate development force at higher running velocities (Wright & Weyand, 2001).

2.1.3 Section Summary

It is evident that BR displays a unique physiological profile when compared to FR. Whilst BR has been shown to have limitations in the form of visual impairment, its beneficial characteristics include increased anterior muscle activation (Flynn & Soutas-Little, 1993;

Sterzing et al., 2016; Uthoff et al., 2018), increased average muscle force per ground force unit (Wright & Weyand, 2001), and increase rate of force development at relevant velocities (Wright & Weyand, 2001). The majority of research findings to date highlight BR as a clinical rehabilitation exercise. With a known reduction of maximal velocity at ~30% (Arata, 1999), it is unknown if these BR findings can be translated at higher relative velocities.

2.2 Post-Activation Potentiation

Post-activation potentiation describes an acute augmentation of skeletal muscle properties, with the aim to enhance muscular performance (Tillin & Bishop, 2009). However, various parameters can limit or enhance the application of PAP. **Section 2.2** will explain the relevant mechanisms of PAP and the limitations of its application. The section will continue with an in-depth overview of sprint related PAP literature before concluding with a summary of findings.

2.2.1 PAP Mechanisms

PAP is a phenomenon by which acute muscular performance characteristics are enhanced as a result of their contractile history (Tillin & Bishop, 2009; Vandenboom, Gittings, Smith, Grange, & Stull, 2013). The manifestation of such phenomena is dependent on a conditioning activity, described to prime muscle twitch velocity, resulting in an increased contractile force (Tillin & Bishop, 2009). This is often observed through the completion of maximal strength conditioning activities prior to the completion of power based movements (Chatzopoulos et al., 2007; Healy & Comyns, 2017; Seitz et al., 2014; Yetter & Moir, 2008).

Force potentiation was first discovered over a century ago (Lee, 1907) and has since been renowned as a central characteristic of fast-twitch skeletal muscle (Vandenboom et al., 2013).

However, it is unclear if one mechanism or multiple mechanisms work together to facilitate PAP. Myosin regulatory light chain phosphorylation and the recruitment of higher order motor units are both proposed to directly influence potentiation (Tillin & Bishop, 2009).

2.2.1.1 Myosin Regulatory Light Chains

Myosin light chain phosphorylation (MLCP) is regarded as a facilitator of force potentiation (Fukutani & Kawakami, 2015; Stull, Kamm, & Vandenboom, 2011; Vandenboom et al., 2013). The role of synaptic receptor excitation at the muscle site resulting in a reactive secretion of calcium ions (Ca^{2+}) from the terminal cisternae is well established (Santulli & Marks, 2015). The binding of Ca^{2+} to the nearby troponin on the actin filament changes the shape of the tropomyosin strand to expose the myosin binding site (Squire, Paul, & Morris, 2017; Stull et al., 2011). The myosin head then binds to the actin filament by discarding the adenosine diphosphate (ADP) and inorganic phosphate (Pi), resulting in muscular contraction (Squire et al., 2017). Myosin binding is broken by the reuptake of adenosine triphosphate (ATP), resulting in the myosin head returning to its original position to restart the binding process (Squire et al., 2017). This contraction sequence occurs in wave-like formations, ensuring a continuous contraction (Squire et al., 2017). Maximal force generation has been linked to the number of instantaneous cross-bridge attachments at a given moment (Fukutani & Kawakami, 2015).

The importance of the MLC has been well established within the physiology of smooth muscle (Grange, Vandenboom, & Houston, 1993), but its relevance to skeletal muscle is still relatively unknown. Evidence from a variety of animal models suggests that the primary mechanism of MLCP is the activity of myosin light chain kinase (MLCK) (Vandenboom et al., 2013). Action potentials at the neuron change the voltage within the sarcoplasmic membrane initiating the opening of Ca^{2+} channels, causing an influx of Ca^{2+} (Jahn & Fasshauer, 2012). As this Ca^{2+} is released from the sarcoplasmic reticulum into the sarcomeres, calmodulin-dependent Sanchez-Sanchez et al. (2018) MLCK activates the phosphorylation of the myosin (Stull et al., 2011). This results in an augmented myosin reattachment rate, thereby increasing the rate of force production (Vandenboom et al., 2013). This augmented cross bridge phosphorylation results in an increased intracellular Ca^{2+} sensitivity, amplifying fast-twitch skeletal muscle force generation through the increased cross-bridge attachments at a given time (Stull et al., 2011). Chang et al. (2016) developed a biochemical model illustrating the Ca^{2+}/CaM activation of MLCK and the phosphorylation of the MLC (See Figure 1).

Figure 1. Ca^{2+}/CaM activation of MLCK and phosphorylation of MLC (Chang, Kamm, & Stull, 2016).

However, vivo studies can only examine tetanic skeletal muscle stimulation. While this gives us an understanding of MLCP physiology, it cannot represent MLCP within complex movement patterns. Vandenboom et al. (2013) has attempted to address this concern in regard to locomotion, stating that concentric contractions are potentiated in a speed-dependent manner; faster forms of locomotion may increase work and power output of potentiated muscles. This may also reduce the neural sensory input required to stimulate lower levels of work and power output.

2.2.1.2 Motor Unit Recruitment

Motor neurons are commonly regarded as the final stage of neural processing, in which their excitation coveys motor behaviours created earlier between inter-neuron circuits (Song, Ampatzis, Björnfors, & El Manira, 2016). However, the magnitude of their activation depends on the total number of recruited motor units, and the rate at which action potentials are discharged (rate coding) (Duchateau & Baudry, 2014). The influence of recruitment and rate coding are dependent on the range of force generation required for a particular action (Milner-Brown, Stein, & Yemm, 1973). Motor unit recruitment is influential during the early phases of contraction, whereas, rate coding is more influential within the top end of the velocity force relationship (Enoka & Duchateau, 2017). Increased excitation potentials across the synaptic junction of the spinal cord have been shown to last several minutes within animal studies (Tillin & Bishop, 2009). An ‘all or nothing’ motor neuron response is said to coincide with a pre-synaptic excitation potential (Tillin & Bishop, 2009). Therefore, pre-excitation potentials must meet or exceed the post-synaptic receptor sensitivity to initiate muscular contraction (Tillin & Bishop, 2009).

The activation of motor units has been confirmed from fine wire electrodes (Oya, Riek, & Cresswell, 2009). Motor units recruited early during contraction reach a consistent peak value despite the continued increase in force generation. This is referred to as the saturation discharge rate and limits the motor neuron discharge rate despite the increased synaptic excitation (Enoka & Duchateau, 2017). Synaptic transmission failure is a major inhibitor of voluntary muscle activation, thought to be related to a pre-established protective reserve (Tillin & Bishop, 2009). Transmission failures have been shown to occur more frequently at large motor neuron sites, particularly within fast twitch fibres during peak force generation due to increased presynaptic branching (Mendell, 2005). However, animal studies have shown an ability to decrease the occurrence of transmission failure as a result of increased excitatory pre-synaptic potentials (Hirst, Redman, & Wong, 1981). This suggests that the utilisation of a pre-conditioning stimulus may increase the pre-synaptic sensitivity, reducing the occurrence of transmission failure. Moreover, increased fast twitch fibre recruitment would result in greater contractile force development. An increased fast twitch muscle fibre excitation has been linked to the use of pre-conditioning exercises (Tillin & Bishop, 2009). Therefore, an increased peak force production may transfer into dynamic movement patterns such as sprinting (Tillin & Bishop, 2009).

When investigating peripheral neural enhancement and its association with acute force enhancements, Hoffmann's reflex (H-reflex) responses are assessed via surface EMG recordings (McNeil, Butler, Taylor, & Gandevia, 2013). H-reflex readings display the motor neuron pool response to a volley from muscle spindle afferents, recorded to assess neuron pool excitability (McNeil et al., 2013). However, conduction feedback from peripheral receptors (e.g., Golgi tendon organs) and other synaptic inhibitions can be influenced by both changes in posture and mindset (McNeil et al., 2013). Therefore, for the H-reflex to display consistent motor neuron excitability, a highly specialised and specific experimental methodology to ensure reliable and valid measures is required (Gago, 2016; McNeil et al., 2013).

Nevertheless, neural influence via H-wave amplitudes has previously been investigated in relation to a PAP response. Güllich and Schmidtbleicher (1996) reported a significant H-wave depression following a 42% potentiation of the lateral gastrocnemius at 8 min 42 sec (± 3 min 36 sec) post maximal voluntary isometric contraction. This would suggest that neural excitation plays at least a partial role in PAP. However, non-central activation factors such as presynaptic inhibition and sodium-potassium regulation within muscle cells were not accounted for in this study. In contrast, other studies suggest that increased rates of excitability as a result of pre-conditioning contractions are unrelated to neural excitability (Folland, Wakamatsu, & Fimland, 2008; Hodgson, Docherty, & Zehr, 2008).

2.2.2 Fatigue and PAP

Muscle fatigue is documented as a major inhibitor of skeletal muscle potentiation (Allen, Lamb, & Westerblad, 2008; Tillin & Bishop, 2009; Vandenboom et al., 2013; Whelan et al., 2014; Winwood et al., 2016). Muscle fatigue is defined as an acute but reversible inhibitor of muscle force, work, and power (Allen et al., 2008). The balance of potentiation and fatigue is recognised as a crucial variable when attempting to initiate a PAP response (Tillin & Bishop, 2009). Although fatigue and potentiation coexist, their dissipation rates differ significantly (Healy & Comyns, 2017). If adequate recovery is provided, acute fatigue will dissipate leaving skeletal muscle in a state of potentiation (See Figure2) (Tillin & Bishop, 2009).

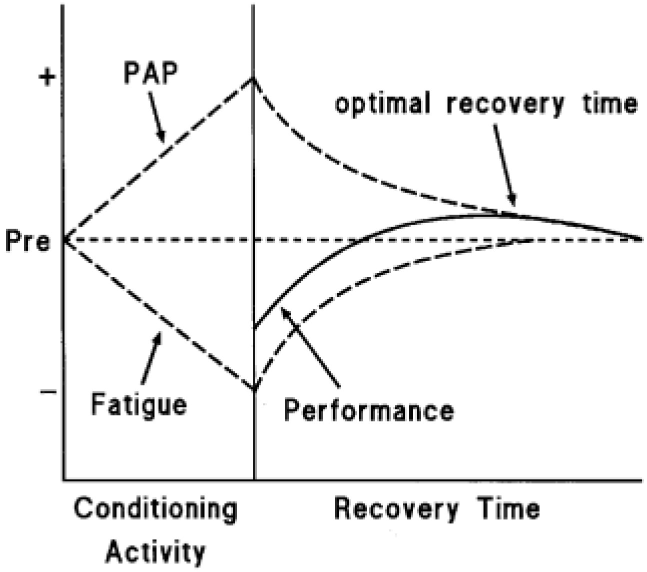

Figure 2. The fatigue - potentiation relationship when utilising a pre-conditioning activity to acutely enhance skeletal muscle performance (Sale, 2004).

The underlying mechanisms of this relationship have been debated within the literature. MLCP relies heavily on the availability of ATP. When fatigued, skeletal muscle reductions of readily available ATP have been observed to reduce sarcoplasmic reticulum (SR) Ca^{2+} release by ~20% (Allen et al., 2008). This effect is further inhibited through the generation of ATP hydrolysis by-products and increased magnesium (Allen et al., 2008). The cost of such a reduction would be a decreased MLCP rate, resulting in a decrease in power output, also known as muscular fatigue.

Neural fatigue is a combined result of central and peripheral mechanisms. Central fatigue is a result of the cerebral cortex, spinal cord, and motivational fatigue (Meidinger, 2017). The fatigue of cerebral and spinal excitation results in a direct decrease in peripheral motor neuron amplitude and recruitment rate (Meidinger, 2017). This decreased excitation rate drastically augments force generation from afferent muscle fibres (Meidinger, 2017).

Xenofondos et al. (2015) findings are in agreement with previous research that inhibited H-reflex excitability of motor inputs play a major role in fatigue onset of skeletal muscle potentiation (Gollhofer, Schöpp, Rapp, & Stroinik, 1997; Trimble & Harp, 1998). These physiological attributes of fatigue perhaps suggest a co-existing relationship between intercellular fatigue and neural fatigue.

2.2.2.1 Optimal Recovery Time

Many authors have investigated the effect of recovery time on potentiation with mixed results (Healy & Comyns, 2017; Seitz et al., 2017; Whelan et al., 2014; Winwood et al., 2016). A limited number of studies aimed at PAP recovery times have yielded no accurate consensus in relation to optimal recovery time post conditioning contraction. However, it is suggested that brief (5 min) (Chatzopoulos et al., 2007; Dello Iacono et al., 2018; McBride et al., 2005), moderate (8 to 12 min) (Dello Iacono et al., 2018; Kilduff et al., 2008; Linder et al., 2010; Winwood et al., 2016), and extensive (<15 min) (Chiu et al., 2003) recovery periods may elicit skeletal muscle potentiation. Gołaś, Maszczyk, Zajac, Mikołajec, and Stastny (2016) found a significant improvement in bench press throws, countermovement jumps (CMJ), and latissimus pull-down performance following a 6 min rest period. Winwood et al. (2016) findings also suggest an optimal rest period of 4-12 minutes. However, it must be noted that the time required for rest may be influenced by the type of conditioning activity and its load (Seitz & Haff, 2016), highlighting the individualised nature of PAP.

2.2.2.2 Intensity of Conditioning Activity

Pre-conditioning exercise intensity plays a large role in the prescription of PAP (Tillin & Bishop, 2009). As previously described, the mechanisms of fatigue and potentiation coexist; therefore, subsequent force development depends on their balance (Wilson et al., 2013).

Hamada, Sale, MacDougall, and Tarnopolsky (2000) illustrated this when isometric MVC force peaked at 127% during the third set of 16 repetitions. However, a 32% decline in MVC peak force was noted with the occurrence of fatigue. These findings are supported by Wilson et al. (2013) meta-analysis suggesting that optimal potentiation occurs when a pre-conditioning activity is completed with a moderate load (60-84% 1RM), as opposed to high load (>85% 1RM). Heavy load exercise has previously been shown to elicit increased energy expenditure when compared to light/moderate loads (Mazzetti et al., 2011). Consequently, heavy loads may elevate the fatigue levels required to effectively initiate a PAP response. Therefore, it is possible that a moderate load conditioning contraction would elicit PAP without the increased fatigue of a pre-conditioning contraction of higher intensity (Wilson et al., 2013). These findings emphasise the coexisting relationship between fatigue and potentiation.

2.2.3 Parameters of PAP

Many studies have reported the onset of PAP through a variety of conditioning methods (Healy & Comyns, 2017; Jarvis et al., 2017; Smith et al., 2014; Winwood et al., 2016). Inter-individual variability is a consistent and significant finding of these studies, which is indicative of a responder versus non-responder PAP relationship (Healy & Comyns, 2017; Whelan et al., 2014; Winwood et al., 2016). Various parameters such as training age, training status, initial muscular strength, power-strength ratio, and individual muscle fibre distribution have been identified to reduce subsequent PAP performance (Wilson et al., 2013). The following topics will further discuss the interaction of these parameters.

2.2.3.1 Training Age / Status

Well-trained individuals are physiologically predisposed to the characteristics required for the onset of PAP (Seitz & Haff, 2016; Wilson et al., 2013). Generally, well-trained individuals have greater muscular strength, greater power-strength ratio, and have a higher distribution of type II muscle fibres than their less trained counterparts (Seitz & Haff, 2016). Metabolic advantages of well-trained individuals, such as the increased buffering rate of hydrogen (Gibala et al., 2006), may reduce the onset of fatigue leaving the individual in a potentiated state for a greater period (Tillin & Bishop, 2009; Wilson et al., 2013). Long-term neural adaptation from exercise has also been suggested to potentiate intracellular pathways (Lynch, 2004), leading to augmented neural performance. Increased synaptic junction excitation and motor-unit synchronisation are postulated as a potentiation advantage of well-trained individuals (Tillin & Bishop, 2009). An example of this, Chiu et al. (2003) reported a 3% increase in vertical jump height following 5 sets of single repetition back squats at 90% 1RM in well-trained individuals. Contrary, untrained individuals exhibited a 4% decrease in performance post conditioning activity. Wilson et al. (2013) has acknowledged these findings by suggesting that athletes with >3 years of resistance training respond optimally to PAP protocols. However, Seitz and Haff (2016) oppose this theory, proposing that manipulating a PAP protocol can lead to a potentiated response in both trained and untrained individuals.

2.2.3.2 Initial Muscular Strength

Initial muscular strength is regarded as a key parameter of PAP (Tillin & Bishop, 2009; Wilson et al., 2013). Previous research has documented moderate correlations of initial 1RM strength and subsequent potentiation, $r = 0.63$ (Kilduff et al., 2007); $r = 0.66$ (G. M. Duthie, Young, & Aitken, 2002). Moreover, a half-back squat protocol reported a 4% increase in CMJ height in strong individuals (>160 kg 1RM) in comparison to a non-significant 0.04% increase within the weaker population (<160 kg 1RM) (Gourgoulis, Aggeloussis, Kasimatis, Mavromatis, & Garas, 2003). However, multiple studies have utilised a mixture of participant conditioning levels, with a significant portion reporting ineffective protocols to acutely enhance performance (Healy & Comyns, 2017). For example, Chiu et al. (2003) initially reported no significant effect from conditioning back squats on vertical jump squat performance. However, upon dividing the experimental cohort into ‘athletically trained’ and ‘recreationally trained’ classifications a ~3% increase in vertical jump squat performance was reported in ‘athletic’ participants. These findings highlight the potential relationship between potentiation and training levels. The significant increase in type II muscle fibres within athletically trained individuals is well known (Fukutani & Kawakami, 2015). Fast twitch II fibres have well-documented relationships with increased MLCP activity and high order motor unit occurrence (Fukutani & Kawakami, 2015). This increased MLCP and higher-order motor unit recruitment are understood to enhance an acute potentiated response in well-trained individuals (Fukutani & Kawakami, 2015; Tillin & Bishop, 2009).

2.2.3.3 Power-Strength Ratio

Individuals that have a low power-strength ratio are thought to attain a more effective potentiation response (Tillin & Bishop, 2009). Schneiker, Billaut, and Bishop (2006) found a significant negative correlation ($r = 0.91$) between the power-strength ratio (<19 Wkg^{-1}) and peak power potentiation during loaded CMJ following a 6RM set of back squats. In contrast, no relationship was found between participants with a power-strength ratio >19 Wkg^{1} and peak power potentiation, suggesting that strength dominant individuals may benefit greater from PAP than their powerful counterparts. Equally, Smith et al. (2014) found an above average vertical maximum jump performance among participants but a decrease in potentiated peak power output in comparison to previous literature. While the literature is scarce, a power dominant individual may decrease its potentiation due to their preconditioned muscle mechanics. An individual who consistently trains in a ‘powerful’ manner may exhibit physiological characteristics of increased motor neuron excitation and increased rates of MLCP. Therefore, a strength-based conditioning activity may not have the same stimulating effect on these particular individuals. More research is required to gain a greater understanding of power-strength relationships and skeletal muscle potentiation.

2.2.3.4 Individual Muscle Fibre Distribution

Individual muscle fibre distribution is understood to be a major component of PAP (Tillin & Bishop, 2009). Hamada et al. (2000) presented a fibre distribution – PAP relationship following a protocol of 16 five-second MVC. Separated into predominantly fast twitch and slow twitch groups, peak potentiation appeared in knee extensors of fast twitch individuals during the early stages of testing (127% force increase following the third MVC repetition). However, the onset of fatigue significantly reduced peak force generation of fast twitch individuals. Although fast twitch dominant participants demonstrated a greater PAP response, they also displayed an increased fatigue response to the conditioning stimulus, which is likely due to the force-fatigue relationship (Allen et al., 2008; Tillin & Bishop, 2009). A high dependence on ATP turnover in fast-twitch individuals would lead to a greater use of stored anaerobic energy, resulting in the generation of metabolites associated with fatigue (Allen et al., 2008; Cairns et al., 2017). Therefore, fast twitch dominant participants may produce greater MVC when potentiated due to their anaerobic turnover rate, but peak force generation will likely decrease due to the metabolic demands associated with anaerobic fatigue (Cairns et al., 2017).

2.2.4 PAP and Sprint Performance

The various proposed mechanisms of PAP have been previously discussed (refer to 2.2.1 PAP Mechanisms), similarly, uncertainty surrounds the prescription of PAP-related conditioning activities. While previous research has discovered positive acute changes in muscle performance during sprint related performance (Healy & Comyns, 2017; Smith et al., 2014; Turner et al., 2015; Winwood et al., 2016), others have found no significant effect of sprint related PAP (Bevan et al., 2010; Whelan et al., 2014). Back squats, power cleans, plyometric exercises and sled towing have been investigated in relation to sprint performance with varying results of potentiation (Healy & Comyns, 2017). The following section will explore contemporary sprint PAP literature, with the aim to examine PAP methodology and report significant findings.

2.2.4.1 Back Squats

Back squat conditioning protocols have reported differing conclusions over sprint distances of 5-40 m (Bevan et al., 2010; Chatzopoulos et al., 2007; Comyns, Harrison, & Hennessy, 2010; McBride et al., 2005; Yetter & Moir, 2008). Over longer distances of 20-40 m, sprint performance increased after heavy squatting protocols (Chatzopoulos et al., 2007; Comyns et al., 2010; McBride et al., 2005; Seitz et al., 2014; Yetter & Moir, 2008), however these same studies reported no significant changes in performance over shorter distances (0-10 m). These findings came as a result of heavy loads (70-90% 1RM) for 1-10 repetitions, with rest periods of 3-12 minutes. Chatzopoulos et al. (2007) investigated 15 male amateur team sport athletes over 30 m following the completion of 10 single repetition back squats at 90% 1RM. No change in sprint time was found after three minutes rest, however, significantly faster 10 and 30 m sprint times were observed following five minutes of rest. McBride et al. (2005) also observed an improvement over a longer distance of 40 m following one set of three back squats at 90% 1RM.

More recently, Seitz et al. (2014) investigated thirteen elite junior rugby players over 20 m following a single set of three back squats at 90% 1RM. The authors reported a significant improvement in sprint time, velocity, and average acceleration following a recovery period of seven minutes. Wyland et al. (2015) reported a significant 3.5% decrease in 9.1m sprint time following five sets of three repetitions 85% 1RM back squats. Interestingly, 30% of resistance was applied in the form of resistance band tension, highlighting the ability for accommodating resistance to onset acute skeletal muscle potentiation. Of particular interest, Sanchez-Sanchez et al. (2018) utilised explosive back squats to induce a 3.2% decrease in total time to complete a repeated sprint ability test (six 20 m sprints separated by 20-sec rest). PAP protocol comprised of a single set of 90% 1RM explosive back squats, at a vertical velocity of 0.5 ms^{-2}, until concentric force production was reduced by ≥10%. These findings highlight an alternative method of PAP prescription, utilising a decrement of force production and highlighting the potential effect of movement velocity during PAP conditioning activities. From the aforementioned research, back squats are able to acutely enhance 5-40 m sprint performance using heavy load (70-90% 1RM) for ~3 repetitions with sufficient rest (4 to 8 min). However, it is noted that the effectiveness of such protocols is dependent on population characteristics such as initial muscular strength and squat technique (Healy & Comyns, 2017).

2.2.4.2 Plyometric Exercise

Acute sprint enhancements have also been reported from plyometric conditioning activities (Healy & Comyns, 2017). Due to the similar biomechanical movement patterns, plyometric exercise has seen an increased popularity when assessing sprint related PAP. Previous studies have investigated a range of plyometric exercise modalities such as depth jumps, tuck jumps, and alternating bounding with a mixture of conclusions (Byrne et al., 2014; Lima et al., 2011; Till & Cooke, 2009; Turner et al., 2015).

Byrne et al. (2014) reported a significant 2.9% reduction in 20 m sprint time where 29 active males completed 1 x 3 depth jumps. Depth jumps were performed from a predetermined height in accordance to a 0.25-sec ground contact time, one minute prior to a 20 m sprint assessment. However, Till and Cooke (2009) had previously assessed a plyometric jump protocol on sprint related PAP and reported non-significant changes in 10 and 20 m sprint performance. They utilised 1 x 5 tuck jumps prior to sprint assessments following rest periods of 4, 5, and 6 minutes. The absence of a PAP response may be related to the cohort training level and stimulus chosen. A single set of tuck jumps may not be a significant stimulus for semi-professionally trained academy footballers. This highlights the importance of utilising a significant conditioning stimulus relative to the cohorts training status.

Lima et al. (2011) adjusted for such variables when assessing ten male sprinters using 2 x 5 drop jumps from a height of 0.75 m. The increase in stimulus resulted in a decreased sprint time following 10 and 15 minutes of rest. Turner et al (2015) reported similar findings via the use of alternating leg bounds prior to 20 m sprint performance. Twenty-three plyometric-trained males completed 3 x 10 alternating bounds with a vest relative to 10% body mass as resistance that significantly improved 10 and 20 m average sprint velocity that occurred 4 to 8 minutes post-bounding. The broad application of PAP is highlighted through the aforementioned studies. Whilst previous work focuses on loaded preconditioning activities, plyometric PAP methods highlight the ability of body weight and rate of force development exercises protocols to potentiate sprint performance.

2.2.4.3 Sled Towing

While sled towing interventions have shown to improve chronic sprint performance (Kawamori, Newton, Hori, & Nosaka, 2014), limited evidence has supported acute sprint performance. Moderate sled loads (75% BM) have been shown to significantly enhance 15 m sprint performance when compared to heavy loads (150% BM) following 12 min rest (Winwood et al., 2016). Furthermore, Jarvis et al. (2017) documented a significant 3.7% improvement in 15 m sprint time 8-minutes post 3 x 50% BM 15 m sled tows. Interestingly, Winwood et al. (2016) and Jarvis et al. (2017) highlight that a 34-44% reduction in velocity may increase sprint PAP. However, the relationship between velocity reduction and individual training status is still unknown.

In contrast, Whelan et al. (2014) observed significant reductions in sprint performance at 2, 4, 6, 8, and 10 minutes following 3 x 30% BM sled tows over 10 m. In support of this Smith et al. (2014) reported no significant changes in 40-yard sprint time following a 20-yard sled tow at 10%, 20% and 30% BM. Although Whelan et al. (2014) and Smith et al. (2014) concluded the inability of sled towing to potentiate sprint performance, both authors acknowledged that a 30% BM load may not be sufficient stimulate a potentiated response. However, Wong et al. (2017) reported a 4.4% decrease in 5 m sprint time following a 30 m 30% BM sled load sprint using an individualised rest protocol. These findings further amplify the linear relationship between PAP and fatigue.

Alternative resisted sprint methods have been investigated to determine if acute sprint performance is enhanced (Matthews, Comfort, & Crebin, 2010; Seitz et al., 2017). For example, Matthews et al. (2010) investigated the sprint skate performance of eleven ice hockey players using a 10-second heavily resisted sprint on ice. Following a 4-minute rest interval, a significant 2.6% reduction in 25 m sprint performance was reported. However, the authors did not report the selected load of the resisted sprints. Although an intraclass correlation coefficient during pilot work (n = 8) highlighted a highly reliable test measure, resistance was self-determined by the individual holding a towing rope. More recently, Mangine et al. (2018) investigated the use of a commercial cable resistance device (1080 sprint, Lidingo, Sweden) on 20 m sprint time. Although a 5% velocity decrement found no significant changes in 20 m sprint time, a significant enhancement in rate of force development was observed (p <0.001).

To the author’s knowledge, only one study has investigated the use of sled pushing to potentiate 20 m sprint performance. Seitz et al. (2017) examined the sprint performance of twenty rugby league players following a moderate (75% BM) and heavy (125% BM) sled push. To ensure equitable work between light and heavy loads sled push distance was calculated at 15 m and 9 m for light and heavy loads, respectively. A significant decrease in sprint time was observed after 8 and 12 minutes rest following the 75% BM sled push (-1.80% and -1.55%, respectively). This supports Winwood et al. (2016) findings that 75% BM (or a velocity decrement of 34-37%) can acutely enhance sprint performance following 12 minutes rest. Jarvis et al. (2017) also discusses velocity decrement in relation to a 40-44% reduction, which is significantly greater than recommended by Winwood et al. (2016). These discrepancies highlight a requirement of further investigation of using velocity decrement as a legitimate loading scheme.

Pre-conditioning exercise protocols offer a way in which PAP parameters can be manipulated to achieve an enhanced acute sprint performance (Wilson et al., 2013). Of the aforementioned studies, it is clear that a conditioning activity must attain a level of fatigue great enough to stimulate a potentiating effect. However, it is unclear if this potentiation is specific to a dominant muscle group of a sprinting. No clear understanding is documented in regards to the specificity of preconditioning exercise selection. Therefore, muscle-specific potentiation may equate to an increased sprint performance.

2.2.4.4 Time Under Tension

Time under tension (TUT) is defined as the cumulative time that a muscle group is contracted during an exercise session (Tran & Docherty, 2006). Both volume load and TUT have previously been shown to onset acute levels of muscle fatigue (Tran & Docherty, 2006). Commonly utilised as a hypertrophic training method (Burd et al., 2012), few studies have directly investigated the acute effect of TUT on sprint performance. Indirectly, Winwood et al. (2016) and Jarvis et al. (2017) displayed a TUT when towing sled loads 15 m resulted in significant improvements in 15 m sprint time. However, Winwood et al. (2016) was unable to induce a potentiated 5 m sprint performance following a sled load of 35% $rVel_{mean}$ (75% BM). This suggests that the ability to produce force over a greater period of time via more ground contacts, both during intervention and performance may be an underlining factor in the presence of sprint related PAP. Furthermore, Wong et al. (2017) suggested the equivalent of twenty ground contacts to initiate a PAP response, perhaps unintentionally highlighting the cumulative effect of sprint related potentiation.

2.2.5 Resisted Backwards Running

Resisted sprint training (RST) is a method of training focused on improving sprint velocity and acceleration (Prieske, Krüger, Aehle, Bauer, & Granacher, 2018). RST utilises resistance modalities such as sled towing, parachutes, uphill running, and weighted vests to promote greater neuromuscular activity and increase the recruitment of fast twitch muscle fibres (Harrison & Bourke, 2009). These adaptations may translate to increase un-resisted running velocity (Harrison & Bourke, 2009; Spinks, Murphy, Spinks, & Lockie, 2007; West et al., 2013). Although backward running is common, its use and understanding for RST to improve sprint ability remains unclear. To the author's knowledge, only one study has investigated the chronic use of backward RST. West et al. (2014) utilised a backward sled towing session (5 sets 2x20 m backward sled tows with 2 min recovery between sets) to determine neuromuscular, hormonal, biochemical and metabolic responses. Neuromuscular function returned to maximal function following 3 hours recovery, and no significant changes in serum creatine kinase (CK) was observed, indicating limited damage to local sarcomere (Koch, Pereira, & Machado, 2014). The lack of CK following backward sled towing highlights the metabolic biochemical differences between concentric and eccentric dominant exercise modalities (Koch et al., 2014; Proske & Morgan, 2001). Eccentric exercise can often result in significant muscle damage, resulting in an increased perception of muscle soreness (Clarkson, Byrnes, McCormick, Turcotte, & White, 1986). Eccentric dominant exercise (e.g. back squats) are highlighted as a significant PAP stimulus; however, current literature does not account for concentric dominant exercise modalities (Healy & Comyns, 2017). To the author's knowledge, no study has utilised backward sprint resistance to acutely assess potentiated muscle activation.

2.2.6 Section Summary

The acute phenomenon of PAP is well established; however, the mechanism(s) remain unclear. Myosin light chain phosphorylation has been shown to increase as a result of tetanic stimulation (Vandenboom et al., 2013), however, no dynamic application of such mechanisms have been shown in complex movement patterns. Augmentation in motor unit recruitment is suggested as a result of increased neural excitation shown through the increased H-wave amplitude associated with PAP (Güllich & Schmidtbleicher, 1996). Initial muscular strength, training age/status, muscle fibre distribution, and individual power to strength ratios are all important determinants of PAP (Tillin & Bishop, 2009). However, the inverse relationship between fatigue and potentiation is highlighted as the major inhibitor of PAP. Therefore, practitioners must ensure conditioning activities are sufficient to generate a potentiated response following 4-12 minutes rest (Healy & Comyns, 2017).

Many conditioning activities have been shown to enhance sprint performance (Healy & Comyns, 2017). Back squats are the most commonly studied conditioning activity used to initiate PAP for sprinting performance. Acute enhancements have been shown in 5-40 m sprint performance preceded by heavy back squats protocols (>90% 1RM) (Healy & Comyns, 2017). In comparison, there is a lack of research of using resisted sled interventions to initiate a sprint related PAP response; therefore, determining its effectiveness remains unclear.

The positive correlation between moderate sled loads (50-75% BM) and sprint time suggests a sprint related PAP relationship (Jarvis et al., 2017; Winwood et al., 2016). In contrast, negative/non-existing findings from Whelan et al. (2014) and Smith et al. (2014) were based on light resistance loads (10-30% BM). This load reduction may translate to lower stimulus, which may explain the lack of sprint related PAP. Although the use of sled towing is equivocal, Winwood et al. (2016) and Jarvis et al. (2017) propose that velocity decrement may be an accurate method to prescribe for PAP sled loading. However, the difference in recommended velocity reductions (34-37% and 40-44%, respectively) indicates the need for further investigation.

To date, Seitz et al. (2017) is the only study to examine the use of anterior chain potentiation and sprint performance through the use of a sled pushing stimulus. A significant reduction in 20 m sprint time suggests a possible muscle targeted potentiation. To fully comprehend the acute physiological and performance response of target PAP, further research is required.

2.3 Chapter Summary

There is a vast range of literature investigating the physiology of PAP and the ability to stimulate a PAP response using exercise (Sale, 2004; Tillin & Bishop, 2009). Currently there are two theories for PAP, an increased calcium sensitivity as the result of an increased phosphorylation of the myosin light chain, and the increased recruitment of higher order motor units (Tillin & Bishop, 2009). Although this is well established, it is still unclear whether one of these mechanisms is solely responsible for PAP or if they work in unison. However, the inverse relationship between fatigue and potentiation and the role it has in the excitation or inhibition of improving acute performance is clear (Sale, 2004). Inter-individual variability has also been widely identified as a key determinant of potentiation (Seitz et al., 2016). Previous authors have identified training age, initial muscular strength, power-strength ratios, and fibre distribution as major contributors to potentiation (Seitz et al., 2016; Tillin & Bishop, 2009).

While the phenomenon of PAP is well established, its relationship to sprint performance is a contemporary idea (Healy & Comyns, 2017). The most common conditioning activities used to enhance sprint performance have been back squats and plyometric jump/bounding exercises. Back squats (3 x >90% 1RM) have been shown to acutely enhance subsequent 10-40 m sprint performance following 4-8 minutes rest (Healy & Comyns, 2017). Plyometric jump and bounding exercises have shown a range of acute sprint enhancements, emphasising the fatigue potentiation relationship through the range of recommended rest periods in relation to conditioning intensity/load (Healy & Comyns, 2017). Sled towing/pushing is a method adopted for chronic training, but only recently has its use included acute training. Of particular interest are the comparisons of Winwood et al. (2016) sled towing and Seitz et al. (2017) sled pushing methods. Although these two studies reflect similar results, the targeted potentiation of such protocols is significantly different. The use of sled tow training to improve sprint acceleration is widely documented (Alcaraz, Palao, & Elvira, 2009; Cottle et al., 2014; Kawamori et al., 2014; Spinks et al., 2007), whereas sled pushing is contemporary (Hoffmann, 2014). Sled towing aims to increase hip extensor strength (Andre, Fry, Bradford, & Buhr, 2013), however, significant changes in the knee, hip, and trunk angles have been observed in comparison to un-resisted sprinting (Cronin, Hansen, Kawamori, & Mcnair, 2008). Sled pushing has been shown to increase rectus femoris and biceps femoris activation similar to back squatting, but significantly increases gastrocnemius activation (Maddigan, Button, & Behm, 2014). Therefore, potentiation via sled pushing would be expected as a result of augmented muscle activation and the sprint specific movement profile. This also highlights the potential for muscle group specific potentiation. Although hamstring activation is proposed as the most active muscle during sprinting (Morin, Gimenez, et al., 2015), quadriceps dominant exercises have shown significant acute performance improvements. Single joint knee extensors are highlighted as major contributors to sprint acceleration due high levels of horizontal concentric force during acceleration (Harland & Steele, 1997), and an increased knee torque requirement (Handsfield et al., 2017; Tottori et al., 2018). Thus, this raises the question of whether the potentiating exercise should focus on a quadriceps dominant exercise, as opposed to hamstring dominant exercise.

Backward running has shown that vastus lateralis and vastus medialis motor patterns are largely concentric and isometric during backward running when compared to forward running conditions (Flynn & Soutas-Little, 1993). Flynn and Soutas-Little (1993) also suggest a significant difference in motor firing patterns between running modes. Forward running initiated rectus femoris, vastus laterlalis, vastus medialis, gastrocnemius and tibialis anterior upon heel strike, whilst biceps femoris were activated at 8% completion of the stance phase. However, during backward running rectus femoris, vastus lateralis, vastus medialis, lateral gastrocnemius were activated at toe strike. This increased concentric quadriceps activation may reduce the acute onset of muscle damage, leaving the muscle in a more advantageous position for PAP to occur. To the author's knowledge, Seitz et al. (2017) is the only study to investigate a quadriceps dominant sprint specific PAP method.

Currently, there is no study that has examined the effect of backward resisted sled towing to improve acute sprint performance using velocity reduction loading. Utilising the knowledge of acute forward sled towing potentiation, the effect of acute backward sled towing may result in potentiated quadriceps activation, resulting in an increased 5 m sprint velocity.

Chapter Three: Research Objectives and Hypotheses

The extensive review of contemporary literature in **Chapter Two** provided a platform to construct the research methodology for this study. It has identified that the effects of heavy sled loads, conditioning movement specificity, and the onset of sprint related PAP requires further investigation. To date, no study has examined the effect of backward resisted sled towing to improve acute sprint performance using velocity reduction loading; further, it is unknown whether the proposed performance enhancement will be neural (higher order motor unit recruitment, motor unit firing rate) or peripheral (myosin light chain phosphorylation).

Therefore, the **objectives** of this thesis are outlined below:

i. To determine whether backward sled towing can elicit PAP to enhance forward sprint acceleration over 5 m.
ii. To determine if sled loading via a reduction in velocity can elicit an improvement in 5 m sprint performance.

The **hypotheses** for this thesis is are:

i. Forward sled towing will be superior to backward sled towing to acutely enhancing 5 m sprint performance.
ii. A heavier sled load (i.e., 55% reduction of mean velocity load) will significantly improve 5 m sprint performance compared to a lighter load (i.e., 35% reduction of mean velocity load).

Chapter Four: Methods

4.1 Experimental Approach

A randomised design was used to examine the effects of forward and backward heavy sled tow loading of 35% and 55% reduction of individual's maximal velocity, on 5 m sprint performance (6 and 12 min post-intervention). The ability to generate explosive muscular force over a short distance (i.e., 5 m) is essential for sprint performance (Slawinski et al., 2017). Chronic sled towing interventions have documented a significant increase in first step ground reaction force, highlighting its contribution to short-distance sprinting (Cottle et al., 2014; Harrison & Bourke, 2009). However, the acute effect of sled towing on sprint performance is unknown.

4.2 Participants

Eighteen well-trained males volunteered to participate in this study. To ensure training consistency across participants, well-trained was defined as having participated in high-intensity exercise 3-5 days per week for 6 months prior to participation. Participant characteristics are outlined in **Table 1.**

Table 1. Physical characteristics of participants (mean ± standard deviation).

Participants (n)	**Age (years)**	**Height (cm)**	**Body Mass (kg)**	**Age Predicted HR_{max} ($bmin^{-1}$)**	**60% HR_{max} ($bmin^{-1}$)**
18	22.17 ± 4.76	182.64 ± 5.15	90.06 ± 11.96	197.83 ± 4.76	118.28 ± 2.74

HR_{max} = Heart rate maximum

A priori t-test analysis was completed prior to data collection to determine statistical power. According to Bevan et al. (2010), an improvement in 5 m sprint performance from 90% 1RM back squats acquired a change of 0.04 sec between baseline (1.09 sec ± 0.06) and post-intervention (1.05 ± 0.05 sec). A meaningful change in 5 m of 0.04 sec with 80% power at an alpha level of 0.05 requires a minimal sample of 18 (G*Power 3, version 3.1.9.2, Heinrich-Heine University, Dusseldorf, Germany).

All participants were required to be free of lower limb or back injury for 6 months prior to participation. Prior to commencement participants were informed of the aims, risks, benefits, and procedures of the study. To account for daily biorhythms participants completed testing at the same time of day. All participants read and completed written informed consent and health questionnaire. This project was reviewed and approved by the Massey University Human Ethics Committee Southern A, Application SOA 18/31.

4.3 Procedure

The present study entailed one familiarisation session (see **Section 4.3.1**) and four intervention sessions (see **Section 4.3.2**). A brief summary of these sessions can be seen in **Figure 3**.

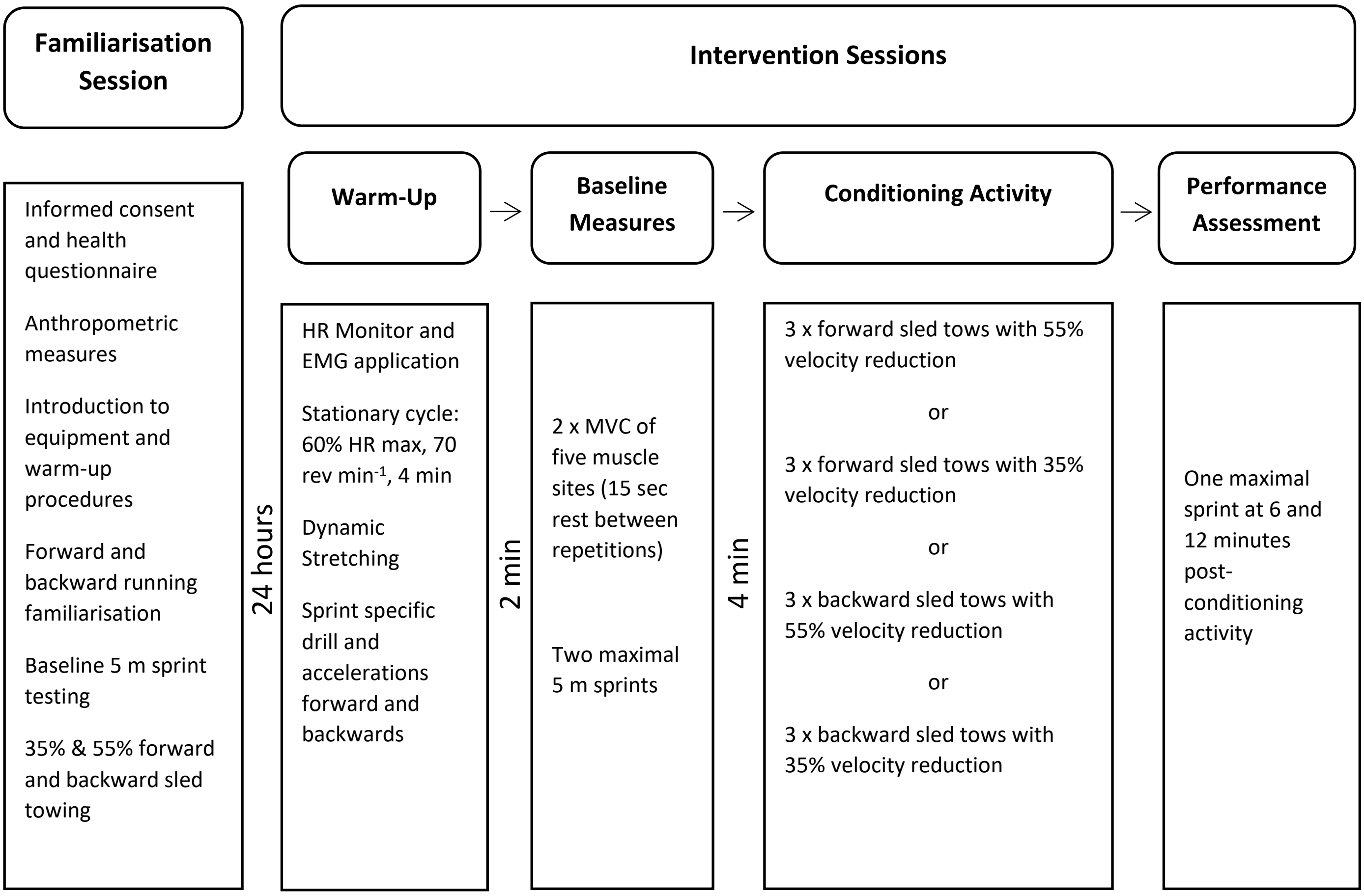

Figure 3. Schematic representation of the experiment design and procedures completed over five sessions.

4.3.1 Familiarisation Session

Familiarisation sessions entailed basic anthropometric measures (height and weight) and the completion of testing procedures. Participants were acquainted with EMG electrode placements at rectus femoris, biceps femoris, gluteus maximus, medial gastrocnemius, and tibialis anterior. Participants then performed a standardised dynamic warm-up that included 4 min of stationary cycling (Monark, Ergomedic 828E, Varberg, Sweden). Intensity was prescribed at 70 rev min^{-1} at a load of 60% of the calculated maximum heart rate (HR$_{max}$, 220-age) (Smith et al., 2014). To ensure accuracy during intervention sessions, 60% HR$_{max}$ steady load was established within the familiarisation warm-up and was recorded as kiloponds. Participants had one minute to reach 60% HR$_{max}$, following 3 min of steady state heart rate cycling. Heart rate (HR) was monitored using a telemetric chest strap (FT1, Polar Electro Oy, Kempele, Finland) that was detected by the display unit of the stationary cycle. The aerobic warm-up was followed by 8 min of dynamic stretching to improve joint range of motion and lengthen muscular-tendon units to minimise the risk of lower limb injury (Su, Chang, Wu, Guo, & Chu, 2017). Leg swings, front lunges with core twist, hamstring floor sweeps, calf pumps, shoulder rotations, and ‘A march’ forward and backward were completed for 8 repetitions per side with minimal rest (>15 sec) between exercises. Participants then completed two forward and two backward 5 m sprints at 85 and 95% of perceived maximal effort, which were interspersed by a 30 sec recovery period. Following this, two forward and two backward non-resisted 5 m sprints were completed to calculate baseline mean sprint velocities.

Reductions in sprint velocity by 34-37% have shown to improve sprint performance over short distances (Winwood et al., 2016). This reduction in velocity was proposed by Winwood et al. (2016) is based on 75% BM. However, reducing sprint velocity by 55% may have a greater potentiating effect but is currently untested. Due to a comparatively shorter sprint distance, an increased time under tension during 55% velocity reduction may provide a greater potentiating stimulus. The starting load for sled towing was determined by percent body mass. Pilot work identified that forward resisted sprinting at ~75% and ~110% of body mass equated to 35% and 55% reduction of velocity. For backward resisted sprinting ~80% and

~100% of body mass reduced velocity by 35% and 55%, respectively. Subsequent sled loads were incrementally increased or decreased by 2.5-5 kg until velocity was within 0.1 ms^{-1} of the target mean velocity reduction ($rVel_{mean}$), which was attained in 2-4 repetitions. The 5 m loaded sled sprints were interspersed with a full recovery period (2 min). At the conclusion of the session, an 8 min cool-down including 4 min of cycling at a self-prescribed intensity and 4 min of static stretching was completed.

4.3.2 Sprint Loading Interventions

Participants were asked to refrain from exhaustive lower body exercise for 24-hours prior to testing. Upon arrival, EMG sensors were positioned on biceps femoris (BF), vastus lateralis (VL), gluteus maximus (GM), medial gastrocnemius (GN), and tibialis anterior (TA) of the participant's dominant lower limb. The dominant lower limb was defined as the rear leg in a standing sprint start. Participants then performed the same dynamic warm-up that was completed in the familiarisation. Following the warm-up, maximum voluntary contractions (MVC) (refer to **Section 4.3.4**) were completed to ensure any changes in peripheral or central fatigue were negated. Two maximal 5 m sprints were completed, interspersed by 90 sec passive rest. Following a 4 min rest, participants completed three loaded sled tows with 60 sec rest. Twenty foot contacts have been suggested as optimal for prescribing load volume in sprint related PAP (Wong et al., 2017). Three 5 m loaded sled tows aim to replicate this optimal foot contact load, to increase the likelihood of a PAP response. The four interventions consisted of forward and backward sled towing with loads representative of 35% or 55% $rVel_{mean}$. Equitable workloads for the 35% and 55% $rVel_{mean}$ were calculated from the equation: *mechanical work = load x distance* (Winwood et al., 2016). Thus, the sled tow distance of 35% and 55% $rVel_{mean}$ was 5 m and 3.2 m, respectively.

Participants initiated forward sprinting in a standing split stance semi-crouched position with their lead foot placed behind the marked start line set 10 cm behind the first timing gate. Participants initiated backward sprinting in a split stance semi-crouched position with the rear of the lead leg placed behind the marked start line. Participants were verbally encouraged throughout the completion of sprints to ensure maximal effort was attained for each repetition. Mean sprint velocity was calculated using timing gates at 3.2 m and 5 m (Smartspeed PRO, Fusion Sport, Queensland, Australia) connected via Bluetooth to an iOS platform (Smartspeed, Fusion Sport, 1.03.02, version 11.3, Queensland, Australia). Data was manually transferred to the appropriate software (Microsoft Excel 2010, Redmond, USA) for post hoc evaluation.

Following the final sled tow participants completed non-resisted 5 m sprints at 6 and 12 min. Previous research suggests a potentiation window of 4 to 8 min (Seitz et al., 2017; Wong et al., 2017). Prescribed rest of 6 min places the participants within this optimal PAP window, whilst a 12 min rest interval explores a longer rest duration, suggested by other authors. Following the completion of the session, an identical cool-down was performed to that of the familiarisation session.

All sprinting sessions were performed in a laboratory setting on a linoleum flooring surface. To protect the linoleum flooring the undercarriage of the custom-built sled was lined with a 4 mm overlay carpet (Needlepunch Puma II Anthracite 9890, Irvine Flooring, Christchurch, NZ). Resisted sled sprints utilised a 12.5 kg custom-built sled loaded with Olympic lifting plates, connected to a waist harness via a 1.6 m tether attached by a carabineer.

4.3.3 Electromyography

Prior to electrode placement, any visible body hair was removed from the muscle site using a razor, and the skin was abraded and cleaned using an isopropyl alcohol wipe (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). Pre-gelled Ag-AgCl surface electrodes (Ambu, Ballerup, Denmark) were then placed over the mid-belly of the desired muscle parallel to the fibre direction with an inter-electrode distance of 10 mm (De Luca, Kuznetsov, Gilmore, & Roy, 2012). Specifically, the BF electrodes were placed at the halfway point on the line between the ischial tuberosity and the lateral epicondyle of the tibia (Hermens et al., 2000). VL electrodes were placed at two-thirds on the line from the anterior spina iliaca superior to the lateral side of the patella (Hermens et al., 2000). GM electrodes were placed superior to the half-way point between the sacral vertebrae and the greater trochanter of the femur (Bartlett, Sumner, Ellis, & Kram, 2014). GN electrodes were placed on the most prominent circumference of the medial GN (Hermens et al., 2000). TA electrodes were placed at one-third on the line between the fibula head, and the superior aspect of the medial malleolus (Hermens et al., 2000). The above muscle sites were measured and traced using a permanent marker to ensure accuracy when reapplying electrodes between experimental sessions.

Wireless EMG sensors where then attached to the electrodes and fixed using semi-permeable adhesive tape. EMG signals were transmitted telemetrically in real-time to a PC interface receiver (Telemyo DTS, Noraxon, Scottsdale, AZ, USA) and recorded to the appropriate data acquisition software (MyoResearch, version MR3.12, Noraxon Scottsdale, AZ, USA). EMG data were sampled at 3000 Hz and synchronised with video capture (Logitech C920 HD Pro Webcam, NSW, Australia) for post hoc analysis. Video capture was positioned 2.5 m from the first timing gate, 5 m laterally from the edge of the timing gates, at 1.7 m vertical. This allowed a full video capture of the sprint repetitions. The synchronisation of EMG, video capture, and force plate data were achieved using an external trigger. EMG data was analysed using MyoResearch software (version MR3.12, Noraxon, Scottsdale, AZ, USA) where signals were then rectified, and smoothed at 50 ms using root means square algorithms and then normalised to individual’s baseline maximal voluntary contraction.

4.3.4 Maximal Voluntary Contractions

Maximal voluntary contractions (MVC) were collected as a baseline measure before each intervention session. This allowed for post hoc muscle activation comparison. This was completed using the aforementioned data acquisition MyoResearch software (version MR3.12, Noraxon, Scottsdale, AZ, USA). All MVC’s were completed on a treatment table. Participants were instructed to maintain a maximal isometric contraction for five seconds. MVC’s were collected manually using a Velcro ankle strap attached to a rope via carabineer unless stated otherwise.

The vastus lateralis MVC was performed in a seated position with the hip and knee angle set at 90 degrees (Meldrum, Cahalane, Conroy, Fitzgerald, & Hardiman, 2007). To provide external resistance a Velcro strap was secured to the ankle joint and participants were instructed to extend their knee maximally. Biceps femoris MVC was performed in a seated position with the hip and knee angle set at 90 degrees (Meldrum et al., 2007). The Velcro strap was secured to the ankle joint and participants were instructed to flex their knee maximally. Medial gastrocnemius MVC was performed lying in a supine position with ankle placed at neutral (Meldrum et al., 2007). The Velcro strap was secured over the metatarsal heads before participants were instructed to perform maximal plantar flexion. Tibialis anterior MVC was performed in a supine position with the ankle at neutral (Frigon, Carroll, Jones, Zehr, & Collins, 2007). The Velcro strap was secured over the metatarsal heads and participants were instructed to perform dorsiflexion maximally. Gluteus maximus MVC was performed in a prone position, with the knee flexed at 90 degrees. Manual resistance was applied just above the knee joint while participants were instructed to complete maximal hip extension (Kendall, McCreary, Provance, Rodgers, & Romani, 2005).

4.3.5 Kinetic and Temporal Sprint Parameters

Ground reaction forces of lead leg sprinting were measured using a three-dimensional force plate (0.6 x 0.9 m, Bertec, model 6090, Columbus, OH, USA) embedded in the ground directly in front of the start line (65.6 cm) and sampled at 1000 Hz. Kinematic and temporal parameters were processed using appropriate computer software (BioWare 2004, Version 3.2.6.104). Vertical and horizontal peak and mean force was expressed relative to body mass (N/kg), and the horizontal impulse (force x time) were normalised to body mass (ns/kg). Initial ground contact of start (touchdown) and end (toe-off) were defined by the vertical force rising above 12 N and decreasing below 12 N. This was determined by visual inspection of the data trace. Total impulse was defined as the sum of both braking and propulsion force, where braking reflected negative impulse and propulsion reflected positive impulse. Braking force was identified from touchdown to the time force elevated from negative to positive. Where no negative force occurred, braking force was assumed to last zero seconds. First step kinetic parameters collected included peak and mean vertical force, vertical and horizontal impulse, vertical and horizontal rate of force development (RFD), peak and mean horizontal force, peak braking, braking and propulsion impulse, peak propulsion, RFD braking and impulse, and RFD propulsion. First step temporal parameters collected included contact time, time to peak vertical, peak vertical to toe-off, braking time, time to peak braking, propulsive time, time to peak propulsion, propulsion to toe-off time. All parameters were transferred to appropriate software (Matlab 2014, Version 8.4, R2014b) for post-hoc calculations.

4.4 Statistical Analysis

A general linear model for repeated measures included a three-way analysis of variance (ANOVA; intervention x time x velocity) to determine changes in sprint velocity. A two-way ANOVA was used to determine the accuracy of sled loading conditions (calculated $rVel_{mean}$ vs. actual $rVel_{mean}$). Three-way (intervention x time x velocity) ANOVA was also used to determine changes in force plate data. When statistical significance was observed, post hoc pairwise comparisons were formed using the Bonferroni adjustment. Mauchly's test was performed to determine data sphericity. A four-way ANOVA (intervention x muscle x velocity x time) determined changes in EMG activity. Any violation in sphericity was corrected using the Greenhouse-Geisser estimates of sphericity. Effect size was calculated in a coded spreadsheet (Microsoft Excel 2010, Redmond, USA) using the Cohens-*d* equation (Cohen, 1988) with a pooled standard deviation (SD). Hopkins (2016) interpretation of effect size magnitude was used as follows: < 0.2 trivial, 0.2 - 0.6 small, 0.6 - 1.2 moderate, 1.2 - 2 large, 2.0 - 4.0 very large, and > 4.0 near perfect.

Statistical Package for Social Sciences (SPSS Statistics v24, IBM New York, USA) analysed all data, with significance set at $p \leq 0.05$ for all main effects. All data is presented as mean ± SD.

Chapter Five: Results

5.1 Data Distribution and Reliability

The Shapiro-Wilk test revealed a normal distribution of all data ($p > 0.05$). Intraclass coefficient (ICC) and coefficient of variation (CV) tests were completed to determine the reliability of sprint data (ICC average measures = 0.897; CV = 5.91%) and force plate data (ICC average measures = 0.789; CV = 6.1%).

5.2 Velocity Reduction

Results of baseline velocity, calculated $rVel_{mean}$, actual $rVel_{mean}$, and sled loads are reported in ***Table 2***. A significant difference was reported between 55% backward actual velocity (1.39 ms^{-1}) and 55% backward calculated $rVel_{mean}$ (1.63 ms^{-1}) ($p<0.01$). Significant difference was also reported between 35% backward actual velocity (2.14 ms^{-1}) and 35% backward calculated $rVel_{mean}$ (2.62 ms^{-1}) ($p<0.01$). This relationship was further displayed by the percentage difference between the target $rVel_{mean}$ and actual $rVel_{mean}$ during backward interventions (55% vs 61.55%; 35% vs 47.08%).

Table 2. *Comparison of baseline velocity, calculated $rVel_{mean}$, actual $rVel_{mean}$, and actual load (mean ± standard deviation).*

	55% $rVel_{mean}$ Backward	**55% $rVel_{mean}$ Forward**	**35% $rVel_{mean}$ Backward**	**35% $rVel_{mean}$ Forward**
Baseline velocity (ms^{-1})	3.62 ± 0.23	3.64 ± 0.19	4.04 ± 0.26	3.95 ± 0.19
Calculated $rVel_{mean}$ (ms^{-1})	1.63 ± 0.11	1.64 ± 0.08	2.62 ± 0.17	2.57 ± 0.12
Actual $rVel_{mean}$ (ms^{-1})	1.39 ± 0.17*	1.64 ± 0.2	2.14 ± 0.23*	2.63 ± 0.24
Actual $rVel_{mean}$ (%)	61.55 ± 0.26	54.94 ± 0.07	47.08 ± 0.14	33.27 ± 0.28
Actual Load (kg)	127.09 ± 15.64	119.57 ± 23.41	80.09 ± 20.55	68.29 ± 12.08
Actual Load (% BM)	141.12	132.77	88.93	75.83

** Significance ($p < 0.01$) actual $rVel_{mean}$ vs calculated $rVel_{mean}$.*

5.3 Sprint Performance

Results of 55% $rVel_{mean}$ forward, 35% $rVel_{mean}$ forward, 55% $rVel_{mean}$ backward, and 35% $rVel_{mean}$ backward baseline, 6 min, and 12 min velocities are reported in **Table 3**. Pairwise comparisons found no main effect ($p > 0.05$) of reduced sprint velocity (35% and 55%) and time (post 6 min and 12 min). Further there was no interaction effect of forward and backward sled towing in relation to 5 m sprint velocity ($p > 0.05$). Individual variation in participant response to PAP interventions are reported in **Table 4**.

Table 3. *Five-metre sprint velocity* (ms^{-1}) *at baseline, 6 min, and 12 minutes post sled tow interventions of forward and backward 55% and 35%* $rVel_{mean}$ *(mean ± standard deviation).*

	BL	6 min	12 min
55% $rVel_{mean}$ **Backward**	3.99 ± 0.25	4.03 ± 0.36	4.01 ± 0.38
ES	-	0.13	0.06
55% $rVel_{mean}$ **Forward**	4.02 ± 0.18	4.01 ± 0.39	3.98 ± 0.28
ES	-	0.03	0.04
35% $rVel_{mean}$ **Backward**	4.04 ± 0.26	4.02 ± 0.36	4.04 ± 0.26
ES	-	0.06	0.08
35% $rVel_{mean}$ **Forward**	3.95 ± 0.19	4.00 ± 0.25	3.99 ± 0.24
ES	-	0.23	0.23

BL = Baseline, ES = Effect size.

Table 4. *Individual percentage (%) change in 5 m mean sprint velocity (ms^{-1}) between interventions at 6 and 12 minutes post baseline (%).*

	35% rVel$_{\text{mean}}$				**55% rVel$_{\text{mean}}$**			
Participant	Forward 6 min	Forward 12 min	Backward 6 min	Backward 12 min	Forward 6 min	Forward 12 min	Backward 6 min	Backward 12 min
1	1.9	-1.0	-1.9	0.5	0.2	-2.7	1.0	-1.3
2	-7.1	-4.8	-3.6	-5.1	5.0	10.0	3.9	0.9
3	-6.6	2.3	-5.5	-5.1	1.3	1.3	0.5	-2.3
4	4.9	4.4	-5.0	-3.1	-6.2	-5.0	2.0	2.3
5	8.2	6.9	3.3	4.2	3.9	3.0	8.5	5.3
6	2.6	-5.4	4.0	-0.1	-11.7	-6.0	-1.0	-13
7	2.4	2.9	-3.7	-1.9	-5.4	1.1	2.2	-1.3
8	0.2	3.1	-4.1	-3.6	-1.6	5.5	-0.1	3.7
9	-3.7	2.0	-14.4	-3.1	-13.3	-1.7	-3.4	-13.0
10	-0.1	1.2	1.8	2.0	3.1	1.8	1.5	4.9
11	4.1	2.0	4.5	2.5	0.0	-0.4	2.9	8.2
12	0.1	2.5	-0.8	-0.6	2.2	7.4	4.0	-2.8
13	-1.0	-1.7	-2.7	-2.9	5.2	0.7	-10.2	-3.4
14	-1.4	-3.6	9.1	3.0	-7.6	1.5	0.1	1.3
15	1.5	-6.8	0.8	2.6	-1.5	0.4	-0.8	3.0
16	3.7	9.6	2.4	1.0	-2.6	-0.4	3.3	-4.1
17	2.7	0.3	-5.1	-1.9	2.2	1.4	0.7	0.4
18	7.8	1.1	1.0	-0.9	10.3	-18.5	11.8	10.0

5.4 EMG

5.4.1 Mean EMG amplitude

EMG amplitudes of TA, GN, VL, BF, and GM are reported at baseline, 6 min, and 12 min as a percent of MVC in **Table 5.** Summary of EMG data presented as a percentage (%) of MVC at baseline, 6 min and 12 min (mean ± standard deviation).

Pairwise comparisons found no main effect ($p > 0.05$) of sprint velocity (35% and 55%) and time (post 6 and 12 min). Further, there was no interaction effect of forward and backward sled towing in relation to EMG mean amplitude ($p > 0.05$).

5.4.2 Inter-Muscle Motor Firing Patterns

The findings of 5 m sprint mean EMG amplitude, irrespective of intervention, are presented in **Table 6**. Pairwise comparisons of EMG and muscle sites showed a significant difference in GN activation compared to TA (71.64% ± 3.78; $p < 0.01$), VL (18.74% ± 3.33; $p < 0.01$), BF (46.64% ± 5.01; $p < 0.01$), and GM (41.68% ± 3.9; $p < 0.01$). Pairwise comparisons report significant difference in VL activation compared to TA (52.91 ± 5.12, $p < 0.01$), BF (27.90 ± 4.65; $p < 0.01$), and GM activation (22.95 ± 4.46; $p < 0.01$). Further, a significant difference in BF activation compared to TA activation (25.00% ± 5.22; $p < 0.01$) was noted and GM activation was significantly higher than TA activation (29.96% ± 4.62; $p < 0.01$). However, there was a non-significant difference between GM and BF activation ($p = 1.00$).

Table 5. *Summary of mean EMG amplitude presented as a percentage (%) of MVC at baseline, 6 min and 12 min (mean ± standard deviation).*

	BL					**6 min**					**12 min**				
	TA	GN	VL	BF	GM	TA	GN	VL	BF	GM	TA	GN	VL	BF	GM
55% rVel$_{mean}$ Backward	27.61 ± 11.97	102.85 ± 29.50	75.21 ± 28.74	50.96 ± 25.36	60.28 ± 28.00	42.08 ± 34.77	111.00 ± 25.62	91.67 ± 20.86	62.53 ± 20.83	74.38 ± 28.87	35.17 ± 19.24	102.86 ± 29.77	83.49 ± 19.58	58.61 ± 21.37	71.35 ± 28.77
ES	-	-	-	-	-	0.56	0.29	0.66	0.50	0.50	0.47	0.00	0.34	0.33	0.39
55% rVel$_{mean}$ Forward	27.57 ± 10.05	100.86 ± 31.36	83.05 ± 26.81	52.00 ± 23.45	59.31 ± 20.55	30.46 ± 12.03	105.51 ± 39.03	88.69 ± 27.87	64.51 ± 24.58	62.10 ± 28.14	34.53 ± 13.23	104.24 ± 41.42	90.17 ± 35.42	55.37 ± 26.48	62.23 ± 23.52
ES	-	-	-	-	-	0.26	0.13	0.21	0.52	0.11	0.59	0.09	0.23	0.13	0.13
35% rVel$_{mean}$ Backward	31.03 ± 13.24	109.22 ± 32.36	92.97 ± 29.12	53.76 ± 16.97	63.48 ± 16.55	34.81 ± 22.84	102.88 ± 45.34	79.34 ± 28.98	52.01 ± 23.06	56.82 ± 25.92	39.89 ± 27.34	105.11 ± 30.88	85.49 ± 24.03	59.49 ± 23.61	60.92 ± 23.16
ES	-	-	-	-	-	0.20	0.16	0.47	0.09	0.31	0.41	0.13	0.28	0.28	0.13
35% rVel$_{mean}$ Forward	27.81 ± 12.62	114.25 ± 33.64	93.93 ± 34.3	60.28 ± 23.76	63.53 ± 23.66	31.16 ± 15.18	97.24 ± 25.67	88.12 ± 33.70	64.51 ± 29.13	59.73 ± 24.87	31.94 ± 12.97	97.78 ± 31.33	76.84 ± 31.09	60.10 ± 24.48	59.49 ± 22.13
ES	-	-	-	-	-	0.24	0.57	0.17	0.16	0.16	0.32	0.51	0.52	0.01	0.18

BL = Baseline, ES= Effect size, TA = Tibialis Anterior, GN = Gastrocnemius, VL = Vastus Lateralis, BF = Biceps Femoris, GM = Gluteus Maximus.

Table 6. *Five-metre sprint EMG activity presented as a percentage (%) of MVC (mean ± standard deviation).*

TA	GN	VL	BF	GM
32.84 ± 17.47	104.48 ± 30.66	84.75 ± 28.11	57.84 ± 23.77	62.80 ± 24.28

Significance (p < 0.01) GN vs TA; GN vs VL; GN vs BF; GN vs GM; VL vs TA; VL vs BF; VL vs GM; BF vs TA; GM vs TA. Non-significant (p=1.00) BF vs GM.

5.5 First Stride Kinetics

First stride kinetic force profiles of: peak vertical, mean vertical, impulse vertical, rate of force development vertical, peak horizontal, mean horizontal, impulse horizontal, RFD horizontal, peak braking, impulse braking, RFD braking, peak propulsion, impulse propulsion, and RFD propulsion are reported at baseline, 6 min, and 12 min that are normalised to body mass (**Table 7**). Where no braking force was documented, all variables related to braking were set to zero.

5.5.1 Peak and Mean Vertical Force

First stride analysis of peak vertical force found a significant decrease at 6 min compared to baseline, during 55% $rVel_{mean}$ intervention ($p < 0.05$). For mean vertical force a significant decrease was observed at 12 min compared to baseline, irrespective of intervention ($p < 0.05$), as seen in **Table 7**.

5.5.2 Vertical and Horizontal Impulse

First stride vertical impulse found a significant increase during baseline compared to 12 min, irrespective of intervention ($p < 0.05$). For horizontal impulse there was no significant change irrespective of time and intervention ($p > 0.05$), as seen in **Table 7**.

5.5.3 Vertical and Horizontal RFD

Vertical rate of force development reported a significant increase at 6 min during 35% $rVel_{mean}$ compared to 55% $rVel_{mean}$ ($p < 0.05$). A significant increase in vertical rate of force development was also found at 12 min during 55% $rVel_{mean}$ compared to 35% $rVel_{mean}$ ($p < 0.05$). Significant increases in vertical rate of force development was also shown at 12 min compared to baseline and 6 min during 55% $rVel_{mean}$ ($p < 0.05$). Horizontal rate of force development found no significant change irrespective of time and intervention ($p < 0.05$), as seen in **Table 7**.

5.5.4 Peak and Mean Horizontal Force

There was no significant change in peak and mean horizontal force irrespective of time and intervention ($p > 0.05$), as seen in **Table 7**.

5.5.5 Peak, Impulse and RFD Braking

Peak braking revealed a significant increase at 6 min during 55% $rVel_{mean}$ compared to 6 min 35% $rVel_{mean}$ ($p < 0.05$). A significant increase in peak braking was also observed at 6 min during backward interventions compared to 6 min during forward interventions ($p < 0.05$). For impulse and RDF braking, no significant change was observed irrespective of time and intervention ($p > 0.05$), as seen in **Table 7**.

5.5.6 Peak, Impulse, and RFD Propulsion

For peak, impulse and RFD propulsion there was no significant change irrespective of time and intervention ($p > 0.05$), as seen in **Table 7**.

Table 7. *First stride kinetics of 5 m sprint performance at baseline, 6 min, and 12 min (mean ± standard deviation).*

	55% rVel$_{mean}$ Backward			**55% rVel$_{mean}$ Forward**			**35% rVel$_{mean}$ Backward**			**35% rVel$_{mean}$ Forward**		
	BL	6 min	12 min	BL	6 min	12 min	BL	6 min	12 min	BL	6 min	12 min
Peak Vertical Force (Nkg^{-1})	1.86 ± 0.30	1.77 ± 0.29 ^{A}	1.84 ± 0.17	1.92 ± 0.16	1.69 ± 0.42 ^{A}	1.75 ± 0.33	1.91 ± 0.19	1.76 ± 0.39	1.79 ± 0.22	1.83 ± 0.25	1.73 ± 0.14	1.69 ± 0.51
ES	-	0.31	0.08	-	0.72	0.66	-	0.49	0.58	-	0.49	0.35
Mean Vertical Force (Nkg^{-1})	1.18 ± 0.19	1.15 ± 0.19	1.18 ± 0.08 ^{B}	1.23 ± 0.10	1.11 ± 0.28	1.12 ± 0.20 ^{B}	1.20 ± 0.10	1.12 ± 0.24	1.16 ± 0.13 ^{B}	1.16 ± 0.15	1.13 ± 0.08	1.08 ± 0.35 ^{B}
ES	-	0.16	0.00	-	0.57	0.70	-	0.44	0.34	-	0.25	0.30
Vertical Impulse (Ns^{-1}kg^{-1})	0.26 ± 0.06 **C**	0.24 ± 0.05	0.26 ± 0.03	0.27 ± 0.04 ^{C}	0.24 ± 0.07	0.25 ± 0.05	0.27 ± 0.04 ^{C}	0.25 ± 0.06	0.26 ± 0.05	0.25 ± 0.05 ^{C}	0.25 ± 0.04	0.22 ± 0.08
ES	-	0.36	0.00	-	0.53	0.44	-	0.39	0.22	-	0.00	0.45
Vertical RFD (Nkg^{-1}s^{-1})	81.19 ± 36.73	74.75 ± 22.28	103.27 ± 40.57 $^{D F}$	88.94 ± 32.86	85.15 ± 41.85	99.77 ± 41.08 $^{D F}$	91.54 ± 45.45	94.90 ± 49.82 ^{E}	80.65 ± 30.68	89.61 ± 37.71	97.95 ± 34.74 ^{E}	89.46 ± 44.54
ES	-	0.21	0.57	-	0.10	0.29	-	0.07	0.28	-	0.23	0.00
Peak Horizontal Force (Nkg^{-1})	0.79 ± 0.15	0.77 ± 0.14	0.80 ± 0.10	0.82 ± 0.07	0.76 ± 0.20	0.78 ± 0.14	0.80 ± 0.11	0.78 ± 0.16	0.79 ± 0.10	0.80 ± 0.14	0.80 ± 0.09	0.73 ± 0.22
ES	-	0.14	0.08	-	0.40	0.36	-	0.15	0.10	-	0.00	0.38
Mean Horizontal Force (Nkg^{-1})	0.45 ± 0.10	0.44 ± 0.08	0.44 ± 0.05	0.46 ± 0.05	0.42 ± 0.12	0.42 ± 0.10	0.44 ± 0.07	0.44 ± 0.10	0.44 ± 0.06	0.43 ± 0.07	0.44 ± 0.07	0.41 ± 0.14
ES	-	0.11	0.13	-	0.44	0.51	-	0.00	0.00	-	0.14	0.18
Horizontal Impulse (Ns^{-1}kg^{-1})	0.10 ± 0.02	0.09 ± 0.02	0.10 ± 0.01	0.10 ± 0.01	0.09 ± 0.03	0.09 ± 0.02	0.10 ± 0.02	0.09 ± 0.02	0.09 ± 0.01	0.09 ± 0.01	0.09 ± 0.01	0.08 ± 0.03
ES	-	0.50	0.00	-	0.45	0.63	-	0.50	0.63	-	0.00	0.45
Horizontal RFD (Nkg^{-1}s^{-1})	53.45 ± 24.22	50.04 ± 17.58	61.38 ± 25.71	58.91 ± 22.32	56.88 ± 24.87	62.69 ± 24.88	59.14 ± 30.60	58.08 ± 37.08	53.15 ± 23.19	62.00 ± 36.58	66.67 ± 27.63	61.05 ± 45.21
ES	-	0.16	0.32	-	0.09	0.16	-	0.03	0.22	-	0.14	0.02
Peak Braking Force (Nkg^{-1})	-0.17 ± 0.16	-0.14 ± 0.12 $^{G H}$	-0.26 ± 0.16	-0.20 ± 0.13	-0.24 ± 0.15 ^{G}	-0.26 ± 0.20	-0.23 ± 0.19	-0.22 ± 0.23 ^{H}	-0.20 ± 0.21	-0.23 ± 0.25	-0.33 ± 0.18	-0.22 ± 0.28
ES	-	0.21	0.56	-	0.28	0.36	-	0.05	0.15	-	0.46	0.04
Braking Impulse (Ns^{-1}kg^{-1})	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.01	-0.01 ± 0.02	-0.01 ± 0.02	0.00 ± 0.00	0.00 ± 0.01	-0.02 ± 0.05	0.00 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	-0.02 ± 0.07
ES	-	0.00	0.00	-	0.00	0.71	-	0.15	0.10	-	0.00	0.40
RFD Braking (Nkg^{-1}s^{-1})	-24.28 ± 21.41	-16.55 ± 15.25	-32.15 ± 22.30	-29.63 ± 13.01	-33.08 ± 21.84	-34.85 ± 28.59	-28.88 ± 24.16	-30.45 ± 33.42	-24.76 ± 29.94	-34.18 ± 32.37	-38.40 ± 23.71	-26.03 ± 31.60
ES	-	0.42	0.36	-	0.19	0.24	-			-	0.15	0.25
Peak Propulsion (Nkg^{-1}s^{-1})	0.79 ± 0.15	0.77 ± 0.14	0.80 ± 0.10	0.82 ± 0.07	0.76 ± 0.20	0.78 ± 0.14	0.80 ± 0.11	0.78 ± 0.16	0.79 ± 0.10	0.80 ± 0.14	0.80 ± 0.09	0.73 ± 0.22
ES	-	0.14	0.08	-	0.40	0.36	-			-	0.00	0.38
Impulse Propulsion (Nkg^{-1}s^{-1})	0.10 ± 0.02	0.09 ± 0.02	0.10 ± 0.01	0.10 ± 0.01	0.09 ± 0.03	0.11 ± 0.04	0.10 ± 0.02	0.09 ± 0.02	0.10 ± 0.02	0.10 ± 0.02	0.10 ± 0.01	0.08 ± 0.03
ES	-	0.50	0.00	-	0.45	0.34	-	0.50	0.00	-	0.00	0.78
RFD Propulsion (Nkg^{-1}s^{-1})	53.45 ± 24.22	50.04 ± 17.58	61.38 ± 25.71	58.91 ± 22.32	56.88 ± 24.87	62.69 ± 24.88	59.14 ± 30.60	58.08 ± 37.08	53.15 ± 23.19	62.00 ± 36.58	66.67 ± 27.63	61.05 ± 45.21
ES	-	0.16	0.32	-	0.09	0.16	-	0.03	0.22	-	0.14	0.02

ES = Effect size; RFD = Rate of force development; BL = Baseline; ***A*** *= Significance at 6 min 55% rVel$_{mean}$ ($p < 0.05$);* ***B*** *= Significance at 12 min compared to baseline irrespective of rVel$_{mean}$ ($p < 0.05$);* ***C*** *= Significance at baseline irrespective of rVel$_{mean}$ ($p < 0.05$);* ***D*** *= Significance at 12 min 55% rVel$_{mean}$ ($p < 0.05$);* ***E*** *= Significance at 6 min 35% rVel$_{mean}$ ($p < 0.05$);* ***F*** *= Significance at 12 min compared to baseline and 6 min 55% rVel$_{mean}$ ($p < 0.05$);* ***G*** *= Significance at 6 min 55% rVel$_{mean}$ compared to 6 min 35% rVel$_{mean}$ ($p < 0.05$);* ***H*** *= Significance at 6 min during backward interventions compared to 6 min forward interventions ($p < 0.05$).*

5.6 First Stride Temporal

First stride temporal profiles of contact time, time to peak vertical, peak vertical to toe-off, braking time, time to peak braking, propulsive time, time to peak propulsion, propulsion to toe-off time are reported at baseline, 6 min, and 12 min in **Table 8**. Where no braking force was documented, all variables related to braking were set to zero.

5.6.1 Contact, Breaking and Propulsive Time

First stride analysis of foot contact time found a significant (0.009 sec) decrease in contact time at 12 min following 35% $rVel_{mean}$ compared to 55% $rVel_{mean}$ ($p < 0.05$). A significant 0.013 sec decrease in contact time was found at 12 min following backward 35% $rVel_{mean}$ compared to backward 55% $rVel_{mean}$ ($p < 0.05$; ES = 0.33 and 0.22 respectively). Braking time significantly decreased following backward towing ($p < 0.05$) at 6 and 12 min compared to forward towing. A significant (0.009 sec) decrease in propulsive time at 12 min was observed following backward sled towing ($p < 0.05$). A significant (0.011 sec) reduction in propulsive time was also reported at 12 min following 35% $rVel_{mean}$ ($p < 0.05$).

5.6.2 Time to Peak Vertical Force

The time to peak vertical force reported a significant (0.014 sec) decrease at 12 min during 35% $rVel_{mean}$ compared to 55% $rVel_{mean}$ ($p < 0.05$). Further, a significant (0.026 sec) decrease in time to peak force was found at 12 min following forward sled towing interventions compared to backward sled towing interventions ($p < 0.05$).

5.6.3 Time to Peak Braking Force

The time to peak braking reported a significant (0.002 sec) decrease at 6 min following backward sled towing ($p < 0.05$). While a small, non-significant, (0.001 sec) decrease was observed in backward sled towing compared to forward sled towing ($p = 0.051$).

5.6.4 Time to Peak Propulsion

There was no significant change in time to peak propulsion irrespective of time and intervention ($p > 0.05$).

5.6.5 Peak Vertical Force to Toe-Off Time

There was a significant (0.012 sec) decrease at 6 min in peak vertical force to toe-off time following forward 55% $rVel_{mean}$ compared to forward 35% $rVel_{mean}$ ($p < 0.05$; ES = 0.02 and 0.02 respectively).

5.6.6 Peak Propulsion to Toe-Off Time

There was no significant change in peak propulsion to toe-off time found no significant change irrespective of time and intervention ($p > 0.05$).

Table 8. *First stride temporal data of 5 m sprint performance at baseline, 6 min, and 12 min (mean ± standard deviation).*

	55% $rVel_{mean}$ Backward			**55% $rVel_{mean}$ Forward**			**35% $rVel_{mean}$ Backward**			**35% $rVel_{mean}$ Forward**		
(Sec)	BL	6 min	12 min	BL	6 min	12 min	BL	6 min	12 min	BL	6 min	12 min
Contact Time	0.24 ± 0.13	0.24 ± 0.12	0.22 ± 0.02	0.21 ± 0.03	0.20 ± 0.05	0.21 ± 0.03	0.22 ± 0.03	0.21 ± 0.02	0.21 ± 0.03 $^{A B}$	0.21 ± 0.03	0.22 ± 0.04	0.20 ± 0.02 ^{A}
ES	-	0.00	0.22	-	0.24	0.00	-	0.39	0.33	-	0.28	0.39
Time to Peak Vertical Force	0.14 ± 0.08	0.13 ± 0.06	0.12 ± 0.03	0.12 ± 0.02	0.12 ± 0.03	0.12 ± 0.03 ^{D}	0.12 ± 0.04	0.12 ± 0.02	0.13 ± 0.02 ^{C}	0.12 ± 0.03	0.12 ± 0.03	0.10 ± 0.05 $^{C D}$
ES	-	0.14	0.33	-	0.00	0.00	-	0.00	0.32	-	0.00	0.49
Peak Vertical Force to Toe-Off Time	0.10 ± 0.05	0.10 ± 0.06 ^{E}	0.09 ± 0.03	0.9 ± 0.01	0.08 ± 0.02 ^{E}	0.09 ± 0.02	0.10 ± 0.03	0.09 ± 0.01	0.09 ± 0.01	0.09 ± 0.01	0.09 ± 0.02	0.10 ± 0.04
ES	-	0.00	0.24	-	51.86	51.23	-	0.45	0.45	-	0.00	0.34
Braking Time	0.01 ± 0.01	0.01 ± 0.01 ^{F}	0.01 ± 0.01 ^{F}	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01 ^{F}	0.01 ± 0.01 ^{F}	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01
ES	-	0.00	0.00	-	0.00	0.00	-	0.00	0.00	-	0.00	0.00
Time to Peak Braking	0.01 ± 0.01	0.01 ± 0.01 ^{G}	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01 ^{G}	0.01 ± 0.01	0.01 ± 0.00	0.01 ± 0.01	0.01 ± 0.01
ES	-	0.00	0.00	-	0.00	0.00	-	0.00	0.00	-	0.00	0.00
Propulsive Time	0.23 ± 0.12	00.23 ± 0.12	0.20 ± 0.03 ^{H}	0.20 ± 0.03	0.19 ± 0.05	0.20 ± 0.03	0.20 ± 0.03	0.20 ± 0.03	0.20 ± 0.03 $^{H I}$	0.20 ± 0.03	0.20 ± 0.04	0.19 ± 0.03
ES	-	0.00	0.34	-	0.24	0.00	-	0.00	0.00	-	0.00	0.33
Time to Peak Propulsion	0.16 ± 0.10	0.16 ± 0.10	0.14 ± 0.02	0.13 ± 0.04	0.12 ± 0.04	0.13 ± 0.04	0.13 ± 0.04	0.14 ± 0.03	0.14 ± 0.02	0.14 ± 0.03	0.14 ± 0.03	0.12 ± 0.04
ES	-	0.00	0.28	-	0.25	0.00	-	0.28	0.32	-	0.00	0.57
Peak Propulsion to Toe-Off time	0.07 ± 0.02	0.07 ± 0.02	0.06 ± 0.01	0.08 ± 0.05	0.07 ± 0.04	0.07 ± 0.03	0.07 ± 0.03	0.06 ± 0.02	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.06 ± 0.03
ES	-	0.00	0.63	-	0.22	0.24	-	0.39	0.45	-	0.00	0.00

BL = Baseline; ES = Effect size; ***A*** *= Significance at 12 min 35% $rVel_{mean}$ ($p < 0.05$);* ***B*** *= Significance at 12 min 35% $rVel_{mean}$ backward ($p < 0.05$);* ***C*** *= Significance at 12 min 35% $rVel_{mean}$ ($p < 0.05$);* ***D*** *= Significance at 12 min forward interventions ($p < 0.05$);* ***E*** *= Significance at 6 min 55% $rVel_{mean}$ interventions ($p < 0.05$);* ***F*** *= Significance at 6 and 12 min backward interventions ($p < 0.05$);* ***G*** *= Significance at 6 min backward interventions ($p < 0.05$);* ***H*** *= Significance at 12 min backward interventions ($p < 0.05$);* ***I*** *= Significance at 12 min 35% $rVel_{mean}$ ($p < 0.05$).*

Chapter Six: Discussion

The aim of this study was to determine the potentiating effect of backward sled towing on forward 5 m sprint performance. To the author's knowledge, this was the first study to investigate the potentiating effect of a backward sled towing protocol on 5 m sprint performance. In contrast to the thesis hypothesis, the main findings of this study indicate that 5 m sprint performance is not acutely enhanced by a heavy sled towing stimulus, regardless of load, movement specificity, or rest period. Due to this, the hypothesis that a heavier sled load (i.e., 55% $rVel_{mean}$) will significantly improve 5 m sprint performance compared to a lighter load (i.e., 35% $rVel_{mean}$) cannot be supported. Similarly, many previous authors have reported an inability to potentiate sprint performance using a multitude of pre-conditioning exercises (Bevan et al., 2010; Comyns et al., 2010; Till & Cooke, 2009; Whelan et al., 2014), highlighting the individual variability in relation to potentiation magnitude and the delayed-onset of PAP (Bevan et al., 2010; Till & Cooke, 2009). Whilst forward sled towing achieved the intended $rVel_{mean}$ (i.e., 55% and 35% $rVel_{mean}$), significant variation in backward intervention $rVel_{mean}$ (55% vs. 62%; 35% vs. 47%; $p<0.05$) highlights the significant learning effect of backwards sled towing. Interestingly, EMG results did not significantly differ between trials, however, mean EMG amplitude analysis supports the previously established muscle activation profile of sprint acceleration (Flynn & Soutas-Little, 1993).

Sprint kinetic and temporal data did not significantly change between interventions. Although no increase in force plate data was documented, the importance of vertical force production during sprint acceleration is highlighted. Both peak and mean vertical force production were found to be significantly higher at baseline measures in comparison to 6 and 12 min respectively. A 35% $rVel_{mean}$ load significantly increased RDF at 6 min, whereas 55% $rVel_{mean}$

significantly increased RFD at 12 min. This finding further highlights that the fatigue-potentiation relationship is related to conditioning activity intensity. Significant difference was found between peak braking at 6 min during 55% $rVel_{mean}$ compared to 35% $rVel_{mean}$, however, no significant changes against baseline measures were found. Backward 35% $rVel_{mean}$ sled towing was shown to significantly decrease ground contact time (-0.013 sec) at 12 min in comparison to 55% $rVel_{mean}$, however, forward sled tow interventions were attributed to a significant decrease in time to peak force (-0.026 sec) at 12 min. Finally, a significant decrease in breaking time was reported during backward sled towing (-0.002 sec) in comparison to forward sled towing. However, this did not translate into a greater force output, therefore, it is not possible to attribute these findings to a potentiated state.

A non-significant change in 5 m sprint velocity following a PAP preconditioning stimulus is consistent with previous literature (Bevan et al., 2010; Crewther et al., 2011; Whelan et al., 2014; Winwood et al., 2016). Most notably, Whelan et al. (2014) reported a non-significant change in 0-5 m sprint performance following a 30% BM sled towing protocol of 3 x 10 m sled tows and concluded that an insufficient sled load was the underpinning reason for a lack of PAP. In this thesis, participants completed 3 x 5 m tows interspersed by 60 sec, compared to Whelan et al. (2014) 3 x 10 m tows separated by 90 sec recovery. Although these prescriptions differ, an increased sled load over a shorter time period would result in the required stimulus to generate fatigue, as fatigue is defined as the loss of muscle equilibrium (i.e., readily available ATP) (Ament & Verkerke, 2009). The relationship between acute fatigue and potentiation has previously been described as reciprocal, meaning one cannot occur without the onset of the other (Tillin & Bishop, 2009). Therefore, providing a preconditioning exercise stimulates a level of acute fatigue, a level of potentiation can be sought. However, in this study, the contrary is seen to be true. Perhaps instead of disproving the relationship of fatigue and potentiation, it is more likely that sled tow sprint potentiation requires a greater total time under tension (TUT).

Recently, Wong et al. (2017) suggested such a relationship when recommending twenty foot contacts to induce a sprint related PAP response. Previous authors may have unintentionally utilised similar TUT in their exercise selection and volume loads. For example, multiple repetition back squats have been shown to successfully induce sprint related PAP (Chatzopoulos et al., 2007; McBride et al., 2005; Seitz et al., 2014). Anecdotally, the time to complete 3-10 x 90% 1 RM back squats is > 30 sec, compared to ~2 sec to complete a 5 m sled tow (35% $rVel_{mean}$). In comparison to a back squat, sled towing foot contact time is significantly shorter. However, back squats have not been shown to specifically enhance 5 m sprint performance (Bevan et al., 2010; Crewther et al., 2011; Deutsch & Lloyd, 2008). Movement specificity has been highlighted as a PAP prescriptive consideration (Crewther et al., 2011), however over a shorter distance of 5 m its significantly not applicable (Bevan et al., 2010; Crewther et al., 2011; Deutsch & Lloyd, 2008; Jarvis et al., 2017; Whelan et al., 2014; Winwood et al., 2016). The unestablished link between PAP and 5 m sprint performance may be relative to the sprint performance distance. It appears that short distances (i.e., 5 m) are insufficient to gain the accumulative increase in muscle tension to potentiate sprint performance.

Reported EMG activity supports such claims with no significant change in surface amplitude across all interventions ($p > 0.05$) implying no significant change in net motor-unit activity. This suggests that central fatigue, defined as an acute reduction in MVC (Bigland-Ritchie, Jones, Hosking, & Edwards, 1978), did not occur across any intervention and was not a factor during performance. Tran and Docherty (2006) previously speculated an increased peripheral fatigue in association with TUT. This would support MLCP as the major mechanism of PAP, as peripheral muscle fatigue is closely linked to an altered ion exchange (i.e., calcium kinetics) (Tran & Docherty, 2006). However, this is an area which requires further investigation.

Although in the current study EMG activity was unable to display a potentiated central nervous system effect, inter-muscle motor firing patterns during running reflect those of previous findings (Flynn & Soutas-Little, 1993). Maximal sprint performance is characterised by increased hip extensor activation (Morin, Gimenez, et al., 2015). However, in the present study, greater vastus lateralis activation during 5 m sprint performance highlighted the role of knee extensors during sprint acceleration. This supports previous claims of increased knee torque due to the increased horizontal concentric force during the acceleration phase of sprinting (Handsfield et al., 2017; Tottori et al., 2018). Gastrocnemius activation was reported as the most active muscle group during 5 m sprint performance. This corresponds with relevant literature highlighting the vertical and horizontal acceleration profiles of plantar flexors during the stance phase of sprint acceleration (Hamner & Delp, 2013; Lai, Schache, Brown, & Pandy, 2016). These findings concur with our aim to potentiate sprint performance via a vastus lateralis dominant preconditioning exercise. However, the ability to comment on the relevance of muscle-specific preconditioning is redundant in this case due to the absence of potentiation.

Sprint acceleration is characterised by the ability to generate large quantities of force in the desired direction (Ciacci et al., 2010; Hunter et al., 2005). Supporting the findings of this thesis, vertical ground reactive forces are essential during early acceleration to ensure relocation of lower limbs during the swing phase (Morin et al., 2012; Morin, Slawinski, et al., 2015).

However, horizontal force production has been previously identified as the major kinetic parameter of early sprint acceleration (Morin et al., 2012; Morin, Gimenez, et al., 2015). The lack of both horizontal force augmentation and sprint performance potentiation only further supports these claims.

Interpersonal variability is accepted as a major contributing factor to the application of PAP, even in a homogenous cohort (Healy & Comyns, 2017; Nibali, Chapman, Robergs, & Drinkwater, 2013; Whelan et al., 2014; Winwood et al., 2016). In support of this, a large variation of individual mean velocities were documented. Although 5 m sprint potentiation was not detected, certain individuals substantially improved their 5 m mean velocity following the potentiation interventions.

6.1 Limitations

This study utilised a randomised design to investigate the effect of heavy sled tow stimulus on the 5 m sprint performance of 18 well-trained volunteers. Well-trained was defined as having participated in high-intensity exercise 3-5 days per week for six months prior to participation. Whilst all individuals matched the participation criteria, the varied response to the sled stimuli may suggest the individual profile of participants were not ideal. Although all participants were involved in high-intensity exercise for six months prior to testing, no initial strength or power testing was undertaken to assess participant’s suitability. However, to the author’s knowledge, all sled tow related sprint PAP studies have relied on training history for participant selection as opposed to initial strength or power testing (Jarvis et al., 2017; Whelan et al., 2014; Winwood et al., 2016; Wong et al., 2017). Nevertheless, training history may have been an influencing factor in the final outcome of this investigation as PAP is renowned for its individual response.

Whilst MVC contractions were required to measure changes in mean muscle amplitude, a variety of methodologies are accepted as most appropriate (Norcross, Blackburn, & Goerger, 2010). Although EMG was reported as normal, manual MVC collection may lead to varied results. It, therefore, may be more reliable to utilise a fixed isometric hold, offered by repeatable equipment such as the Biodex Isokinetic Dynamometer (Feiring, Ellenbecker, & Derscheid, 1990).

Backward sprinting is a fairly uncommon practise. Therefore, the novel design of this study may have consigned participants to a state of learning as opposed to a state of mastery. The difference between forward and backward sprint velocity would support the former. Although time was dedicated within familiarisation and warm up procedures to upskill backward running efficacy, perhaps this was insufficient to overcome the associated learning effect.

6.2 Future Research

In respect to the aforementioned discussion, the future research recommendations should focus on improving the understanding of sprint related PAP and the general physiology of its application.

Firstly, time under tension is speculated within the discussion as a potential inhibitor of sled tow related sprint PAP. Time under tension during sled towing may not replicate the TUT of more consistent PAP protocols (i.e., back squats), however, to the author's knowledge this is currently unknown. Based on current literature, there is no reason to assume that short force impulses cannot generate a potentiated performance greater than a long force impulse

(Chatzopoulos et al., 2007; Jarvis et al., 2017; McBride et al., 2005; Seitz et al., 2017; Seitz et al., 2014; Winwood et al., 2016). Therefore, future research may look to investigate the required force profiles of PAP prescribed back squats. Determining the net force required to bring about a potentiated state could then be transferred to a sled towing stimulus. To date, the relationship between sled load and velocity is found to be non-linear (Cross et al., 2018), therefore, future research should investigate either velocity or load as opposed to both. However, if the net force to complete these tasks can be equated, more specific prescription methods may be developed.

Secondly, Turfrey (2014) emphasised the current inadequacies in PAP physiology and the mechanism behind its dynamic application. Whilst this study attempted to generate a physiological understanding of PAP through EMG, a vast number of authors have claimed to generate a PAP response by an association of findings. Therefore, it is unknown if acute muscular augmentation is due to the proposed mechanisms of PAP or a general warm-up effect. Supporting Turfrey (2014) conclusions, the complexity and uncertainty of PAP mechanisms leave practitioners seeking a performance orientated model as opposed to a mechanism based model of PAP. To date, the understanding of PAP has been largely engulfed by the adjustment of PAP protocols to bring about acute enhancement, as opposed to further understanding the physiological mechanisms that elicit PAP. To the author's knowledge, no study to date has identified a clear relationship between the aforementioned PAP mechanisms and an acute dynamic augmentation in performance. Future research exploring the dynamic application of PAP would hopefully provide clarity of the PAP mechanisms, therefore providing practitioners with a refined understanding of the individual protocols to elicit a potentiated state. As this understanding increases, one may assume that the practical application will likely enhance also.

Chapter Seven: Conclusion

The purpose of this study was to: 1) determine whether backward sled towing can elicit PAP to enhance forward sprint acceleration over 5 m; and 2) determine if sled loading via a reduction in velocity can elicit an improvement in 5 m sprint performance. In relation to the hypothesis' outlined in **Chapter Three**, it can be concluded that for this particular population:

- Heavy backward sled towing does not potentiate forward 5 m sprint performance.
- Heavy forward sled towing does not potentiate forward 5 m sprint performance.
- Reduction in velocity loading does not elicit an acute improvement in 5 m sprint performance.
- Inter-individual variability greatly impacts the magnitude of potentiation during 5 m sprint performance.
- Central nervous fatigue does not influence the magnitude of potentiation during 5 m sprint performance. Illustrated by insignificant changes in EMG across interventions.
- Quadriceps activation plays a significant role in short sprint acceleration.
- Heavy sled tow interventions do not acutely enhance first stride ground kinetic or temporal parameters. Illustrated by insignificant changes in kinetic and temporal parameters across interventions.

With the aim to acutely enhance 5 m sprint performance, a rigorous methodology was devised using previous research to theoretically leave participants in an augmented state. However, the current results showed no significant change in sprint performance regardless of intervention, sled load, or rest period. These findings support previous literature of an inability to potentiate 5 m sprint performance, regardless of the loading technique (Bevan et al., 2010; Crewther et al., 2011; Whelan et al., 2014; Winwood et al., 2016). To this, the author acknowledges that both conditioning activities and performance measures require a certain degree of force accumulation, otherwise known as time under tension. A lack of identified physiological dynamic potentiation in both this and previous studies highlights a current constraint of PAP. This is not intended to reduce the value of previous findings, but instead strengthen the understanding of the acute phenomenon that is PAP. Future research must ensure to address the physiological reasoning behind the potentiated state, otherwise an acute augmentation may in fact be a result of a general warm up effect.

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Appendices

Participant Information Sheet

MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

Acute effect of resisted sled loads

INFORMATION SHEET

Researchers Introduction

Daniel Monaghan (Masters Student) from the School of Sport, Exercise & Nutrition, Massey University, will be undertaking this research. Daniel has successfully completed a previous study as a research assistant in this area of sport performance that has included muscle power and speed measures and has experience in muscle activation analysis.

Brief Description and Invitation

Resisted sprint training employs various methods such as towing tyres, sleds, and wearing weighted vests that have been shown to improve the 'acceleration' phase during sprint performance. However, little is known about the acute effect of sprinted-resistance to elicit a post activation potentiation (PAP) - a phenomenon that acutely and temporarily enhances muscle performance above that of a normal warm-up. To date, only four studies have investigated the acute effect of sled towing on sprint performance with equivocal results. To provide new insights this project will examine different velocity reductions (35% and 55%) during forward and backward running over a sprint distance of 5m to determine if PAP can be elicited by speed-resisted towing and movement specificity.

Therefore, the purpose of this study is to assess the whether external resisted loads will enhance sprint performance.

If you are interested, we invite you to consider participating in this research.

Participant Identification and Recruitment

At least 23 participants are being recruited from a local team. To meet the selection criteria you must be a healthy active male athlete (18 - 35 yrs.) who participates in vigorous exercise 4-6 time per week. Participants must have not suffered any significant lower limb or back injury for 6 months prior to participation.

Participation is voluntary, and all interested participants will be screened using a customised health screening questionnaire before being accepted into the research.

The study will be conducted at the Practical Teaching Complex Lab 1.36, Massey University, Palmerston North and it is expected that it will take five hours of your time. You will need to make five separate visits each lasting one hour in duration.

Project Procedures

For this study it is important to be dressed appropriately for exercising (shorts, t-shirt and running shoes). You will complete a health questionnaire. If the completed health questionnaire does not indicate any reason why you should not participate, you will be invited to take part in the research.

Familiarisation

Familiarisation sessions entailed basic anthropometric measures (height and weight) and the completion of testing procedures. Participants will be acquainted with EMG electrode placements before completing a pre-determined dynamic warm up. Following this, two forwards and two backwards non-resisted 5 m sprints will be completed to calculate baseline mean sprint velocities. Following this, participants will complete 5 m sled tows to determine 35% and 55% of mean velocity for forwards and backwards sled tow modes. The starting load for sled towing was determined by percent body mass. The 5 m loaded sled sprints were interspersed with a 2 minute recovery period. At the conclusion of the session, an 8 minute cool-down including 4 minutes of cycling at a self-prescribed intensity and 4 minutes of static stretching was completed with the aim to restore muscle length.

Sprint Testing

Following a 10 minute warm-up, sprint testing will be measured by speed gates at intervals of 3.2 m and 5 m. Two 5 m un-resisted maximal sprints will be performed with 4 minutes rest separating each sprint. Following this you will attached a harness from which a sled will be attached with a load of ~75% of your body mass and you will complete three repetitions over 5 m. Following the resisted sprint you will perform maximum effort un-resisted sprints at 6 and 12 minutes. The following sessions will be identical except that the third session will entail a load of ~110% of body mass; fourth session will entail a load of ~80% of body mass backwards; and fifth session will entail a load of ~100% of body mass backwards.

Muscle activation

Muscle activity of the quadriceps, hamstrings, gluteus, calf and shin will use surface electrodes (see figure 1). Prior to electrode placement, the area of the aforementioned muscles will be shaved, gently abraded using general purpose scouring pad (Scotch-Brite™) and cleaned with an isopropyl alcohol pad. To manage infection control a new scouring pad will be used for every participant. Surface pre-gelled electrodes, 10 mm diameter will be placed on the skin over the mid-belly of the muscle parallel to the direction of the fibres. The surface electrodes record muscle activity of the muscle they do not emit any electrical charge and are harmless. The muscle signals along with the synchronised video capture of sprinting will be transmitted to a PC interface-receiver where off-line analysis will be conducted at a later date.

Video Capture

Video capture will also be utilised to measure characteristics of sprint performance. This video capture omits no audio. Video data will also be used as a mean to synchronise data collection points. Video data will be collected from a stationary point and only collected during sprint repetitions.

Data Management

After collection, all data will be de-identified for statistical analysis and will be kept strictly confidential; password protected electronically and hard copy stored in a locked filing cabinet. It will be used only in summary form for reporting or publication purposes. After five years it will be destroyed.

At the completion of the study you will be provided with a summary of the results. This will be personally emailed to you and will include your individual data and the overall findings. Furthermore, the findings of the study will be disseminated for an international journal publication.

Participant's Rights

You are under no obligation to accept this invitation.

If you do decide to participate, you have the right to:

- decline to answer any particular question;
- withdraw without reason from the study at any point in time;
- ask any questions about the study at any time during participation;
- provide information on the understanding that your name will not be used unless you give permission to the researcher;
- be given access to a summary of the project findings when it has concluded.

Project Contacts

If you have any questions at any time about this project, please contact:

Mr. Daniel Monaghan, School of Sport and Exercise, Massey University.

Phone: [redacted]; email [redacted]

Dr Darryl Cochrane (Project Supervisor), School of Sport and Exercise, Massey University.

Phone: 356 9099 Extn. 84532; email D.Cochrane@massey.ac.nz

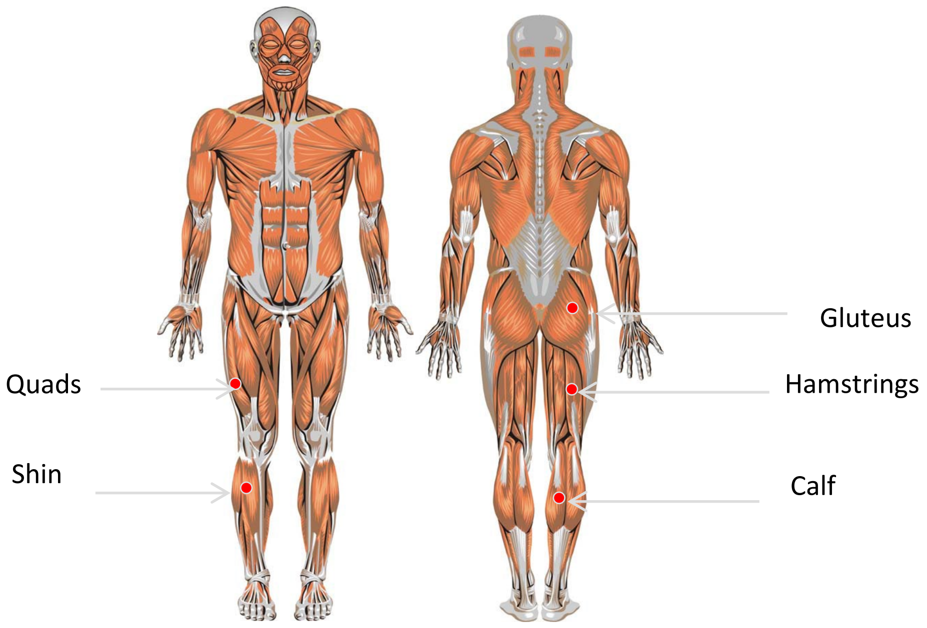
This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A, Application SOA 18/31. If you have any concerns about the conduct of this research, please contact Dr Lesley Batten, Chair, Massey University Human Ethics Committee: Southern A, telephone 06 356 9099 x 85094, email humanethicsoutha@massey.ac.nz .

Compensation for Injury

If physical injury results from your participation in this study, you should visit a treatment provider to make a claim to ACC as soon as possible. ACC cover and entitlements are not automatic and your claim will be assessed by ACC in accordance with the Accident Compensation Act 2001. If your claim is accepted, ACC must inform you of your entitlements, and must help you access those entitlements. Entitlements may include, but not be limited to, treatment costs, travel costs for rehabilitation, loss of earnings, and/or lump sum for permanent impairment. Compensation for mental trauma may also be included, but only if this is incurred as a result of physical injury.

If your ACC claim is not accepted you should immediately contact the researcher. The researcher will initiate processes to ensure you receive compensation equivalent to that to which you would have been entitled had ACC accepted your claim.

Figure 1 – Surface Electrode Placement



Health Screening Questionnaire

School of Sport, Exercise & Health
Private Bag 11 222
Palmerston North
New Zealand
Telephone: 64 6 356 9099

MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

PRE-EXERCISE HEALTH SCREENING FORM

Please read the following questions carefully. If you have any difficulty, please advise the researchers who are conducting the muscular performance tests.

Please answer all of the following questions by ticking only one box for each question:

This questionnaire has been designed to identify the small number of persons (15-69 years of age) for whom physical activity might be inappropriate. The questions are based upon the Physical Activity Readiness Questionnaire (PAR-Q), originally devised by the British Columbia Dept of Health (Canada), as revised by [1]Thomas *et al.* (1992) and [2]Cardinal *et al.* (1996), and with added requirements of the Massey University Human Ethics Committee. The information provided by you on this form will be treated with the strictest confidentiality.

PERSONAL INFORMATION

Name:____

Age:________________ Birth Date:______/______/_______

Address:____

Telephone:______________________________(hm)_____________________________

Emergency: Contact Name:______________________________Telephone_________________

1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

Yes ☐ No ☐

2. Do you feel a pain in your chest when you do physical activity?

Yes ☐ No ☐

3. In the past month have you had chest pain when you were not doing physical activity?

Yes ☐ No ☐

4. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition? ☐ ☐

Yes No

5. Have any immediate family had heart problems prior to the age of 60?

Yes ☐ No ☐

6. Do you lose your balance because of dizziness or do you ever lose consciousness?

Yes ☐ No ☐

7. Do you have a bone or joint problem that could be made worse by vigorous exercise?

Yes ☐ No ☐

8. Have you recently had any lower and upper limb injuries?

Yes ☐ No ☐

9. Have you had a history of pain, injury, or surgery over the past 6 months, including back surgery?

Yes ☐ No ☐

10. Do you have a recent fracture?

Yes ☐ No ☐

11. Do you have a neuromuscular disorder?

Yes ☐ No ☐

12. Do you know of any other reason why you should not do physical activity?

Yes ☐ No ☐

13. Have you been hospitalised recently?

Yes ☐ No ☐

You should be aware that even amongst healthy persons who undertake regular physical activity there is a risk of sudden death during exercise. Though extremely rare, such cases can occur in people with an undiagnosed heart condition. If you have any reason to suspect that you may have a heart condition that will put you at risk during exercise, you should seek advice from a medical practitioner before undertaking the following tests.

I have read, understood and completed this questionnaire.

Signature: ____ Date: ___________________

References

1. Thomas S, Reading J and Shephard RJ. Revision of the Physical Activity Readiness Questionnaire (PAR-Q). *Can J Sport Sci* 17(4): 338-345.
2. Cardinal BJ, Esters J and Cardinal MK. Evaluation of the revised physical activity readiness questionnaire in older adults. *Med Sci Sports Exerc* 28(4): 468-472

Informed Consent Form

School of Sport, Exercise & Nutrition
Private Bag 11 222
Palmerston North
New Zealand
Telephone: 64 6 356 9099

MASSEY UNIVERSITY
COLLEGE OF HEALTH
TE KURA HAUORA TANGATA

Acute Effect of Forward & Backwards Resisted Sprint Loads

PARTICIPANT CONSENT FORM

This consent form will be held for a period of five (5) years

I have read the Information Sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that the research involves video recording and that I may ask further questions at any time.

I agree to participate in this study under the conditions set out in the Information Sheet.

Participants Full Name – printed ____

Signature of Participant ____

Date _______/______/ 2018

Ethics Letter of Approval

Date: 26 June 2018

Dear Daniel Monaghan

Re: Ethics Notification SOA 18/31 Can Backwards Sled Towing Potentiate 5 Metre Sprint Performance?

Thank you for the above application that was considered by the Massey University Human Ethics Committee:

Human Ethics Southern A Committee at their meeting held on **Tuesday, 26 June, 2018**.

Approval is for three years. If this project has not been completed within three years from the date of this letter, re-approval must be requested.

If the nature, content, location, procedures or personnel of your approved application change, please advise the Secretary of the Committee.

Yours sincerely

Tracy Riley

Associate Professor Tracy Riley, Dean Research

Acting Director (Research Ethics)

Research Ethics Office, Research and Enterprise
Massey University, Private Bag 11 222, Palmerston North, 4442, New Zealand **T** 06 350 5573; 06 350 5575 **F** 06 355 7973
E humanethics@massey.ac.nz **W** http://humanethics.massey.ac.nz

Cultural Consideration for Ethical Approval

24 May 2018

Dr Lesley Batten
Chairperson
Human Ethics Committee - Southern A
Massey University
PALMERSTON NORTH

RE: Letter of Support: Mr Daniel Monaghan

Tēnā koe Dr Batten,

I have been approached for Māori consultation regarding a research project being conducted by Mr Daniel Monaghan (MSpEx candidate), who is supervised by Assoc. Prof. Daryl Cochrane and Dr Phil Fink, School of Sport, Exercise and Nutrition, Te Kura Hauora Tangata/College of Health, Te Kunenga ki Pūrehuroa/Massey University. Mr Monaghan's research question and working title is *"Can Backwards Sled Towing Potentiate 5 Metre Sprint Performance?"* and aims to determine whether backwards sled towing can elicit Post-Activation Potentiation (PAP) to enhance forward sprint acceleration over five metre distances. His hypothesis is that backwards sled towing elicits greater quadriceps activation compared to forward resisted sprinting, and consequently an improvement in sprint-related movements due to changes in neural excitation. Mr Donaghan will select 24 well trained males to participate in his study that involves:

- One (1) familiarisation session entailing basic anthropometric measures, and the completion of testing procedures;
- Four (4) intervention sessions of 16x5m sprints of a loaded sled tow in both forward and backward modalities to deduce specific reduction in mean velocity;
- Measurement data will be gathered by electromyography (EMG), first stride kinetics and kinematics, and video capture and analysed using statistical software;
- The session will conclude with an appropriate physical warm-down to assist with recovery.

I am satisfied the study that has been outlined meets the mandatory requirements of cultural consultation based on the following points:

1. His study does not specifically focus on Māori participants; rather his participants will come from the general populace. Hence, there may or may not be people who identify as Māori who volunteer for this project. If indeed there are participants that identify as Māori in the study, I am happy to act in the capacity of advisor if required by either the participants and/or Mr Donaghan and his supervisors;

2. Mr Donaghan engaged with basic literature endeavouring to assist his understanding of Māori participant ethicality, complimented by a lengthy discussion explicating his notions of responding appropriately to the needs and aspirations of Māori in his field of research.

3. No blood samples are required for the purposes of the research project.

These points have been discussed and in my opinion, are consistent with Te Tiriti o Waitangi as stated in policy 1.2, "to consult meaningfully with tangata whenua on all research that concerns Māori and to ensure that research maintains the integrity of Māori" (Smith, 2010, p. 3)[1]. I hope this letter of support will be sufficient to that end. As previously mentioned in point one, I am happy to provide ongoing support and advice either to him and his participants throughout the data gathering and dissemination process if required.

If you or the committee have any queries please do not hesitate to contact me at the details below.

Nāku me ngā mihi maioha ki a koe, kōutou te komiti,

Dr Bevan Erueti (Taranaki, Ngāti Tūwharetoa, Te Atihaunui-a-Pāpārangi)

Kaiarataki Māori / Associate Dean Māori
Te Kura Hauora Tāngata / College of Health
Te Kunenga ki Pūrehuroa/Massey University
Email: B.Erueti@massey.ac.nz
Phone: + 64 6 356 9099 ext. 83087

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[1] Smith, L. T. (2010). *NZARE Ethical Guidelines*. New Zealand Association for Research in Education (NZARE)/Te Hunga Rangahau Mātauranga o Aotearoa (PDF). Retrieved from http://www.nzare.org.nz/research-ethics.html, January 12 2011.