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CARDIFF SCHOOL OF SPORT

DEGREE OF BACHELOR OF SCIENCE (HONOURS)

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I would like to thank Dr Jon Oliver for all his help and words of wisdom in my times of need. I would also like to thank all the participants who made this study possible.
Abstract

The purpose of this study was to conduct an individual-based analysis of the acute response to a loaded sled pull on the initial acceleration phase during sprinting. Four university level sprinters (age; 20.5 ± 0.6, height; 180.5 ± 4.6, Mass; 75.8 ± 8.1, 100m personal best; 11.4 ± 0.1) completed five control trials and five different loaded sled pulls over three weeks. Sprint time was recorded at both 10 and 20m and ground reaction force (GRF) data was recorded from the first step following block clearance. Each loaded sled pull was performed for 10s and after a 6 minute recovery, a 20m sprint was performed. The loads used were; the unloaded sled (12.5kg), 25%, 50%, 75% and 100% of each participants body mass. The typical error of estimate from the five control trials were calculated for each participant for each variable of interest, and this value was deemed as the smallest worthwhile change in performance (SWC). GRF data were subsequently analysed from any trails where improvements in sprint time were > SWC. All participants had at least one sled resistance which resulted in a worthwhile change in sprint performance, representing improvements in sprint times of 0.9 – 1.6%. However, the load at which this occurred was highly individualised, ranging from the unloaded sled to 100% loading. Analysis of the GRF data revealed large variation in how each participants force profile was augmented following the loaded sled pull, especially in the braking and propulsive phase of the ground contact. However, rate of force development (RFD) was increased by all participants. Loaded sled pulling elicited a PAP response resulting in worthwhile improvements in sprint performance for all participants. However, the load at which this occurred and kinetic changes underpinning improved performance were highly individualised, highlighting the need for individualised PAP training programmes.
CHAPTER ONE

INTRODUCTION
1.1 Introduction

Increasing the velocity at which an athlete can sprint has long been the goal of coaches and researchers, and different types of resistance training have been designed with the aim of maximising sprint performance (Young, Benton, Duthie & Pryor, 2001; Sleivert and Taingahue, 2004; Cissik, 2005). Consequently, the phenomenon of postactivation potentiation (PAP) has been researched heavily, as findings suggest it has the potential to significantly enhance explosive performance (McBride Nimphius, & Erickson, 2005; Chatzopoulos et al., 2007; Yetter & Moir, 2008; Linder et al., 2010). The proposed method to elicit a PAP response is commonly referred to as complex training (Jenson & Ebben, 2003), and involves alternating biomechanically similar heavy resistance exercises with plyometric exercises; such as a loaded back squat and a countermovement jump (Young et al., 1998). By alternating biomechanically similar heavy resistance exercises with plyometric exercises it is possible to elicit a potentiating response within the muscle, and cause an acute enhancement in plyometric ability (Ebben, 2002; Mathews, Matthews, & Snook, 2004). However, the extent to which performance can be enhanced has yet to be determined.

Despite a plethora of research on PAP, there is no consensus regarding the underpinning mechanism (Robbins, 2005). Tillen & Bishop (2009) identify two primary mechanisms which are thought to be responsible for the PAP response. Firstly, the phosphorylation of myosin regulatory light-chains (RLC) causes alterations to the myosin molecule (Szczesna et al., 1993) increasing the rate at which myosin cross bridges move from a non force producing state to a force producing state (Abbate, Sargeant, Verdijk, & De Hann, 2002; Sale, 2002; Hodgson, Docherty & Robbins, 2005). Secondly, reduced transmission failure at synaptic junctions allows for the activation of higher order motor neurones (Hirst et al., 1981), which increases the contribution of fast twitch fibres and enhances explosive performance (Gullich & Schmidtbleicher, 1996).

The majority of PAP literature has focused on the lower body, and jumping performance has been investigated due to its application to many sporting movements and relative simplicity (Chui et al, 2003; Jensen & Ebben, 2003; Kilduff et al., 2008; Mitchell & Sale, 2011). Many studies are in agreement that a protocol of heavy loading prior to an explosive countermovement jump can result in significantly enhanced jump performance.
(Weber, Brown, Coburn & Zinder, 2008; McCann & Flanagan 2010; Mitchell & Sale, 2011). However, studies with similar protocols of pre-loading and recovery have reported conflicting results with no significant improvements being observed (Jensen & Ebben, 2003; Scott & Docherty, 2004; Rixon, Lamont & Bemben, 2007).

Furthermore, research has attempted to apply the PAP theory to more ballistic movements such as sprinting, which arguably has even greater application to a large number of sports than jumping movements (Gaffney, 1990; McInnes, Carlson, Jones & McKenna, 1995; Deutsch, Young & Aitken, 1998; Duthie, 2003). There is evidence to suggest that sprint performance can be acutely enhanced following a heavy resistance exercise (McBride et al., 2005; Yetter & Moir, 2008; Linder et al., 2010). However, there is again conflicting literature with studies finding no significant enhancement in sprint performance following a similar PAP procedure (Till & Cooke, 2009) Moreover, the initial acceleration phase has proved particularly difficult to enhance, with few studies observing significant improvements over the 0-10m phase (Chatzopoulos et al., 2007). The acceleration phase has arguably the greatest application to sport as during team games maximal speed is not always achieved (Deutsch et al., 1998).

1.2 Rational

It is possible to criticise the current literature regarding PAP and sprinting performance twofold. Much of the current literature uses a traditional experimental design, focusing on the group response to a specific PAP procedure (Chui et al., 2003; Chatzopoulos et al., 2007; Kilduff et al., 2008; Mitchell & Sale, 2011). This method is used despite the literature indicating that the response to PAP procedure is highly individualised and dependant on a large number of factors including; training status, training age, chronological age, genetics, anthropometrics, gender, muscle fibre type, relative strength, absolute strength and resistance training experience (Duthie et al., 2002; Robbins, 2005). A PAP procedure may significantly enhance performance in one participant but cause a significant reduction in another (Till & Cooke, 2009). Significant individual responses are masked by the group response and prevent the true extent of PAP from being demonstrated.

Furthermore, much of the literature regarding PAP and sprint performance has used a vertical loading stimulus, such as back squats, as the method to elicit a PAP response and
failed to observe significant improvements in the initial acceleration phase (McBride et al., 2005; Yetter & Moir, 2008; Till & Cooke, 2009). Research has indicated that the maximal velocity phase and acceleration phase have different biomechanical requirements, most notably increased contribution of horizontal force production during the acceleration phase (Mero, 1988; Hunter, Marshall & McNair, 2004; Hunter, Marshall & McNair, 2005; Cronin, Hansen, Kawamori & McNair, 2008). A vertical loading stimulus may not satisfy the biomechanical requirements of the initial acceleration phase, and the muscle specific to generating horizontal force are not potentiated. By utilising a resistance exercise with similar biomechanical requirements to that of the initial acceleration phase, it may be possible to acutely enhance sprint performance over 0-10 M. Research has demonstrated that loaded sled pulling can cause chronic adaptations to stride length and enhance the initial acceleration phase (Zafeiridis et al., 2005; Cronin & Hansen, 2006; Spinks, Murphy, Spinks & Lockie, 2007; Lockie, Murphy, Schultz, Knight & Janse de Jonge, 2012). However the acute response to such an exercise has yet to be investigated.

1.3 Aims and Hypothesis

The aim of the current study was to conduct an individual-based analysis of the acute effects of a loaded sled pull on sprint performance over the initial acceleration phase. It was hypothesised that a loaded sled pull would augment the kinetic and kinematic variables associated with the acceleration phase; however, the load which an improvement was observed would vary between participants.
CHAPTER TWO

CRITICAL REVIEW OF LITERATURE
2.1 Postactivation Potentiation

Following repeated contractile stimulation, muscular fatigue will occur, leading to attenuation in performance (Sale, 2002). However, a large body of research has been established which demonstrates the potential to improve human performance through a mechanism labelled postactivation potentiation (PAP) (Young et al. 1998; Hrysomallis & Kidgell, 2001; Chiu et al., 2003). In contrast to fatigue, PAP can acutely enhance muscular force generating ability for a short time as a result of contractile history in the muscle (Robbins, 2005). It has been suggested that fatigue and potentiation coexist within the contracting muscle and it is the balance between them that determines if the consequent contractions are improved, stay the same or decrease (Macintosh & Rassier 2002). The method which has commonly been used to elicit a PAP response in athletes is based upon the “complex training” principle. This involves alternating a biomechanically similar heavy resistance exercise with plyometric exercises in the same session (Ebben, 2002). An example which has been commonly exploited in the literature is combining heavy resistance squats prior to a vertical jump performance (Weber et al., 2008; Mitchell & Sale, 2011). Although numerous studies have provided evidence for the existence of PAP, the physiological mechanisms through which it occurs are still not completely understood (Tillin & Bishop, 2009). Furthermore, the magnitude of the PAP response has been found to be largely dependent on a number of individual and methodological factors (Hansen, Leigh & Mynark, 2007; Kilduff et al., 2008; Xenofondos et al., 2010; Brown et al., 2012), and as a result, not all studies agree that PAP can acutely enhance performance (Jensen & Ebben, 2003; Till & Cooke, 2009).

2.2 Mechanisms of Postactivation Potentiation.

From the current literature, it is possible to identify two main mechanisms through which PAP is thought to operate. The first is phosphorylation of myosin RLC (Szczesna et al., 1993; Tillin & Bishop 2009) and the second is an increase in the recruitment of higher order motor units (Gossard et al., 1994; Folland, Wakamatsu & Finland, 2009). There is also emerging evidence that the pennation angle may be augmented (Fukunaga, Ichinose, Ito, Kawakami & Fukashiro, 1997). However further research is required to quantify the magnitude of its contribution to PAP.
2.2.1 Phosphorylation of Myosin Regulatory Light Chains

The role of myosin within the body is primarily to facilitate muscular contraction in muscle cells (Wilmore, Costil & Kenny, 2008). Each myosin molecule is comprised of two myosin heavy chains, and at the end of each chain is a myosin head which is comprised of two RLCs, each with a specific binding site for a phosphate molecule (Figure 2.1; Szczesna et al., 1993; Tillin & Bishop 2009). During muscular contractions, Ca\(^{2+}\) is released from the sarcoplasmic reticulum and binds to the contractile proteins. This causes the enzyme myosin light chain kinase to facilitate RLC phosphorylation which acts in two ways; altering the position of the myosin head to potentiate subsequent contractions, and rending the contractile proteins more sensitive to Ca\(^{2+}\), increasing in the rate at which myosin cross bridges move from a non force producing state to a force producing state (Abbate et al., 2002; Sale, 2002; Hodgson et al., 2005).

Support for the acute phosphorylation of RLC following tetanic stimulation of neural fibres is largely based upon studies which have used skinned animal models (Manning & Stull, 1982; Vandenboom, Grange & Houston, 1993; Szczesna et al., 2003). However, human studies have received comparatively less attention. Alway, Hughson, Green, Patla and Fliank (1987) observed an increased force production during a twitch contraction following a five second maximal voluntary plantar flexion. These findings were later supported by Hamada, Sale, Macdougall and Tarnopolsky (2000) who used maximal voluntary isometric contractions of the knee extensor muscles to evoke a PAP response. Shorter twitch contraction times were observed and a higher percentage of type II fibres were reported to be responsible for the greatest PAP response. Nevertheless, some findings have proved inconclusive in reporting significant changes in RLC phosphorylation (Smith & Fry, 2007), and Stuart, Lingley and Grange (1988) suggest that other factors may provide a greater
contribution to the PAP response.

2.2.2 Increased Recruitment of Higher Order Motor Units

Animal studies have indicated that by inducing tetanic isometric contractions, the transmittance of excitation potentials across synaptic junctions at the spinal cord can be elevated (Tillin & Bishop, 2009), resulting in an increase in post-synaptic potential during subsequent activity (Luscher, Ruenzel & Henneman, 1983; Gossard et al., 1994), and this state to last for several minutes (Gullich & Schmidtbleicher, 1996). The “all or nothing” principle applies to the release of α-motoneurons (Luscher et al., 1983) and transmission failure at various synaptic junctions is common during reflex or voluntary responses. Hirst, Redman & Wong (1981) demonstrated that following induced isometric contraction, transmission failure is reduced during subsequent activity, allowing for greater recruitment of motor units. Furthermore, Hirst et al. (1981) demonstrated that there was a 54% increase in transmitter success following a 10s tetanic isometric contraction, and this was primarily at larger motor neurones which are responsible for activating higher-order or fast twitch motor units (Luscher et al., 1983).

Research has also demonstrated similar responses in human studies. Trimble & Harp (1998) and Folland et al. (2009) reported a potentiated H-reflex following eights sets of dynamic MVC and 10s isometric MVC respectively. These findings suggest that PAP can enhance H-reflex in humans and may be due to increased higher-order motor neuron recruitment at the spinal cord (Tillin & Bishop, 2009). Theoretically, by increasing the activation of higher-order motor neurones and therefore increasing the fast twitch fibre contribution to muscular activity, explosive performance could be enhanced (Gullich & Schmidtbleicher, 1996).

2.3 Effect of Postactivation Potentiation of Athletic Performance

Jumping exercises have been traditionally used in PAP investigations due to their similarity to many sporting movements, and relatively low complexity (Xenofondos et al., 2010). Young et al. (1998) reported four minutes after a 5 RM back squat protocol, vertical jump height was improved by 2.8%. This type of protocol indicative of research into PAP and jumping performance and many other studies have followed similar protocols and observed significant improvements in jump performance. Weber et al. (2008), McCann & Flanagan (2010) and Mitchell & Sale (2011) all used back squats as the conditioning
activity to induce a PAP response and all observed significant increases in vertical jump performance following the conditioning activity. In an attempt to explain the mechanism through which vertical jump height was improved, McCann & Flanagan (2010) examined the GRF profile during the jumping movement. In agreement with other studies (Jones & Lees, 2003; Comyns, Harrison, Hennessy & Jensen, 2006) no significant increase in peak GRF was found in the PAP condition. However the changes in vertical jump performance after PAP are related to changes in the overall GRF profile, and PAP acts to increase RFD during the jumping movement (Gilbert & Lees, 2005; McCann & Flanagan, 2010). This relates to the proposed mechanism that PAP increases recruitment of higher order neurones, and activates a greater percentage of type II fibres (Tillin & Bishop, 2009; Gullich & Schmidtbleicher, 1996). However, not all of the literature is in agreement that a PAP protocol can enhance performance and some research has indicated it may actually have a detrimental effect on performance (Jensen & Ebben, 2003).

2.3.1 Conflicting Literature

Despite existing evidence for PAP, not all studies are in agreement that it can lead to an improved performance. In contrast to Young et al. (1998), Jensen & Ebben (2003) observed no change in jump performance up to 4 minutes after a 5RM protocol and a decrease in jump performance when performed immediately after the 5RM protocol. A potential limitation of this study was that it included a heterogeneous sample. Using a similar protocol, McCann & Flanagan (2010) concluded that despite using a homogeneous sample, the PAP response was highly individualised. Furthermore, Rixon et al. (2007) found that both gender and training experience affected the PAP response with inexperienced males jumping higher than experienced female lifters following a 1RM protocol. Using a heterogeneous sample would therefore present potentially confounding results.

Scott & Docherty (2004) followed a similar procedure to that of Jensen & Ebben (2003) and also found there was no improvement in jump performance following a 5RM protocol. It was cited that the type and intensity of the resistance exercise that may have led to no improvement being observed, with the weight not providing a large enough stimulus to cause a PAP response. These findings are in contrast to that of Mitchell and Sale (2011) who also used a 5RM protocol and did observe an improvement in jump performance. A
much smaller sample was used by Mitchell and Sale (2011), and all participants were male with experience in resistance training. These factors may explain why an improvement in performance was observed despite using a similar protocol to Jensen & Ebben (2003) and Scott & Docherty (2004) which resulted in no improvement in jump performance. The variation in the current literature, despite using similar methodologies, suggests that PAP is a highly complex mechanism and dependant on several individual subject characteristics, and caution should be taken when comparing different studies.

2.3.2 Post-activation Potentiation and Sprint Performance

Jump performance has been just one measure of how PAP can acutely enhance performance following a heavy resistance exercise (HRE). There has been a large amount of literature devoted to investigating the effect on sprint performance following a PAP protocol. Similar to the research investigating jump performance, there has been conflicting results within the sprinting literature to how effective a PAP protocol can be at enhancing sprint performance. Till & Cooke (2009) found no significant improvement in sprint performance following various PAP inducing exercises including deadlifts, tuck jumps and MVC’s. The study did however comment on the individual basis on which PAP can occur, citing a range of results form a 7.1% decrease in performance to a 8.2% increase in performance between participants. With such a large variation in the data it makes statistically significant findings hard to achieve when using a traditional experimental design examining the group response, and emphases the need for a design and analytical approach that considers the individual response.

In contrast to Till and Cooke's (2009) findings, McBride et al. (2005) did observed a significant decrease in 40m time following a protocol including 3 sets of a 1RM squat. Interestingly, the study failed to report a similar improvement in 10 M and 30 M time and concluded that the sprinting action has a large amount of variability as it is a repeated ballistic action, unlike the single maximal effort such as a counter movement jump (CMJ), used in previous studies. It was also suggested that despite being “well trained” the subjects were unable to produce identical starts and therefore 10 M and 30 M times had a large amount of variance and made any significant improvements over these distances negligible.
Yetter & Moir (2008) conducted a similar study investigating the effect of different HRE over each 10 M interval up to 40 M. They used a similar sample to that of McBride et al. (2005) and reported similar results. The 30 – 40 M interval resulted in a 2.3% improvement in sprint performance. Such an improvement would be meaningful and over a 100m race could move a sprinter from outside of the medals to gold medal position. The 2.3% improvement observed by Yetter & Moir (2008) was greater than the 0.9% increase McBride et al. (2005) observed, however different protocols were used when creating the PAP response. Consistent with McBride et al. (2005), Yetter & Moir (2008) reported no significant improvement in the initial stages of the sprint, in this case the 0 – 10 M interval. A further observation by Yetter & Moir (2008) was that the 0 – 10 M interval and 30 – 40 M interval represented different phases of the sprinting action, and has different biomechanical characteristics.

A further study conducted by Chatzopoulos et al. (2007) used a greater volume in their PAP procedure with subjects performing 10 single repetition squats at 90% of their 1RM. This was after Mcbride et al. (2005) proposed that a more intense resistance exercise could positively affect the acceleration phase. It was found that this procedure significantly improved both 10M and 30M sprint performance, but only after a rest period of 5 minutes. A rest period of 3 minutes was also examined but this did not result in any significant improvement. These results highlight another potentially confounding factor in the PAP literature regarding the amount of recovery between the resistance exercise and consequent explosive movement. A limitation of all the above studies is the use of a vertical loading stimulus being applied to the horizontal action of sprinting. Literature has suggested that during the initial acceleration phase of sprinting, horizontal force production is more important than the vertical component (Hunter et al., 2005). Using a resistance exercise that has a greater emphasis on horizontal force production may be able to enhance the initial acceleration phase greater than a vertical loading stimulus.

2.4 Importance of the Acceleration Phase

The literature provides evidence that sprint performance can be enhanced by utilising a PAP protocol (McBride et al., 2005; Chatzopoulos et al., 2007 Linder et al., 2010), although the magnitude of improvement may be dependent on a number of factors. The acceleration phase has proved to be more difficult to enhance and research has
suggested that the conditioning activity prior to the sprint has not been specific enough to the characteristic of the acceleration phase (Yetter & Moir, 2008). It would seem reasonable to investigate this further as the acceleration phase has been described as the most important phase during the 100 M sprint (Gaffney, 1990) and contributes an estimated 64% to the total 100 M performance (Tellez & Doolittle 1984). It also has application to team sports where maximal velocity running is not always achieved (Deutsch et al., 1998; McInnes et al., 1995). Research investigating the effect of PAP on sprinting has typically only measured sprint time and velocity (Mcbride et al. 2005; Yetter & Moir, 2008). A deeper analysis of kinematic and kinetic variables associated with the acceleration phase could lead to a better understand of how PAP can enhance sprint performance. However, it is first necessary to outline the key kinematic and kinetic characteristics of sprinting during the initial acceleration phase.

2.4.1 Kinematic and Kinetic Characteristics of Sprinting

To understand how PAP may be used to enhance the initial acceleration phase it is important to first understand the kinematic and kinetic characteristics that define acceleration. The primary goal of the initial acceleration phase is to generate rapid horizontal velocity, which explains why vertical loading protocols may not be suitable for improve the acceleration phase. Sprint speed is determined by the product of step length (SL) and step frequency (SF), with “step” being defined as one foot contact to the opposite foot contact (Hunter et al. 2004; Maulder, Bradshaw & Keogh, 2008). To increase horizontal velocity either SL or SF must increase without causing a similar or larger decrease in the corresponding factor (Hay, 1994). During the initial acceleration phase, Čoh, Tomažin and Štuhec, (2006) highlighted the importance of the first step out of the blocks and specifically the length of the first step. In addition to this, Mann et al. (1982) stated that the ability to perform well over short sprints is determined by the ability to produce large amounts of force at critical times. These forces can be described as vertical and horizontal forces, with the latter being comprised of breaking and propulsive forces (Mero, 1988). Hunter et al. (2005) identified that faster athletes produce greater magnitudes of relative propulsive force during the initial acceleration phase, which has the effect of increasing SL, which Weynard, Sternlight, Bellizzi & Wright (2000) identified as a greater contributor to sprint performance than SF. This finding was in agreement with Mero (1988) who identified that horizontal force production was 46% greater during the
acceleration phase compared to the maximal velocity phase and suggested a positive correlation between force production and sprint velocity.

The knowledge of these factors has influenced the type of training used by athletes to try and enhance sprint performance. There is strong evidence to suggest that resistance training can lead to enhanced sprint performance through a number of mechanisms including increased neural activity, greater muscular force output and greater rate of force development (Lockie, Murphy & Spinks, 2003; Cronin & Hansen, 2006; Spinks et al., 2007). More specifically, resisted sprinting has become a popular method to improve sprint speed as is considered to be the most effective way to increase the strength of the muscle closely associated with sprint performance (Zafeiridis et al. 2005). The specificity of the resistance movement to the desired athletic movement may be the key factor in determining if the PAP can occur and lead to improved performance (Hansen et al., 2007).

2.5 Loaded Sled Pulling as a Resistance Exercise.

Typically, studies using loaded sled pulls have investigated the training effect over a period of weeks as opposed to any acute PAP effect that may be gained from doing the exercise. Spinks et al. (2007) found that after a period of eight weeks resisted sprint training using a weighted sled (approximately 10% of body mass) led to enhanced acceleration up to 15 M. However, this enhancement was no greater than the control group who did not use the weighted sled protocol. Lockie et al. (2012) concluded a six week training period using a weighted sled (12.6% of body mass) which led to a 10% increase in 0 – 10 M velocity and increased step length. Specifically, Lockie et al. (2012) noted that using sled towing can develop reactive power, leading to an improved stretch-shortening capacity during each ground contact, which contributed to the enhanced acceleration. Interestingly, Murray et al. (2005) suggested that towing resistances up to 30% of a subject’s body mass would have a detrimental effect on the kinematics of the sprinting technique, which would counteract the potential benefits shown by other studies (Spinks et al. 2007; Lockie et al. 2012). Further studies have attempted to quantify the effects pulling sleds has on kinematic and kinetic variables associated with sprinting. A reduction in step length and step frequency combined with increased contact time have been cited as potentially detrimental changes to the sprint performance, following sled pulls, with the effects being magnified by pulling loads in excess of 20% body mass (Lockie et al. 2003; Maulder et al. 2008; Alcaraz et al.
Despite this, a recent study by Keogh, Newlands, Blewett, Payne, & Chun (2010) used loads of up to 171.2 kg for sled pulls over 25 M. Keogh et al. (2010) argued that only by significantly overloading the muscles with movements closely associated to the sporting context can performance be improved. It was suggested that the ability to successfully pull the sled required large propulsive forces and short ground contact times, factors which were identified by Hunter et al. (2004) as vital for sprinting and more specifically the acceleration phase.

The above studies have examined the training response to loaded sled pulls, and the chronic adaptation that follows after a period of weeks. The acute effects of pulling a loaded sled, however, have received very little attention in the literature. A sled pull replicates the biomechanical requirements of the sprinting action more closely than that of a squatting action (Keogh et al., 2010), and require a greater amount of horizontal force production which is of great importance to the initial acceleration phase (Hunter et al., 2005). It would be reasonable to assume that sprint performance could be enhanced through using a loaded sled pull to induce a PAP response. However, the lack of literature investigating the acute effects means that a suitable load or intensity has yet to be established. Guidelines for training with loaded sled advise a load no greater than 20% of body weight (Maulder et al., 2008; Alcaraz et al., 2009; Lockie et al., 2003) for fear of causing detrimental changes to the sprinting technique due to the increased load placed on the body during the sled pull. However, PAP studies traditionally use high loads to induce a PAP response (Young et al., 1998; Duthie et al., 2002; Chatzopoulos et al., 2007), and it is likely that loads using 20% of body weight may not be demanding enough to cause a PAP response.

2.6 Methodological Factors Affecting Postactivation Potentiation.

Despite the large amount of evidence supporting the positive effect that PAP can have on performance, there are a large number of variables that need to be considered when designing a protocol to induce a PAP response and maximise the following explosive performance. Xenofondos et al. (2010) identify a plethora of variables that can affect PAP, all of which could have an impact on the PAP response. Training level, fibre type and gender can influence how effective the PAP protocol will be to any given individual, while the type, duration and intensity of the resistance exercise can also affect the PAP
response. Figure 2.2 demonstrates the complex nature and interaction of different variables in how a PAP response is achieved.

![Figure 2.2 The complex interaction of the conditioning activity in relation to the individual subject characteristics and how this causes a PAP response which results in an improved explosive performance. Adapted from Tillen & Bishop (2009).](image)

2.6.1 Individualised Response to Postactivation Potentiation

Most studies which have investigated PAP in human performance follow a traditional experimental design, examining the group response over a number of different conditions (Chui et al., 2003; Weber et al., 2008; McCann & Flanagan, 2010). However, as suggested by Xenofondos et al. (2010), the PAP response can be highly individualised, and as a result, important information regarding individual responses are masked in any analysis of the group response. Brown et al. (2012) conducted a meta-analysis of post activation potentiation, examining the effects of the conditioning activity, volume, gender, rest periods and training status. The main finding of the analysis suggested that for individuals with little experience with high intensity weight training; only a small augmentation in performance can be expected following a PAP protocol. Although studies have attempted to collate data from subjects which are “strength trained”, the level of training can vary a significant amount between subjects. This could potentially affect the outcome of investigations involving large numbers of subjects with different levels of “strength training”. This is a further weakness of using the traditional group response when investigating the effects of PAP, despite many studies concluding that there are specific individual responses, few have actually attempted to investigate them.

Furthermore, Brown et al. (2012) suggest the coexistence of fatigue and potentiation, as described by Macintosh & Rassier (2002), is more favourable with increased training
Individuals with greater experience in resistance training can expect greater increases in power output when using >90% 1RM compared to untrained individuals who may experience a negative effect on performance. This evidence for highly specific individual responses provides a justification for using a case study approach in future research to try and accurately quantify the level of improvement that can be achieved in an individual following a PAP procedure.

### 2.6.2 Recovery Time

Studies have used a range of recoveries from 10 seconds (Jensen & Ebben, 2003) to 20 minutes (Jones & Lees, 2003) in an attempt to establish the optimum time after the conditioning activity to maximise the PAP response. Studies have reported no significant improvement in performance using a recovery period of 3 minutes or less (Jensen & Ebben, 2003; Chatzopoulos et al., 2007) as it is likely that fatigue overpowers any PAP effect. Furthermore, after 20 minutes any benefit from PAP is thought to have dissipated (Kilduff et al., 2008). Research has established that there is an optimum window in which performance can be enhanced following a conditioning activity. Chatzopoulos et al. (2007) reported significant improvement in sprint performance five minutes following ten single repetitions at 90% of 1RM. Kilduff et al. (2008) found approximately 8 minutes provided optimum recovery time between heavy resistance training and an explosive activity, and this was in agreement with Brown et al. (2012) who concluded 7 to 10 minutes was the optimal time to augment power output following a conditioning activity. From the literature is it reasonable to suggest that a recovery time between 5 and 10 minutes would be suitable for the effects of PAP to be optimised. However, even within this small time frame there may be potential for individual differences to occur.

### 2.6.3 Movement Pattern Specificity

Movement pattern specificity has been attributed to failure in eliciting a PAP response. Hansen et al. (2007) found that using a Smith Machine produce significantly different kinematic characteristics compared to a free weight squat or a CMJ. The added support from the Smith Machine had the effect of reducing stress on hip extensors and ankle plantar flexors, which resulted in less functional crossover to performing a CMJ. This movement specificity is magnified when comparing a back squat to the sprinting action.
Typically, back squats have been used as a PAP inducing method when investigating the effect on sprint performance (Mathews et al., 2004; McBride et al., 2005; Linder et al., 2010). Few improvements have been observed in the initial acceleration phase suggesting that a resistance exercise with greater movement specificity to that of the initial acceleration phase may be necessary. Jacobs & VanIlgren-Schenau (1992) provide further justification for this as after assessing the inter-muscular coordination during the initial phases of a sprint, it was noted that the initial acceleration phase requires a specific activation pattern that optimizes the horizontal and vertical impulses during each step. However, there has been limited research devoted to examining the potential effects of using a PAP procedure containing a sprint specific resistance exercise, with the aim of acutely enhancing sprint performance.

2.7 Summary

The above sections have shown that PAP can exist in a variety of conditions. However, it may be highly individualised and influenced by a number of confounding factors such as; training status, fibre type, gender, recovery time, the duration, intensity and volume of conditioning activity, type of explosive movement and the specificity of the preload stimulus to the explosive activity (Xenofondos et al., 2010). In the context of sprinting, research has found little evidence to suggest that the initial acceleration phase can be acutely enhanced, despite finding significant improvements over 30 – 40 m when using a vertical loading stimulus (McBride et al., 2005). From a training perspective, research has shown that loaded sled pulls using no more than 20% of body weight as resistance, can cause chronic adaptations, and enhance the initial acceleration phase after a number of weeks (Maulder et al., 2008; Alcaraz et al., 2009; Lockie et al., 2003). However, it is still unclear if a loaded sled pull can cause a PAP response and acutely enhance sprint performance during the initial acceleration phase, and if so, what load would be suitable to cause the enhancement. It would be interesting to investigate the acute response to loaded sled pulls on kinematic and kinetic variables to determine if it possible to enhance initial acceleration phase, and through what mechanism(s) this can be achieved. Furthermore, through conducting an individual-based analysis, significant individual responses could be examined. The objective of this study was to examine the individual PAP responses sled towing may have on the performance, kinetics and kinematics of the acceleration phase in well trained sprinters.
CHAPTER THREE

METHODOLOGY
3.1 Ethics

The ethics board at Cardiff Metropolitan University approved the investigation and all subjects provided written informed consent to participate in the investigation. Examples of the participant information sheet (appendix A), informed consent sheet (appendix B) and Par Q questionnaire (appendix C) are available.

3.2 Participants

Participants were recruited by invitation from a sprint group who trained regularly in the National Indoor Athletics Centre (NIAC) located on Cardiff Metropolitan University campus. After seeking permission from the head coach, suitable participants were asked if they would be interested in taking part in the study. All participants were competitive sprinters and had competed at the British University and Colleges Sport (BUCS) championships in distances from 60m to 400m. It was required that all participants had a minimum of two years resistance training, be familiar with towing a sled and proficient in using starting blocks. It was also required that participants had been injury free for at least three months prior to the study taking place.

The current study employed a single subject design, and consequently, individual anthropometric information is included to give a detailed picture of each participant. The individual characteristics for each participant are demonstrated in table 3.1. Anthropometric measurements of mass and stature were taken using SECA digital sales (Model 770, Vogel & Halke, Hamburg, Germany) and a Holtain fixed stadiometer (Holtain LTD, Pembrokeshire, United Kingdom), respectively. Values for 1 RM were obtained from the participants own weight training programs.

Table 3.1 Participant anthropometric, strength and speed values.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Age (y)</th>
<th>Height (cm)</th>
<th>Body mass (kg)</th>
<th>1 RM (kg)</th>
<th>100m PB (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>181.3</td>
<td>79.1</td>
<td>130</td>
<td>11.3</td>
</tr>
<tr>
<td>2</td>
<td>21</td>
<td>181.1</td>
<td>67.2</td>
<td>125</td>
<td>11.6</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>185.4</td>
<td>85.1</td>
<td>150</td>
<td>11.3</td>
</tr>
<tr>
<td>4</td>
<td>21</td>
<td>174.3</td>
<td>70.8</td>
<td>150</td>
<td>11.5</td>
</tr>
<tr>
<td>Mean</td>
<td>20.5 ± 0.6</td>
<td>180.5 ±4.6</td>
<td>75.6 ± 8.1</td>
<td>138.8 ± 13.1</td>
<td>11.4 ± 0.1</td>
</tr>
</tbody>
</table>

1 RM = one repetition maximum back squat; PB = Personal Best
3.3 Experimental Summary

Testing took place in NIAC on a mondo track over a three week period, with one session per week. Participants were asked to refrain from maximal sprint work for at least 48 hours prior to testing as neural fatigue can last up to 48 hours following maximal sprint training (Peters, 1995). Each session lasted a total of two hours which ensured participants had adequate recovery between each of the experimental conditions. The first session was used to determine each participant's baseline measure for the sprint trials over both 10 and 20m, and GRF data for the first step following block clearance (see 2.3.2). In the following two weeks, five different loaded sled protocols were carried out and the following sprint performance was recorded (see 2.3.4). Finally, an individual analysis as outlined by Hopkins (2004) was carried out to test for worthwhile enhancements in sprint performance following the resisted sled pulls (see 2.4).

3.3.1 Warm-up

Participants were instructed to warm up before each testing session as they usually would prior to a normal training session with the exception of not including any plyometric activities such as bounding or hopping. This was in attempt to limit any additional PAP response as research has indicated the plyometric activity can also have a potentiating effect (Robbins, 2005). Each warm-up mainly included light jogging, dynamic stretching, running drills and fast sprints over 30 to 40 m. Participants then put on spiked shoes and completed three short runs using the starting blocks until they were satisfied with the set up.

3.3.2 Control Condition

The first session was used as a control condition and a baseline measure for each participant was recorded. Timing gates (Smartspeed, Fusion Sport, Brisbane, Australia) were placed at 10 and 20 m and participants instructed to sprint maximally to a cone placed at 25m, ensuring that there was no deceleration prior to 20m. A Kistler 5233A force plate (Kistler, Winterthur, Switzerland) located in the track recorded the GRF profiles generated during the first step following block clearance, and the data was captured using CODA motion software (Charnwood Dynamics, Leicester, UK). In total, five trials were
recorded to assess the amount of intra-subject variability in all test measures. This variability, expressed as a typical error, could then be used to identify meaningful individual changes in performance from the PAP intervention (see 2.4).

3.3.3 Force Data

Force data was collected at 1000Hz and filtered at 11Hz using a low pass filter (Winter, 2009). Research has indicated that horizontal force production during the initial acceleration phase is of greater importance than the vertical component (Hunter et al., 2005) and for this reason horizontal force profiles were analysed. Raw data was exported into excel from the CODA motion software at a sampling rate of 200 outputs and this was standardised across all trials to ensure consistent comparison when examining intra-individual differences between trials. In excel the data could be manipulated to express the following variables; peak propulsive and braking force (N), time taken to peak force (t), Rate of force development (RFD), braking impulse (N), propulsive impulse (N) and the net impulse (N) generated. Figure 3.1 provides an example of how these variables were calculated.

![Ground reaction force profile with braking impulse (B) and propulsive impulse (P).](image)

Net horizontal impulse = P - B

Figure 3.1 Ground reaction force profile with braking impulse (B) and propulsive impulse (P).
Impulse was calculated using the trapezoid rule to integrate the net force curve. The ground reaction force impulses are shown as areas under the GRF curves. B is the braking impulse and is based on all negative force data during the stance phase. P is the propulsive impulse and is based on all of the positive force data during the stance. Net impulse is calculated as the propulsive impulses – the braking impulse. RFD was calculated using the formula: peak force/time to peak force.

3.3.4 Experimental Condition

The PAP intervention required participants to complete a 10 s sled pull prior to performing a 20 m sprint, as used in the control condition. In total, five difference resistances were examined and were calculated as a percentage of each participant’s body mass. Table 3.2 demonstrates the total sled resistance used for each participant.

Table 3.2 Total sled resistance for each participant in the experimental condition.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Body mass (kg)</th>
<th>Percentage of body mass loaded onto sled (kg)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sled 25%</td>
</tr>
<tr>
<td>1</td>
<td>79.1</td>
<td>12.5</td>
</tr>
<tr>
<td>2</td>
<td>67.2</td>
<td>12.5</td>
</tr>
<tr>
<td>3</td>
<td>85.1</td>
<td>12.5</td>
</tr>
<tr>
<td>4</td>
<td>70.8</td>
<td>12.5</td>
</tr>
</tbody>
</table>

* The sled and harness combined weighed 12.5 kg. The weights shown in the table are with the sled and harness included. For example, participant 1 during the 25% condition, 7.5kg was added to the sled to make a total of 20 kg. The smallest weight available was 2.5kg, so weights for each sled pull were rounded up or down accordingly.

For each loaded sled pull, a harness was secured around the waist of the participant which attached to the sled through a length of rope (~3 m). For each resistance, participants were given the commands “set” and “go” to initiate the start of the sled pull. Verbal encouragement was given throughout the 10 s to ensure the sled pull was performed maximally. The 10 s was timed using a stopwatch which was started on the “go” command and a verbal command “stop” instructed the participants to stop pulling the sled once the 10 s were over. The harness was then removed and participants walked slowly back to the starting blocks.
Following the loaded sled pull, participants had a 6 minute walking recovery before they performed the 20 m maximal sprint. This recovery period was initiated immediately after the 10 s sled pull. Previous research investigating the effects of a PAP procedure on sprinting had found significant improvements in sprint performance when using this recovery period (Yetter & Moir, 2008; McBride et al., 2005). The sprint protocol was the same as that used during the control condition, with time being recorded over both 10 and 20m and GRF data recorded from the first step following block clearance.

During the second week of testing, data for the sled, 25% and 50% conditions were recorded and during the final week of testing, data for the 75% and 100% conditions were recorded. Due to the athletes training schedules, it was not practical to carry out five separate experiential sessions, so to try and minimise a cumulative PAP response during sessions, large rest periods were used between different sled resistances. Research has indicated that any PAP benefit is lost after 20 minutes (Kilduff et al., 2008), and consequently the current study utilised a rest period of 30 minutes between different resistance protocols. Figure 3.2 demonstrates the procedure for testing.

![Study design](image)

Figure 3.2. Study design. * = 30 minute recovery. ** = 6 minute walking recovery.
Participants had a minimum of 30 minutes between different sled pulls (*) and had a 6 minute walking recovery between sled pull and sprint protocol (**). For the baseline measure participants performed five sprint trials with a 6 minute recovery between each.

3.4 Data Analysis

For statistical analysis, raw data was copied into Statistical Package for the Social Sciences 17.1 software (SPSS Inc., Chicago, IL). The mean (± SD) group response was calculated for each of the loaded sled pulls and control trials. Repeated measures, one way analysis of variance (ANOVA) was used to determine if there was any difference between the group response after the experimental conditions. Statistical significance was set at $P < 0.05$.

However, as a case study approach was used in the current study the individual PAP responses to the different loaded sled pull were of greater interest, and an alternative analytical approach was employed based on the suggestions of Hopkins (2004). To determine meaningful PAP responses, intra-individual variability in all test measures was established from the five baseline trails. This provided a measure of the level of random noise inherent to each test measure for each individual. Hopkins (2004) suggests that the typical error of estimate (TEE) is calculated using the formula:

\[
\text{TEE} = \frac{\text{Individual SD}}{\text{Individual Mean}}.
\]

For elite performers, the smallest worthwhile enhancement in performance is 0.3 of the TEE (Hopkins, 2004), however the current study used a more stringent cut-off value to determine worthwhile changes in performance. This value was twice the TEE or simply, the standard deviation in each of the test measures from the five baseline measures, and this was expressed as the smallest worthwhile change (SWC) in performance. When improvements in sprint time over both 10 and 20m were greater than the SWC in performance, further analysis of the force data (see 2.3.3) was carried out for each participant.
CHAPTER FOUR

RESULTS
4.1 Group Response

Mean times (± standard deviation) for the control and experimental conditions for both 10 and 20m are demonstrated in figure 4.1. There was large variation between participants and a repeated measures ANOVA revealed no significant difference between any of the experimental conditions and the control condition.

![Figure 4.1 Mean (±SD) sprint performance for control condition and each of the resistance protocols. A = 10 m performance. B = 20 m performance.](image)

4.2 Individual Response

The results for individual performance are presented in two parts. Firstly, sprint performance is shown and worthwhile changes are highlighted. Secondly GRF data for the first step following block clearance is shown for sprint performances which resulted in a worthwhile change in performance.

4.2.1 Sprint Performance

The intra-participant variability for the control condition is expressed as the typical estimate of error over both 10 and 20m (table 4.1 and 4.2). This value is the smallest worthwhile change (SWC) in performance and is the method Hopkins (2001) advises for assessing individual performances. All individuals had at least one resistance where a response greater than the SWC was observed.
Table 4.1 Individual sprint performance over 10m for control (with SWC) and each of the resistance protocols

<table>
<thead>
<tr>
<th>Resistance</th>
<th>Participant</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td></td>
<td>1.95</td>
<td>2.01</td>
<td>1.96</td>
<td>1.99</td>
</tr>
<tr>
<td>SWC</td>
<td></td>
<td>0.019</td>
<td>0.016</td>
<td>0.020</td>
<td>0.019</td>
</tr>
<tr>
<td>Sled</td>
<td></td>
<td>1.96</td>
<td>2.02</td>
<td>1.95</td>
<td>1.98</td>
</tr>
<tr>
<td>25%</td>
<td></td>
<td>1.99</td>
<td>1.98*</td>
<td>1.96</td>
<td>1.96*</td>
</tr>
<tr>
<td>50%</td>
<td></td>
<td>1.94</td>
<td>2.01</td>
<td>1.93*</td>
<td>1.97*</td>
</tr>
<tr>
<td>75%</td>
<td></td>
<td>1.92*</td>
<td>2.03</td>
<td>2.01</td>
<td>1.98</td>
</tr>
<tr>
<td>100%</td>
<td></td>
<td>1.92*</td>
<td>2.02</td>
<td>1.96</td>
<td>1.96*</td>
</tr>
</tbody>
</table>

* = More than SWC

Table 4.2 Individual sprint performance over 20m for control (with SWC) and each of the resistance protocols

<table>
<thead>
<tr>
<th>Resistance</th>
<th>Participant</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td></td>
<td>3.12</td>
<td>3.25</td>
<td>3.23</td>
<td>3.25</td>
</tr>
<tr>
<td>TEE</td>
<td></td>
<td>0.029</td>
<td>0.013</td>
<td>0.031</td>
<td>0.023</td>
</tr>
<tr>
<td>Sled</td>
<td></td>
<td>3.12</td>
<td>3.25</td>
<td>3.21</td>
<td>3.19*</td>
</tr>
<tr>
<td>25%</td>
<td></td>
<td>3.16</td>
<td>3.23*</td>
<td>3.22</td>
<td>3.21*</td>
</tr>
<tr>
<td>50%</td>
<td></td>
<td>3.10</td>
<td>3.25</td>
<td>3.20*</td>
<td>3.20*</td>
</tr>
<tr>
<td>75%</td>
<td></td>
<td>3.10</td>
<td>3.26</td>
<td>3.28</td>
<td>3.25</td>
</tr>
<tr>
<td>100%</td>
<td></td>
<td>3.08*</td>
<td>3.26</td>
<td>3.23</td>
<td>3.24</td>
</tr>
</tbody>
</table>

* = More than SWC

There was a varied response across all participants and worthwhile changes were observed in the unloaded sled up to the 100% body weight condition. P1 had a worthwhile change in performance in the 75% condition over 10m, but this did not translate to an improved performance over 20m. The 100% body weight condition resulted in worthwhile change over both 10 and 20m. P2 and P3 only had one worthwhile improvement at 25% and 50% respectively and this was over both 10 and 20m. P4 had the most worthwhile responses including 25%, 50%, and 100% over 10 m and sled, 25% and 50% over 20m. A summary of the individual response is shown in table 4.3.
Table 4.3 Resistance protocols which resulted in a worthwhile change in performance over both 10 and 20m.

<table>
<thead>
<tr>
<th>Resistance</th>
<th>10m Performance (s)</th>
<th>20m Performance (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Participant</td>
<td>P1</td>
</tr>
<tr>
<td>Sled</td>
<td>P1</td>
<td>**</td>
</tr>
<tr>
<td>25%</td>
<td>P2</td>
<td>**</td>
</tr>
<tr>
<td>50%</td>
<td>P3</td>
<td>**</td>
</tr>
<tr>
<td>75%</td>
<td>*</td>
<td>**</td>
</tr>
<tr>
<td>100%</td>
<td>**</td>
<td>*</td>
</tr>
</tbody>
</table>

* = worthwhile change over single distance; ** = worthwhile change over both 10 and 20m.

4.2.2 Ground Reaction Force Profile

For performances which were greater than the SWC in performance over both 10 and 20m, analysis of the individual force data was carried out. Analysis of the first step following block clearance provided a ground reaction profile (GRF) from which force variables were calculated. Intra-participant variability for the force data was calculated from the control trials to give a value which determined the SWC in performance for each of the variables. Figure 4.2 demonstrates the GRF for each participant with the resistance protocol which resulted in a worthwhile change in performance. Table 4.4 demonstrates the force variables expressed as the change in performance from control and resistance protocol and the SWC in performance for each participant.
Figure 4.2 Ground reaction profile for the first step following block clearance of control condition and resistance protocol > SMC in performance for both 10 and 20m (A = P1, B=P2, C=P3 D=P4).

Table 4.4 Force variables from the first step after block clearance for each participant.

<table>
<thead>
<tr>
<th>Resistance</th>
<th>Peak Force (N)</th>
<th>T Peak Force (s)</th>
<th>RFD (N/s)</th>
<th>Impulse (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B (-)</td>
<td>P (+)</td>
<td></td>
<td>B (-)</td>
</tr>
<tr>
<td>P1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SWC</td>
<td>47</td>
<td>35</td>
<td>0.01</td>
<td>113.9</td>
</tr>
<tr>
<td>Change (100%)</td>
<td>2</td>
<td>31</td>
<td>0.00</td>
<td>175.7*</td>
</tr>
<tr>
<td>P2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SWC</td>
<td>75</td>
<td>13</td>
<td>0.002</td>
<td>113.9</td>
</tr>
<tr>
<td>Change (50%)</td>
<td>-569</td>
<td>-64</td>
<td>-0.001</td>
<td>152.4*</td>
</tr>
<tr>
<td>P3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SWC</td>
<td>75</td>
<td>13</td>
<td>0.002</td>
<td>113.9</td>
</tr>
<tr>
<td>Change (25%)</td>
<td>85*</td>
<td>38*</td>
<td>0.02*</td>
<td>997.6*</td>
</tr>
<tr>
<td>P4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SWC</td>
<td>91</td>
<td>45</td>
<td>0.002</td>
<td>113.9</td>
</tr>
<tr>
<td>Change (25%)</td>
<td>-199</td>
<td>11</td>
<td>0.00</td>
<td>78.6</td>
</tr>
<tr>
<td>Change (50%)</td>
<td>-564</td>
<td>43</td>
<td>-0.01*</td>
<td>676.4*</td>
</tr>
</tbody>
</table>

*= Worthwhile Change B = Braking; P = Propulsive; T = Time; RFD = Rate of Force development.
Analysis of the force data revealed large variation between participants in the number and magnitude of worthwhile changes when comparing the control response to the individual resistance protocols which caused a worthwhile change in sprint performance. All participants had at least one worthwhile change in their force variables but changes were not consistent across participants. P1 had very similar GRF profile for the control and 100% condition, and only recorded one worthwhile change in the RFD. P2 reduced their braking force by 596 N but also reduced their propulsive force by 64 N. Consequently, small worthwhile changes were observed in braking, propulsive and net impulse. P3 had worthwhile changes in all force variables and the difference in GRF profile is clearly demonstrated in figure 4.2 (C). P4 increased their breaking force but did increase their propulsive force in both resistance protocols despite improving sprint time. Consequently, breaking impulse was increased and propulsive impulse decreased.
CHAPTER FIVE

DISCUSSION
5.1 Group and Individual Response

The aim of the current study was to investigate the acute individual response to a loaded sled pull during the initial acceleration phase of a sprint performance. Typically, studies have used a traditional experimental design and examined the group response to various PAP protocols (McBride et al., 2005; Yetter & Moir, 2008; Linder et al., 2010; Mitchell & Sale, 2011; Weber et al., 2008). Results of the group response from the current study did not find any significant improvement \((p \leq 0.05)\) in sprint performance following any of the loaded sled pulls. This was in agreement with Till & Cook (2009), but conflicted with the findings of McBride et al. (2005), Yetter & Moir (2008) and Linder et al. (2010) who reported significant improvements in sprint performance, although not in the initial acceleration phase. Using a traditional experimental design investigating group responses seems counter-intuitive as much of the literature indicates that the response to a PAP protocol is highly individualised (Duthie et al., 2002; Robbins, 2005) and consequently, significant individual results go unreported as they are masked by the group response (Till & Cook 2009). Individual analysis from the current study revealed large variation between participants and the response to each of the sled pulls was highly individualised, in both kinematic and kinetic characteristics. All participants had at least one response to a sled pull which resulted in a worthwhile enhancement in sprint performance, however the sled pull that caused the worthwhile change was highly individualised, and ranged from the unloaded sled condition up to the 100% body weight condition.

5.2 Individual Analysis

Ball & Best (2012) identify a number of arguments for using an individual-based analysis, many of which are applicable to this study. Firstly, it provides important individual information which may have otherwise been masked by the group response. In the current study worthwhile improvements were observed for all participants, however, as has been suggested by the literature (Duthie et al., 2002; Robbins, 2005; Xenofondos et al., 2010), the response was highly individualised. For loaded sled pulls which did result in a worthwhile change, sprint performance was enhanced on average by \(1.5\% \pm 0.07\%\) and \(1.0\% \pm 0.31\%\) for 10m and 20m respectively. Hopkins (2004) suggests that the smallest worthwhile improvement (SWC) for elite athletes competing individually is 0.3% of the TEE, and this moves to 0.5% for high-level athletes. The current study used a more robust
approach by setting the SWC in performance at the same level as the individual TEE in an attempt to identify truly meaningful improvements in performance. The individuals used in the current study were not of an elite standard, (highest level of competition was BUCS) and this was one of the reasons why a more robust SWC was used compared to the value suggested by Hopkins (2004). Using this method, all participants had at least one response to a loaded sled pull that was greater than the smallest worthwhile change. To put into a practical context, an improvement in sprint performance of 1.5%, as observed in the current study, would have moved 4th place to joint 1st in the 2012 BUCS 100m final (BUCS, 2012). Likewise, an improvement of 1% would move 7th place into the medal positions (BUCS, 2012). These examples demonstrate that even seemingly small enhancements in performance can have a significant impact on performance.

5.3 Individual Ground Reaction Force Profiles

Perhaps more interestingly was the way in which the sled pull augmented the GRF profiles, and the vastly differing responses observed between participants. This provides a second argument for using an individual-based analysis as Dufek, Bates, Stergiou & James (1995) found evidence to suggest that during running, individuals demonstrated a number of different strategies during the ground contact phase. A strategy can be defined as a selected neuro-musculo-skeletal solution for the performance of a task (Dufek et al., 1995). Furthermore, Salo, Bezodis, Batterham & Kerwin (2011) found that even within elite sprinting, individuals demonstrated could be SF or SL dominant, which would be characterised by different GRF profiles, as SL dependant athletes would have to produce greater GRF to generate and maintain velocity (Salo et al., 2011). Looking at the group “average” can cause misinterpretation of results and significant individual strategies can be ignored. Research has found experimental evidence in support of individual movement strategies (Jensen & Phillips, 1991; Reinschmidt & Nigg 1995; Lees & Bouracier, 1994) however, individual movement strategies within PAP research has received little attention. This study showed that there was large variation between participants GRF profiles in both the control condition and sled pull which caused a worthwhile change in performance (Figure 4.2). These findings suggest that the proposed mechanisms behind PAP may only partly explain the observed improved performance, and there may be a number of subtle individual responses involved with PAP which also contribute to performance. The complex interaction between kinematic characteristics, such as SF and SL and kinetic characteristics in the GRF profile, combined with the complex nature of the mechanisms
associated with the PAP response make for a highly intricate and complex observation.

### 5.4 Dynamical Systems Theory and Postactivation Potentiation

A possible theory which could be applied to the PAP response and explain the high level of individualisation and complexity is the dynamical systems theory. This theory views human movement as a complex network of co-dependant sub-systems, such as; respiratory, circulatory, nervous, skeletomuscular and perceptual (Glazier, Davids & Bartlett, 2003). Through training, athletes are encouraged to control the redundant degrees of freedom associated with the desired movement, and develop a consistent movement pattern for specific tasks (Newell & Van Emmerik, 1989; Glazier et al., 2003). However it has been theorized that an increased variability in movements may actually be beneficial to performance (Van Emmerik, Rosenstein & McDermott 2004).

Pulling a loaded sled places a greater demand on the lower extremities, compared to unresisted running, by augmenting the kinematic and kinetic characteristics of each step (Lockie et al., 2003; Maulder et al., 2008; Alcaraz et al., 2009; Keogh et al., 2010) and this could also have the effect of increasing the degrees of freedom associated with the sprinting movement (Wuebbenhorst & Zschorlich, 2012). Combined with this, Trezise, Bartlett & Bussey (2011) reported that fatigue increases movement variability during sprinting, and individual can exhibit unique strategies to combat this fatigue. It is possible that the increased biomechanical exigencies during the loaded sled pull caused participants to utilise a greater number of degrees of freedom to complete the task successfully, and combined with the fatiguening effect of pulling the sled, movement variability is likely to have increased. This response could still be active during the following sprint trial and may have contributed to the improved sprint performance. The proposed individual movement strategies (Jensen & Phillips, 1991; Reinschmidt & Nigg 1995; Lees & Bouracier, 1994; Salo et al., 2012), combined with the increased movement variability due to fatigue (Trezise et al., 2011) may explain the variation between participants GRF profiles, and could indicate the unique strategies employed to maintained performance, such as; decreased peak braking force, increased peak propulsive force, increased RFD and increased net impulse. However, Bradshaw, Maulder & Keogh (2007) concluded that movement variability in sprinting can also be detrimental to performance, and the outcome is highly dependent on the individual (Bradshaw et al., 2007; Trezise et al., 2011).
5.4.1 Method Used to Calculate Variability

Continuing with the topic of variability, the control trials within this study were used as an attempt to quantify the within-participant variability, and was expressed as the typical error of estimate; the standard deviation of an individual's repeated measurements, as suggested by Hopkins (2000). It was later suggested by Hopkins (2004) that this value, or a percentage of this value, be used to determine the smallest necessary enhancement in an athlete’s performance that would increase the chance of winning a medal. However, each participant’s variability is likely to be a combination of both technological error (smartspeed and force plate) and biological variability (Rodano & Squadrone, 2002). This may reduce the sensitivity of the smallest worthwhile change in performance and lead to some performances being labelled “not worthwhile” because of the technological error associated with the measurements. This is especially apparent with force data, and Street, McMillan, Board, Rasmussen & Heneghan (2001) identify a number of potential errors when collecting and analysing force data including; selected cut-off frequency of the low-pass filter, sampling frequency, method of integration and start of integration. Attempts have been made by Bartlett, Bussey & Flyger (2006) and Bradshaw et al. (2007) for methods which accurately determine the amount of biological variability and technological variability when analysing movement variability in tasks such as sprinting. The sources of errors in this study are likely to be small as variability was only analysed in sprint time to 10 and 20m and GRF data for the first step following block clearance. Potential sources of error may lie within the calculations of the force as highlighted by Street et al. (2001), but by using methods such as the trapezoid rule to integrate the net force curve to determine the impulse, as suggested by Street et al. (2001), due to its low systematic error (≤0.3%) potential errors were minimised. By reducing the sources of possible errors, worthwhile changes could be confidently identified.

5.5 Rate of Force Development

Despite the variation in the response shown by participants, especially in the force data, one variable that was consistently improved across all participants was the RFD. This was either due to an increased peak propulsive force, an increased time to the peak propulsive force or a combination of both. Aagaard, Simonsen, Andersen, Magnusson & Dyhre-Poulsen (2002) identify RFD as important during fast limb movements such as sprinting (~200ms) as maximal force is not always achieved. Being able to reach a higher level of
muscular force in the early phase of muscle contraction is therefore a desirable characteristic during sprinting (Aagaard et al., 2002). Research has suggested that a heavy resistance exercise can acutely increase motor neuron excitability, enhance motor unit recruitment patterns or increase activation of synergists (or a combination of all three) in the following explosive movement, all of which would act to increase the RFD (Masamoto, Larson, Gates & Faigenbaum, 2003).

Previous studies examining the effect of a PAP protocol on sprint performance have traditionally used a vertical loading stimulus, such as squats, and have failed to observe any significant improvements in the initial acceleration phase (McBride et al., 2005; Yetter & Moir, 2008). This study used a loaded sled pull that attempted to replicate the sprinting action more closely, especially the horizontal competent, which has been identified as a key characteristic in faster athletes during the initial acceleration phase (Jacobs & VanLingren-Schenau, 1992; Hunter et al., 2005). Although not measured directly, it can be speculated that using a weighted sled as the heavy resistance exercise caused the specific activation pattern during initial acceleration phase to be enhanced to a greater extent compared to when a vertical loading stimulus was used in previous studies (McBride et al., 2005; Yetter & Moir, 2008). This is supported by the improvement in sprint performance over 10m and also the increased RFD development during the first ground contact following block clearance observed in the current study. Through reducing the transmission failure at synaptic junctions and increasing the quantity of large motor neurones activated (Hirst et al., 1981), a greater percentage of type II fibres could be recruited and explosive performance was enhanced (Gullich & Schmidtbleicher, 1996). This however is only speculation, but does fit within the proposed neural mechanism (Hirst et al., 1981; Luscher et al., 1983; Tillin & Bishop 2009) through which PAP can enhance performance. There may also be a contribution from the increased phosphorylation of myosin light chains, which act to decrease twitch contraction time by increasing the rate at which myosin cross bridges move from a non force producing state to a force producing state (Hamada et al., 2000; Szczesna et al., 2003; Hodgson et al., 2005). However, it is difficult to objectively observe changes within these two mechanisms, and consequently adds to the complex interaction between PAP and sprinting.
5.6 Step Characteristics

As previously identified, greater horizontal force, or propulsive phase (PP) during the initial acceleration phase is considered to be indicative of faster athletes (Jacobs & VanIngren-Schenau, 1992; Hunter et al., 2005). There is however an opposing force that is observed during running, the negative horizontal force, or braking phase (BP) (Mero, Komi & Gregor, 1992). During constant speed sprinting, the ratio of BP and PP is on average 40% and 60% of the total support phase respectively (Luhtanen & Komi, 1980), however this ratio is strongly variable during the first few stride of the acceleration phase (Mero et al., 1992). This was supported in the findings of the current study, and can be observed in the GRF profiles in figure 4.2. A interesting observation is how the resistance protocol augmented the GRF profile, and again this was largely dependent on the individual, with some participants reducing their BP and other increasing their BP. Theoretically, it would seem advantageous during the initial acceleration phase to minimise BP, as this would prevent any reduction in the horizontal velocity in early stance phase (Mero & Komi, 1986; Mero et al., 1992). This was true for P2 and P3 who reduced the braking impulse during the first ground contact and recorded improved sprint performance. However, a lack of evidence for this hypothesis has meant some researchers have proposed that the BP may actually be beneficial as it has other important mechanical factors such as storage of elastic energy and the stretch shortening cycle (Nicol, Avela & Komi, 2006). This theory is supported by the GRF profile of P4 who, despite increasing BP and reducing PP, still improved sprint performance.

Research investigating the training adaptations to sled towing have demonstrated horizontal power can be enhanced (Spinks et al., 2007), that step length can be increased (Lockie et al., 2012), but the acute effects of sled towing have yet to be investigated. The current study observed worthwhile improvement in horizontal force production in only one participant; however RFD was increased for all participants. This suggests that it there was greater acute neural response associated with the sled towing, compared to the chronic adaptations in muscular strength observed in previous studies (Spinks et al., 2007; Lockie et al., 2012). Waynard et al. (2000) concluded that faster top speeds are achieved by applying greater support forces to the ground, and consequently increasing step length. Despite only one participant increasing the horizontal force, worthwhile changes were observed in net impulse, due to a combination of decreased braking forces and small increases in propulsive forces. However, the contribution of the braking and propulsive
phases to the overall GRF profile was highly individualised. Future research should investigate kinematic characteristics such as step length and step frequency following loaded sled towing to examine the acute effect of the PAP response.

5.7 Limitations

The current study used an individual-based analysis, and consequently the sample size was small, which may be considered a limitation. However, this type of methodology allowed for an in-depth individual analysis, which was deemed fundamentally important based upon the literature regarding the highly individualised response to PAP procedures (Xenofondos et al., 2010). Following on from this, the methodology used to conduct an individual analysis may also be considered a limitation, as it is not the traditional experimental design. However, by utilising the method suggested by Hopkins (2004), an alternative individual analysis was applied, and worthwhile changes in performance were observed by calculating the typical estimate of error from five baseline trials to provide a value for the smallest worthwhile change in performance. Using this method meant individual changes in performance could be observed, which may have otherwise been masked by the group response. A further potential issue in the methodology was that each of the five PAP procedures (loaded sled pull and sprint performance) was only performed once for each participant. This may be considered a weak experimental design as a traditional statistical analysis could not be used. However, due to the paucity in the literature surrounding the acute response to sled pulling, and highly individualised response to PAP, the current study used a variety of different loads in an attempt to increase the likelihood of observing an enhanced performance. Future research can build on these limitations and attempt to further understand the acute effects of sled pulling on sprint performance.
CHAPTER SIX

CONCLUSION
In conclusion, the current study demonstrated that by using a loaded sled pull, sprint performance could be acutely enhanced in the initial acceleration phase (0-20m). However, the load at which elicited a worthwhile improvement was highly individualised, and ranged from the sled only to 100% body weight condition. Furthermore, analysis of the GRF profile of the first step revealed large variation between participants. This suggests that individuals may employ specific movement strategies, and there is more than one mechanism through which the PAP response to the loaded sled pull can enhance sprint performance. The application of the dynamical systems theory to the current study provides a novel way of explaining the effect of the loaded sled pull on sprint performance. Through the increased biomechanical exigencies in the lower extremities, and consequently the increased movement variability in the sprinting movement, different mechanisms were activated to combat the fatiguing effect of the loaded sled pull. These mechanisms were largely dependent on the individual and are influenced by a number of physiological factors. Increased neural activity is likely to have been partly responsible for the enhanced performance as all participants had worthwhile improvements in their RFD, which has been identified as a desirable characteristic in sprinting (Aagaard et al., 2002). The findings from this study highlight the need for an individual-based analysis when examining the effects of PAP on athletic performance, or when designing training programmes utilising the complex training principle, to maximise the potential PAP response. Future research should attempt to quantify the acute neural contribution to sprint performance following a resistance protocol, however there are likely to be numerous methodological issues involved. From a broader perspective, an investigation into the movement profiles and power outputs at the ankle, knee and hip during jumping and sprinting following a PAP protocol would provide a detailed picture of how performance may be improved, and lead to a greater understanding of the mechanisms linked to the PAP response.
REFERENCE LIST


BUCS (2012) Athletics: Mens 100m Final. [on-line]  
http://c1593.r93.cf3.rackcdn.com/Mens_100m_Final.PDF [accessed 9 March 2012].


APPENDICIES
APPENDIX A

Informed consent sheet
CARDIFF METROPOLITAN INFORMED CONSENT FORM

CSS Reference No: ST10001351

Title of Project: The effect of a sprint specific resistance exercise on sprint performance.

Name of Researcher: Harry Fisher

Participant to complete this section: Please initial each box.

I confirm that I have read and understand the information sheet dated ______ for this evaluation study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

☐

I understand that my participation is voluntary and that it is possible to stop taking part at any time, without giving a reason.

☐

I also understand that if this happens, our relationships with the Cardiff Metropolitan University, or our legal rights will not be affected

☐

I understand that information from the study may be used for reporting purposes, but I will not be identified.

☐

I agree to take part in this study

☐

Name of Participant:___________________

Signature of Participant:________________  Date_________

Name of person taking consent:_________________  Date_________

Signature of person taking consent:__________________________
APPENDIX B

Participant information sheet
Project Title:

The acute effects of a loaded sled pull on sprint performance: An individual-based analysis.

This document provides a run through of:

- The background and aim of the research.
- Your role as a participant.
- How the data will be collected.
- Requirements.
- Possible risks.
- Benefits of taking part.
- How your data will be used.

The purpose of this document is to assist you in making an informed decision about whether you wish to be included in the project, and to promote transparency in the research process.

1) Background and aims of the research

Previous research has shown the potential benefits of using post-activation potentiation to improve athletic performance. This involves performing a heavy resistance exercise (HRE) with similar biomechanical characteristics to the movement being performed. For example, performing a heavy squat prior to a countermovement jump may lead to improved performance in the countermovement jump compared to when a heavy squat is not performed. Research has also suggested that the resistance exercise needs to be specific to the following movement to achieve the greatest benefit.

The aim of this research is to investigate the effects of different weighted sled pull on 20 M sprint performance. The sled pull has greater movement specificity to the sprint start than previous interventions used such as back squats. The acute effects of this type of sled pulling are yet to be known, but could potentially enhance acceleration.

2) Your role as a participant:

If you volunteer to take part in the study your role will be to three sessions over three weeks lasting no more than two hours. You will not necessarily be need for the whole time. In total there will be five different weights loaded onto the sled for you to pull and a control condition, where you will not do a sled pull. The weight on the sled will be determined by your body mass of which a percentage will be loaded onto the sled. You will complete a 30 M pull of the sled and following a five minute recovery, complete a 20 M sprint.

3) How the data will be collected

Data will be collected in a number of ways. Firstly a force plate will be used to record the forces you generate during the block start. This will allow your braking and propulsive forces, impulse and contact time to be calculated. Timing gates will record your time for 20 M and also provide a 10 M split time. This will enable your average acceleration to be calculated.
4) Requirements
To take part in this study it is required that you are injury free at the start of the study and have been injury free for at least three months prior to the start of study. Also you should be a university level sprinter who has competed at county level or above and competent in using starting blocks. It is also required that you have had previous experience in resistance training and specifically performing the back squat.

5) Possible risks
Within the study you will be required to pull a sled with 200% of your body mass loaded on to it. This will be strenuous but should not pose a risk. A suitable warm up will be conducted before each of the sessions so the risk of injury is small and you will not be asked to perform any movements you have not previously performed as an athlete.

6) Benefits of taking part
The information obtained in this study will allow for a greater insight into how post-activation potentiation may affect sprint performance. Benefits to you as a participant include:

- Using force plates measure rate of force development from the starting blocks
- Accurate recordings for 20 m times.
- Potential way of increasing your sprint performance which could be adapted and included in your own training programs.

7) How the data / research will be used:
In agreeing to become a voluntary participant, you will be allowing me to use the results from the study and include them within a larger data set that includes the data of other participants. Your personal data will be anonymous and will not be reported alone, but within the total sample of participants.

Your rights
Your right as a voluntary participant is that you are free to enter or withdraw from the study at any time. This simply means that you are in full control of the part you play in informing the research, and what anonymous information is used in its final reporting.

Protection to privacy
Concerted efforts will be made to hide your identity in any written transcripts, notes, and associated documentation that inform the research and its findings. Furthermore, any personal information about you will remain confidential according to the guidelines of the Data Protection Act (1998).

Contact
If you require any further details, or have any outstanding queries, feel free to contact me on the details printed below.

Harry Fisher                          P: 07716891305
Cardiff School of Sport              E: st10001351@cardifmet.ac.uk
Cardiff Metropolitan University
CF236XD, United Kingdom
APPENDIX C

Activity Readiness Questionnaire (PAR-Q)
Physical Activity Readiness Questionnaire (PAR-Q)

Participants name………………………………………………………………………………

Please circle the answers to the following questions:

1. Do you have asthma or any breathing problems? Yes / No
2. Has your doctor ever said you have heart trouble? Yes / No
3. Do you frequently suffer from pains in the chest? Yes / No
4. Do you often feel faint or have spells of severe dizziness? Yes / No
5. Has a doctor ever said your blood pressure was too high? Yes / No
6. Has a doctor ever said that you have a bone or joint problem such as arthritis that has been aggravated by exercise, or might be made worse with exercise? Yes / No
7. Is there a good physical reason not mentioned here why you should not take part in a fitness test? Yes / No
8. Are you unaccustomed to vigorous exercise? Yes / No

If you have answered yes to any of these questions, please add details below. Similarly, if there are any situations which will prevent you from exercising write them here (or let us know if they arise through the experiment).

If your situation changes regarding your responses to these questions, please notify the appropriate staff/Researcher member.

Signed (participant)………………………………………………………………………

Signed (investigator)………………………………………………………………………

Date………………………………………………………………………………