NAME: ROBERT DAVEY

UNIVERSITY NUMBER: ST05003426

DEPARTMENT: PHYSIOLOGY

INSTITUTION: UNIVERSITY OF WALES INSTITUTE CARDIFF
EFFECT OF POSTACTIVATION POTENTIATION UPON AN AGILITY TEST
ACKNOWLEDGMENTS

The author would like to express his appreciation to the following people:

To my principle supervisor Dr. Joseph Esphormes, thank you for your support and time throughout these past few months. Special thanks to my good friend Tom Hargroves, who assisted main data collection, without you, collecting subjects’ second agility score would not have been possible.

To my eleven subjects, who turned up to each testing session on time, even when facilities and equipment constraints meant rearrangements at the last minute, I owe a great deal of gratitude. For giving 100%, and never asking for anything in return, I thank you for doing so.

To the technical staff Mike and Danny, at the School of Sport, University of Wales Institute Cardiff, without your knowledge and time I would not have had the equipment required to collect my data.
ABSTRACT

The ability change direction while sprinting is a determinant of sport performance in many field and court sports. Performance has theorised to be enhanced following a maximal or near maximal contraction for a subsequent explosive sports activity; this may be possible by inducing acute Postactivation Potentiation (PAP). PAP refers to the phenomenon by which the muscle elicits a heightened state of skeletal muscle, facilitating the volitional production of force. The potentiated state has been attributed to phosphorylation of myosin regulatory light chains, which makes actin and myosin more sensitive to Ca$^{2+}$, also to an increase in neural activation. Recent studies have applied the principles of PAP to short-term motor performance as well as using it as a method for producing long-term neuromuscular changes through complex training. Complex training couples a dynamic maximal strength training exercise, with a biomechanically similar plyometric exercise. Optimal performance occurs when fatigue has subsided but the potentiated effect still exists. No investigations have implemented the phenomenon of PAP to a subsequent agility performance. Sports involving explosive actions, at present, cannot assume that sprint training methods will enhance agility. The aim of this study therefore, was to assess whether the performance of 5 RM voluntary pre-conditioning contraction, would elicit a response on a subsequent agility test (n=11). Findings produced no significant evidence (0.05 alpha level) to support the hypothesis that performance and muscle activation increases after a pre-conditioning contraction, agility times were not significantly different pre and post-stimulus. However, no detrimental effects were observed. Before any conclusions can be made as to the efficacy of exploiting PAP as a warm up for explosive agility activities, or as part of a complex training protocol, further scientific research is required.
TABLE OF CONTENTS

Acknowledgements i
Abstract ii

CHAPTER I - INTRODUCTION
1.1 Rationale 1
1.2 Hypotheses 3

CHAPTER II - LITERATURE REVIEW
2.1 Postactivation Potentiation 4
2.2 Applying Postactivation Potentiation to Explosive Sports Activities 5
2.3 Acute Effects of Postactivation Potentiation as a Warm Up 7
2.4 Relationship between Postactivation Potentiation & Fatigue 9
2.5 Pre-conditioning Exercise 12
2.6 Subject Characteristics 14
   2.6.1 Muscular Strength and Fibre-Type Distribution 14
   2.6.2 Training Status 15
   2.6.3 Gender 16
2.7 Type of Subsequent Activity 16
2.8 Summary 17

CHAPTER III - METHOD
3.1 Study Design 19
3.2 Sample 19
3.3 Pilot Study 20
3.4 Experimental Procedure 21
   3.4.1 Familiarisation & 1RM determination 21
   3.4.2 Agility Trials Pre-Stimulus 23
   3.4.3 Main Testing 25
3.5 Reliability 25
3.6 Statistical Analysis 26
3.7 Ethical Guidelines 27

CHAPTER IV - RESULTS
4.1 One-Sample Kolmogorov-Smirnov Test 28
4.2 Paired Samples Statistics 29
4.3 Paired Samples Correlations 29
4.4 Paired Sample Test 30
4.5 Means & Standard Deviation for Pre and Post-Stimulus Agility Scores 31
4.6 Individuals’ Percentage Potentiation 32
4.7 Relationship between Power-to-Weight Ratio and Agility Post-Stimulus 33

CHAPTER V - DISCUSSION
5.1 Relationship between PAP & Fatigue 34
5.2 Power-to-Weight Ratio 35
5.3 Effect of the Pre-conditioning Exercise 36
5.4 Subject Characteristics 36
5.5 Subsequent Agility Performance 37
5.6 Technical Error of Measurement (TEM) 38

CHAPTER VI - CONCLUSION
6.1 Limitations 40
6.2 Practical Implications and Future Research 42

REFERENCES
References 43
APPENDICES

A Table of Subjects’ Characteristics
B Table Showing Subjects’ Agility Scores Pre and Post-Stimulus
C Power-to-Weight Ratio & Agility Post-Stimulus Score
D PAR-Q and Consent Form
LIST OF FIGURES

**Fig. 2.2** Sale (2002), hypothesised relationship between force and velocity. The doted line represents an upward and rightward shift of the force-velocity curve, due to an increase in RFD. PAP cannot increase maximum isometric force or maximum shortening velocity because they determined with high frequency stimulation. In contrast, PAP can increase RFD at high frequencies, an effect that may increase the acceleration and therefore with loads intermediate between the extremes of maximum force and velocity. If this were to occur, the load-velocity relation would become less concave; therefore shift upward and to the right.

**Fig. 2.4** A model of the relationship between PAP and fatigue following an MVC protocol, adapted from Sale (2002). Potentiation is represented as a ratio of post MVC value to pre MVC value (post/pre). As a result of fatigue subsiding at a faster rate than PAP, a potentiation in performance of a subsequent explosive activity is realised at a specific point in time during recovery.

**Figure 3.4.2** Representation of the adapted Illinois Agility Run. Players sprinted 10 meters, went around the cone and returned to the centre cone level to the starting line. They then swerved in and out of the four markers, returning to the centre cone once again. Two 10 m sprints finished the agility course.

**Fig. 3.6** Percent Potentiation Equation (Chiu et al., 2003).

**Fig. 4.5** Means & Standard Deviation for Pre and Post-Stimulus Agility Scores.

**Fig. 4.6** Change in Individuals’ Percentage Potentiation.

**Fig. 4.7** The Relationship between Power-to-Weight Ratio and Agility Post-Stimulus.

**Fig. 5.6** Equation for measuring Technical Error of Measurement ($d =$ difference between replicated measures, $n =$ number of subjects).
LIST OF TABLES

4.1 One-Sample Kolmogorov-Smirnov Test

4.2 Paired Samples Statistics

4.3 Paired Samples Correlations

4.4 Paired Sample Test
CHAPTER I
INTRODUCTION
1.0 INTRODUCTION

1.1 Rationale

Some form of preparatory exercise or warm up prior to the commencement of any strenuous physical activity, is a well accepted practice by athletes, coaches and sports scientists. Various forms of warm up exist, however the traditional paradigm involves a short period of low intensity aerobic activity, followed by static stretching and activity specific movements (Schilling & Stone, 2000). The justification for including a period of static stretching during this preparation phase is however unclear. Although static stretching has been theorised to enhance performance (Holcomb, 2000; Martens, 2004), a number of researchers have reported that an acute bout of pre-exercise static stretching may actually reduce anaerobic performance in adults through decreases in force (Kokkonen et al., 1998; Fowles et al., 2000) and power (Young et al. 1998; Cornwell et al. 2001; Cornwell et al. 2002). Faigenbaum et al. (2005) reported that jumping and sprinting performance declined significantly in children after an acute bout of static stretching.

Attention has turned to warm up procedures that involve the performance of dynamic movements consequently elevating body temperature, improving kinaesthetic awareness, enhancing motor unit (MU) excitability and developing fundamental movement skills. A relatively new training technique, Complex Training (CT) couples a dynamic maximal strength training exercise, with a biomechanically similar plyometric exercise.

Optimising these variables during an explosive sports activity might be possible by inducing acute Postactivation Potentiation (PAP). PAP refers to the phenomenon by which skeletal muscle “facilitates the volitional production of force” (Hodgson et al., 2005, p 586). According to Hodgson et al. (2005), two theories or mechanisms have been proposed to explain the potentiated state of muscle after
maximal or near maximal stimulation. One is the phosphorylation of myosin regulatory light chains (RLC) (Gossen & Sale, 2000; Hamada et al., 2000; Sale, 2002; Chiu et al., 2003; Sale, 2004; and Hodgson et al., 2005), resulting in structural alterations of the myosin head, making it more accessible to actin (Szczesna, 2003; and Hodgson et al., 2005). Subsequently, there is an increase in both the strength of myosin-actin cross-bridges, and the rate at which myosin-actin cross-bridges move from a non-force producing state to a force-producing state (Szczesna, 2003; Hodgson et al., 2005). As a result, there is a potentiation of subsequent activity, with the effect lasting for up to 20 minutes after initial activation (Ebben et al., 2000).

The other theory is an increase in neural activation, which may occur through the recruitment of higher-order MU, better MU synchronisation, a decrease in pre-synaptic inhibition, or greater central input to the motor neuron (Gullich & Schmidtbleicher, 1996; Chiu et al., 2003; and Hodgson et al., 2005). It is possible that PAP is the result of interactions between neural and muscular mechanisms that are not well understood at this time. If PAP could be utilised effectively, it might prove to be an optimal warm up technique prior to competition, or could enhance the training stimulus of power exercises (Gullich & Schmidtbleicher, 1996).

The ability to sprint repeatedly and change direction while sprinting are determinants of sport performance in many field and court sports, as evidenced in sports such as soccer (Reilly et al., 2000; Mohr et al., 2002), rugby (Meir et al., 2001) and field hockey (Keogh et al., 2003). Motor skills common to these sports, for example sprinting, agility and jumping, have biomechanical, kinematic, and muscular similarities (Bobbert & van Zandwijk, 1999), but proving associations between these motor skills is inconclusive. Evidence shows a weak relationship between straight sprint performance and change of direction speed performance (Young et al., 1996; Baker, 1999; Tsitskarsis et al., 2003; Little & Williams, 2005). Little & Williams (2005) reported that acceleration (10-m sprint times), top speed (20-m sprint times), and agility were distinct motor characteristics in a group of
professional male soccer players. In comparing the relationship between performance of the Illinois agility test and a 20-m sprint, Draper & Lancaster (1985) reported a statistically significant low to moderate correlation (r = 0.472). This represents an emphasis on the specificity of training with specific movement patterns, as straight sprint training appears to have little or no influence on the improvement of sprinting that involves changes of direction (Young et al., 2001).

To the author’s knowledge, no investigations have implemented the phenomenon of PAP to a subsequent agility performance. Sports involving explosive actions, at present, cannot assume that sprint training methods will enhance agility. The aim of this study therefore, is to assess whether the performance of 5 RM voluntary pre-conditioning contraction, would elicit a response on a subsequent agility test. Furthermore, the overall purpose is to help establish guidelines for utilising PAP as a warm-up technique to enhance the performance and/or training stimulus of an explosive sports activity.

1.2 Hypotheses

H¹: A pre-conditioning contraction will induce a significant increase in the performance of a subsequent agility test.

H null: There will be no significant difference between the observed agility scores of the two test conditions; pre and post conditioning contraction.

H²: Individuals with a high power-to-weight ratio will observe a greater response to potentiation, evident in a faster agility time post stimulus.
CHAPTER II
LITERATURE REVIEW
2.0 LITERATURE REVIEW

2.1 Postactivation Potentiation

Explosive sports movements such as straight line sprinting, speed while changing direction (agility), jumping and throwing, are partly determined by a number of kinetic and kinematic variables. These include muscular force (Newton & Kraemer, 1994), power (Newton & Kraemer, 1994; Gullich & Schmidtbleicher, 1996; Baker & Nance, 1999), velocity of movement (Newton & Kraemer, 1994), and muscular rate of force development (RFD) (Newton & Kraemer, 1994). Sports that involve these explosive movements require proper warm-up and training modalities to achieve high levels of explosive force production. Optimising these factors might be possible by inducing acute Postactivation Potentiation (PAP).

The presence of PAP in skeletal muscle has been recorded by many studies, in both mammals and humans (Vandenboom et al., 1993; Gullich & Schmidtbleicher, 1996; Young et al., 1998; Gossen & Sale, 2000; Hamada et al., 2000; Szczesna et al., 2002; Gourgoulis et al., 2003; and Hamada et al., 2003), however to date, evidence demonstrating the effects of PAP on the performance of ESA’s remains inconclusive. If however, PAP could be utilised effectively it might prove to be a valuable warm-up technique prior to competition (Gullich & Schmidtbleicher, 1996). It could also be implemented into a power-training routine to enhance the training stimulus. This is the premise on which CT is based (Robbins, 2005). Complex Training couples a dynamic maximal strength training exercise, with a biomechanically similar plyometric exercise, termed ‘complex pair’ (Gullich & Schmidtbleicher, 1996; Young et al., 1998; Ebben, 2002; Gourgoulis et al., 2003).
2.2 Applying Postactivation Potentiation to Explosive Sports Activities

Explosive sports activities (ESA’s) require force and velocity production between the extremes of the force-velocity curve (fig 2.2) and typically involve contraction times of 50-250 ms (Aagaard et al., 2002). In comparison, maximal force is generally achieved at contraction times >300 ms (Aagaard et al., 2002). The ability to apply force quickly would therefore appear more important for an explosive athlete, than achieving maximal force production. If during these activities RFD could be increased, this would result in a greater force production within a shorter period of time, subsequently increasing velocity for the force being applied (Gossen & Sale, 2000; and Sale, 2002). Therefore PAP could theoretically enhance all of the movement mechanics that influence mechanical power during ESA’s.

Fig. 2.2 Sale (2002), hypothesised relationship between force and velocity. The dotted line represents an upward and rightward shift of the force-velocity curve, due to an increase in RFD. PAP cannot increase maximum isometric force or maximum shortening velocity because they determined with high frequency stimulation. In contrast, PAP can increase RFD at high frequencies, an effect that may increase the acceleration and therefore with loads intermediate between the extremes of
maximum force and velocity. If this were to occur, the load-velocity relation would become less concave; therefore shift upward and to the right.

It has been demonstrated that PAP increases the force of subsequent isometric contractions stimulated at low frequencies (Vandenboom et al., 1993). As previously mentioned in section 1.0, this is thought to be due to the increased sensitivity of the myosin-actin interaction to Ca²⁺, having its greatest effect in conditions of low myoplasmic Ca²⁺. Additionally, a greater number of higher-order MU are being activated, despite the relatively low stimulation frequency. PAP does not however, increase the force of subsequent isometric twitch contractions stimulated at higher frequencies (Vandenboom et al., 1993).

It is important to note however, that although there is consensus over the existence of PAP, and its possible benefits to performance of ESA’s, most studies evaluating its effects have been conducted on mammals. Consequently, the preconditioning contraction employed by these researchers has been an induced isometric contraction, resulting in a twitch response. The measurement of PAP’s effect on performance of a subsequent ESA in humans is inconsistent. Also, the degree to which the two proposed mechanisms that induce an elevated neuromuscular response, is not known. If PAP is to be utilised by explosive athletes, research should confirm that PAP can be induced by an isometric or dynamic MVC, and then show the benefits during a subsequent ESA. As a result, there are no established guidelines for the implementation of PAP into training, or as a warm-up prior to competition (Ebben & Watts, 1998). The following sections will discuss research that has investigated the effects of a MVC on subsequent performance of an ESA.
2.3 Acute Effects of Postactivation Potentiation as a Warm Up

Regarding the short term effects of pre-conditioning contractions on subsequent explosive activities, the literature appears inconclusive. Difficulties arise when comparing the studies because of differences in methodology and design, however it is widely accepted that a contraction of high intensity is required to optimise PAP (Sale, 2004).

Hamada et al. (2000) investigated the effect of a 10-s isometric MVC of the knee extensors on subsequent twitch responses. A twitch reflex was stimulated at the femoral nerve pre, 5 s post, and then every 30 s post the isometric MVC, for 300 s. Significant increases in twitch peak torque (Pt) (+71%; p<0.01) were recorded 5 s post the isometric MVC. By 30 s post the isometric MVC, twitch Pt potentiation had decreased to +44%, but was still significantly greater than prior to the isometric MVC (p<0.01). Twitch Pt remained significantly (p<0.01) elevated at 60 s post isometric MVC, but potentiation had dropped by more than half that was recorded 5 s post the isometric MVC (+31% vs. +71%). Potentiation continued to decrease at a more gradual rate for the remainder of the recovery period, but twitch Pt was still significantly greater 300 s post than prior to the isometric MVC (+12%; p<0.01).

Similar findings were reported by Gossen & Sale (2000) who measured a significant potentiation in twitch Pt (+62%; p<0.01) 5 s post a 10-s isometric MVC of the knee extensors. By 50 s post the isometric MVC however, twitch Pt potentiation, although still significant (p<0.01), had dropped to +41%. These studies demonstrate that peak PAP, induced via a 10-s isometric MVC, is achieved immediately after the MVC, but will decrease.

It is therefore accepted that PAP can be induced by an isometric MVC, and this effect has consistently been measured using twitch stimulation. In contrast, research investigating the acute effects of PAP on performance of ESA’s is equivocal. Although many studies have demonstrated that an isometric or dynamic MVC can
potentiate performance of a subsequent ESA (Gullich & Schmidtbleicher, 1996; Young et al., 1998; Gilbert et al., 2001; French et al., 2003; Gourgoulis et al., 2003), a number of studies have presented conflicting results (Ebben et al., 2000; Gossen & Sale, 2000; Jenson & Ebben 2003).

Gossen & Sale (2000) demonstrated the difference between twitch and voluntary contraction responses to the same pre-conditioning contraction. They measured power performance parameters of dynamic knee extensions in two separate conditions; kicks were performed 20 and 40 s post the 10-s isometric MVC, and the other was a control condition, where both kicks were performed at the same time interval, without a prior isometric MVC. Although significant potentiation had been reported in the twitch-reflex response, PAP did not significantly enhance peak power (control 1st kick: 456.9 ± 23.5 W vs. PAP 1st kick: 425.7 ± 19.5 W; and control 2nd kick: 467.6 ± 22.9 W vs. PAP 2nd kick: 444.5 ± 20.8 W; p>0.05), peak power tended to be lower in the PAP condition. In addition, peak power of the second kick was significantly greater than the first kick during the PAP trials only (p<0.05). This suggests that the pre-conditioning contraction caused a negative effect on the first dynamic kick, and that 40 s of recovery was required to return peak power back to pre-MVC values.

A possible explanation for the inability of Gossen & Sale (2000) to elicit a potentiation in performance of a subsequent voluntary contraction, despite observing twitch potentiation following a pre-conditioning contraction, is that contractile activity produces both fatigue and PAP. Robbins (2005) suggested that it is the balance between the two that determines whether the subsequent contractile response is enhanced, diminished, or unchanged.
2.4 Relationship between Postactivation Potentiation & Fatigue

The coexistence of fatigue and PAP may result in a net potentiated state, a net attenuated state, or a constant state as compared to the pre-stimulus state. The optimal recovery time depends on the decay rate of PAP and the dissipation of fatigue (Robbins, 2005).

Gilbert et al. (2001) recorded RFD during isometric MVC’s executed 2, 10, 15, 20 and 30 min post 5 sets of 1 RM back-squats. RFD recorded 2 and 10 min post the MVC’s was 5.8% below control values, however, there were 10% and 13% increases in RFD above control values (p<0.05), 15 and 20 min, respectively, post the MVC’s. Gullich & Schmidtbleicher (1996) similarly observed a 13% decrease (p<0.05) in RFD during isometric MVC plantar-flexions performed 2-3 min after a pre-conditioning contraction protocol of 5, 5-s MVC’s. There was however a 19% increase in RFD 4.5-12.5 min after the pre-conditioning contraction protocol (p<0.05). The enhanced twitch response following a MVC, demonstrates that PAP has been induced, but the results of Gilbert et al. (2001) and Gullich & Schmidtbleicher (1996) suggest that a MVC also produces fatigue during subsequent voluntary contractions. This fatigue is more prominent early on, resulting in either no change, or a drop in performance. During the subsequent recovery period however, fatigue subsides at a faster rate than PAP, and consequently, a potentiation of performance can occur at some point.
Fig. 2.4 A model of the relationship between PAP and fatigue following an MVC protocol, adapted from Sale (2002). Potentiation is represented as a ratio of post MVC value to pre MVC value (post/pre). As a result of fatigue subsiding at a faster rate than PAP, a potentiation in performance of a subsequent explosive activity is realised at a specific point in time during recovery.

It is important to note that both Gilbert et al. (2001) and Gullich & Schmidtbleicher (1996) used isometric contractions post MVC’s, to measure the effects of a preconditioning contraction. ESA’s however, are dynamic, so when trying to apply the results of these studies to dynamic performance there may be implications. There is evidence of an enhancement in the performance of an explosive dynamic sports activity, after a rest period following a pre-conditioning contraction. In a study by Gullich & Schmidtbleicher (1996), subjects were required to perform a series of 8 CMJ, each separated by 20 s, before and 3 min after 3 sets of 5-s isometric MVC leg presses. Each jump performed post the MVC’s was on average
1.4 cm (+3.3%) higher than those recorded prior to the MVC’s (p<0.01). These results were supported by findings of Young et al. (1998), who observed a significant increase in loaded counter movement jump (CMJ) height, 4 min after a set of 5 RM back squats (+2.8%; p<0.05). Both studies concluded that performance of an explosive dynamic sports activity is enhanced when preceded by a MVC, but a sufficient recovery period is required to realise this effect.

On the other hand, research has also shown that a recovery period may not be required to benefit from PAP, or that even with a recovery period, performance of a subsequent activity may remain unchanged. French et al. (2003) did not utilise a recovery period, but still observed a significant increase in both drop jump height (+5.0%) and knee extension (+6.1%), immediately after 3 sets of 3-s isometric MVC knee extensions. Similarly, Gourgoulis et al. (2003) reported a significant increase in CMJ height (+2.4%), immediately after 2 back-squats performed with 90% of 1 RM. On the other hand, Chiu et al. (2003) were unable to detect a significant improvement in peak power of 3 CMJ, or 3 loaded squat jumps (p>0.05), even though they were performed after a recovery period of 5, 6, and 7 min, respectively, following 5 sets of one back-squat, with 90% 1 RM. The three CMJ were executed with different loads (30, 50 and 70% of 1 RM, respectively). This therefore, may have affected peak power output, and makes it difficult to compare differences in performance over the time-course.

As a result of these contradictory findings, an appropriate recovery time required to optimise the benefits of PAP has not been determined. The relationship between PAP and fatigue, and the overall effect of contractile history, on subsequent performance, is influenced by a combination of factors (Robbins, 2005). These include; type, volume and intensity of the pre-conditioning contraction; subject characteristics (muscular strength, fibre-type distribution, training status, gender) and the type of activity performed after the pre-conditioning contraction (Hodgson et al., 2005; Robbins, 2005). These factors are explored in more detail, in the following sections.
2.5 Pre-conditioning Exercise

The effect of the pre-conditioning contraction volume on the interaction between PAP and fatigue is highlighted well by research conducted by Hamada et al. (2003). He used a fatiguing protocol of 16, 5-s isometric MVC knee extensions, with each MVC separated by a 3-s rest interval. The findings of Hamada et al. (2003) clearly demonstrate that PAP was more dominant than fatigue, after the first 3 MVC’s, when the volume was small, therefore minimising fatigue. Twitch $P_t$ then remained potentiated for the majority of the fatigue protocol, but the dominance of PAP is reduced, as the volume of MVC’s escalates, thus increasing fatigue. By the 11th MVC, fatigue is large enough to be the dominant factor, and consequently twitch $P_t$ decreases below base-line values. During the recovery period however, fatigue gradually decreases while PAP is still present. Hamada et al. (2003) therefore demonstrate that MVC volume will partly determine whether PAP or fatigue is the dominant factor, ultimately influencing subsequent twitch tension. Also, that a greater pre-conditioning contraction volume will require a greater recovery period before PAP will exceed the fatigue effect, and enhance subsequent performance.

Although, to varying degrees, any type of contraction is likely to activate the mechanisms of PAP (Sale, 2004), the degree of potentiation achieved is likely to be related to contraction type. Consequently, the use of different types of preconditioning contractions has probably contributed to the inconsistent results that have already been discussed.

Gullich & Schmidtbleicher (1996); Gossen & Sale (2000) and French et al. (2003) all investigated the effects of an ‘isometric’ MVC on performance of a subsequent ESA. Of these, Gullich & Schmidtbleicher (1996) recorded a 3.3% increase in CMJ height, 3-5 min after 3, 5-s isometric MVC leg presses; and French et al. (2003) reported a 5.0% and 6.1% increase in DJ height, and knee extension $P_t$, respectively, immediately after 3, 3-s isometric MVC knee extensions. On the other
hand, Gossen & Sale (2000) reported no change in knee extension peak power 20-40 s after a 10-s isometric MVC of the knee extensors.

In contrast to the above three studies, Young et al. (1998); Ebben et al. (2000); Gilbert et al. (2001); Chiu et al. (2003); Gourgoulis et al. (2003) and Jenson & Ebben (2003) used ‘dynamic’ MVC’s to induce PAP. Young et al. (1998) recorded a 2.8% increase in loaded CMJ height, 4 min after a set of 5 RM back-squats; Gilbert et al. (2001) measured a 10-13% increase in isometric leg press RFD, 15-20 min after 5 sets of 1 RM back-squats; and Gourgoulis et al. (2003) observed a 2.4% increase in CMJ height, immediately after 5 sets of 2 reps of back-squats, where the sets were performed with 20, 40, 60, 80, and 90% of 1 RM, respectively. However, Chiu et al. (2003) reported no change in CMJ height, 5-7 min after 5 sets of one back-squat with 90% of 1 RM. In addition Ebben et al. (2000) measured no change in GRF during medicine ball power drops, immediately after 1 set of 3-5 RM bench presses; and Jenson & Ebben (2003) observed no change in CMJ height 1-4 min after a set of 5 RM back-squats.

The results of these studies present no clear relationship between contraction types, level of induced PAP, and performance of a subsequent ESA. Theoretically, different types of contraction would have different effects on neuromuscular fatigue (Kay et al., 2000). If isometric and dynamic contractions can induce different fatigue responses, then it is fair to assume that they might also have different affects on the mechanisms of PAP. On the other hand, Duchateau et al. (1984) states that isometric MVC’s activate a greater number of MU, than dynamic MVC’s. Consequently, more muscle fibres might be involved during an isometric contraction, and this might result in a greater percentage of RLC phosphorylation.


2.6 Subject characteristics

Several subject characteristics have been suggested to affect an individual’s PAP and fatigue response to a pre-conditioning contraction. These include muscular strength, fibre-type distribution, gender and training status.

2.6.1 Muscular Strength and Fibre-Type Distribution

There is evidence to suggest that an individual’s muscular strength might partly determine their PAP response, following a pre-conditioning contraction. Gourgoulis et al. (2003) observed a 4% increase in CMJ height (p<0.05), following 5 sets of back-squats, in those subjects able to squat a load of >160 kg. Conversely, those subjects unable to squat loads of >160 kg, only recorded a 0.4% increase in CMJ height (p>0.05). A possible explanation for these findings might be associated with subject fibre-type distribution. The positive linear relationship between muscular strength and percentage of type 2 muscle fibres is well documented, most recently by Aagaard & Anderson (1998). As previously discussed in section 1.0, type 2 muscle fibres display the greatest increase in RLC phosphorylation, following a pre-conditioning contraction (Vandenboom et al., 1993). Furthermore, subjects with a higher percentage of type 2 muscle fibres would have a greater number of higher-order MU in reserve, which could be activated. The combined effect of both a greater RLC phosphorylation and a greater increase in higher-order MU recruitment would theoretically predispose individuals with a higher percentage of type 2 muscle fibres, to a greater PAP response. Consequently, it could be speculated that the stronger subjects in Gougoulis et al.’s (2003) study had a higher percentage of fast-twitch muscle fibres, therefore achieved a greater PAP response.

Hamada et al. (2003) provided evidence to support a relationship between fibre-type distribution and PAP. They separated their subjects into two groups; one with predominantly fast-twitch (type 2) muscle fibres (T-2; n = 4); and a second, with
predominantly slow-twitch (Type 1) muscle fibres (T-1; n = 4). During a 3-s isometric MVC the T-2 group recorded a significantly larger absolute Pt (250.0 vs. 171.0 N.m; p<0.01). Furthermore, in response to a fatigue protocol of 16 5-s isometric MVC’s of the knee extensors, the T-2 group showed significantly greater twitch tension potentiation during the early stages of the fatigue protocol (+127% vs. +40% increase in Pt after the 3rd MVC; p<0.05). Hamada et al. (2003) however, also observed a greater reduction of both twitch Pt and MVC Pt in the T-2 group (-32.0% and – 49.3%, respectively), compared to the T-1 group (-15.0% and –22.8%, respectively), during the later stages of the fatigue protocol (p<0.05). Therefore, although subjects with a greater percentage of Type 2 muscle fibres elicited a greater PAP response, they also elicited a greater fatigue response, following a high volume preconditioning contraction protocol.

2.6.2 Training Status

Subject characteristics such as muscular strength and fibre-type distribution however, may not be the only factors that influence PAP and fatigue responses, following a pre-conditioning contraction. Chiu et al. (2003) separated a sample of 24 subjects into athletes that were training and participating in a sport at national and/or international level (RT; n = 7), and those that participated in recreational resistance training (UT; n = 17). The RT group reacted to 5 sets of 1 back-squat with 90% 1 RM, with a PAP response, recording a 1-3% increase in CMJ and SJ height 5-7 min after the back-squats. In contrast the UT group reacted to the same pre-conditioning contraction protocol with a fatigue response, recording a 1-4% decrease in CMJ and SJ height 5-7 min after the back squats. Chiu et al. (2003) explained this effect by suggesting that those training at higher levels would develop fatigue resistance as an adaptation of their intensive training regime, and therefore were more likely to produce PAP. Chiu et al. (2003) however, did not measure fibre-type distribution, so it is possible that a greater percentage of fast-twitch muscle fibres in the RT group were the main cause of the effects observed in this study.
2.6.3 Gender

Gender may be a potential component when assessing PAP due to the fact that males possess larger type 2 cross sectional area and have shorter twitch contraction times (Rixon et al., 2007). Supporting this statement, are the results from Comyns et al., (2006), who examined flight time performance between men and women. There was a significant (p<0.05) improvement for both sexes and for males (p<0.01), however females indicated no significant improvement compared with control values. Similarly, significant gender differences were found between boys and girls aged 9-10, even though BMI measures were similar for both groups. Paasuke et al., (2003) found that boys produced a higher MVC in the plantar flexor muscle, eliciting PAP. Additionally, Rixon et al. (2007) observed a significantly higher jump height than women, after MVC PAP protocol.

In contrast, previous research has shown no gender effect when males and females were analysed together (O’Leary et al., 1998; Jensen & Ebben, 2003). O’Leary et al. (1998) found that men and women responded similarly to conditioning stimuli when only relative magnitude of PAP was assessed. Research is limited in the area of gender and its affect on PAP, as most studies have included only male participants, and because there are anatomical, muscular and biomechanical differences between the sexes, generalising to female athletes is questionable.

2.7 Type of subsequent activity

An additional explanation for the inconsistent results of past research is the difference in the type of subsequent voluntary contraction used by these studies. For example, Gullich & Schmidtbleicher (1996) and Gilbert et al. (2001) both followed a preconditioning contraction with an ‘isometric’ MVC. In contrast, Gullich & Schmidtbleicher (1996), as well as studies by Young et al. (1998); Ebben et al. (2000); Gossen & Sale (2000); French et al. (2003); Gourgoulis et al. (2003) and Jenson & Ebben (2003), assessed the effects of a pre-conditioning contraction
on a subsequent ‘dynamic’ contraction. The results of these studies present no clear relationship between the type of voluntary contraction executed post activation, and the level of PAP or fatigue recorded during this contraction. This is probably due to the different protocols implemented by these studies. Factors such as pre-conditioning contraction volume, recovery period following the pre-conditioning contraction, and subject characteristics, are most likely to have influenced the contrasting results.

McBride et al., (2005) were the first to utilise sprint times as a measure of PAP, which is arguably the closest determinant of agility prediction, according to Bobbert & van Zandwijk, (1999). The primary finding from McBride et al. (2005) was that heavy squat protocol, 4 minutes prior, generated faster sprint times (40m dash significant p = 0.018). Due to no tests on the neuromuscular activation, the exact mechanism responsible for the decrease in sprint times could not be assessed.

Due to the dynamic nature of ESA’s, a more important issue is the validity of inferring the effects of a pre-conditioning contraction on a subsequent dynamic activity, from results measuring the PAP response in isometric contractions. Haff et al. (1997) reported moderate to strong correlations between isometric and dynamic RFD (r = 0.65-0.75), and moderate to strong correlations between isometric and dynamic peak force (r = 0.66-0.77) during isometric and dynamic power cleans.

2.8 Summary

There is consensus over the existence of PAP, supported particularly by the research investigating its effects on twitch tension. There is also evidence that PAP might enhance performance of subsequent ESA’s, by enhancing movement mechanics partly responsible for determining performance. However there lacks evidence for the existence of positive potentiation on a subsequent agility exercise, furthermore, the literature is inconsistent regarding the relationship between ESA’s.
It would appear that different movement activities, although biomechanically and physiologically similar, are indeed distinct motor characteristics.

The presence of PAP, and the degree of potentiation realised, seems to be determined by the relationship between PAP, and the simultaneously-induced fatigue. Also, this relationship appears to be dependent upon the combination of a number of other variables. These include pre-conditioning contraction type, volume and intensity, intra-complex rest interval, type subsequent exercise and subject characteristics.
CHAPTER III
METHOD
3.0 METHOD

3.1 Study Design

A quantitative approach to the assessment of whether the performance of 5 RM voluntary pre-conditioning contraction, would elicit a response on a subsequent agility test, was administered. Quantitative research involves the measuring of events using numerical data, and assumes that there is an objective truth which can be measured and explained scientifically. Subjectivity is minimised using this method (Thomas & Nelson, 2001).

3.2 Sample

Eleven healthy, physically active male students (mean, ± standard deviation (SD)) (age: 20.9 ± 0.9 years; stature: 176.3 ± 5.7 cm; mass: 73.8 ± 7.2 kg), were recruited from the University of Wales Institute Cardiff (UWIC). The criteria for selection included a history of competitive participation in an explosive sport (i.e., sprinting, rugby, soccer, tennis), previous resistance training experience, an ability to squat at least 1.5 times their body mass, and the passing of a physical activity readiness questionnaire (PAR-Q) examination (appendix D). Participants were instructed to abstain from any strenuous exercise including strength, power, aerobic training, forty eight hours prior to each testing session, the reason being, previous studies have reported that fatigue negatively affects neural activation responses, and highly trained subjects are more able to experiment PAP (Gullich & Schmidtbleicher, 1996; Chiu et al., 2003; Gourgoulis et al., 2003). Gullich & Schmidtbleicher (1996) commented that high anaerobic loads on the previous day lead to a reduction of the MVC effect on speed-strength performance. Recruits were also requested before each testing session to avoid alcohol, caffeine and the consumption of large meals for at least two hours prior to testing. Declaration that they did not ingest any performance enhancing ergogenic aids, in the form of illegal food supplements or medication related to performance, was sort.
3.3 Pilot Testing

Two of the eleven subjects completed several pilot testing sessions, two weeks prior to the main trials. The protocol for data collection was adapted from a combination of several studies (Radcliffe & Radcliffe, 1996; Young et al., 1998; Jensen et al., 1999; Ebben et al., 2000; Jensen & Ebben, 2003; Jones & Lees, 2003) for obtaining an individual’s 5 RM half-squat. Using methods described in section 3.3, the Smith machine bar, loaded with the athletes perceived 5 RM, was lowered to the desired position. From these prior studies, three or four trials were expected to be required for the subject to complete 5 repetitions with correct form. The subject decided if they could manage a higher weight, load was increased by 5 - 10 kg and the subject attempted another 5 repetitions. This process continued until the subject achieved their true 5 RM. A recovery period of 5 min between each set was implemented. The two participants in the present study however, obtained their 5 RM after the fifth trial; underestimation of their perceived 5 RM was to blame. Consequently the observed load at which the individual maxed out, was subject to criticism. After 3 or 4 sets subjecting one muscle group to isometric contractions, fatigue will become a major factor and the intensity at which the athlete can perform will decrease (Kraemer, 1997). Therefore, the observed 5 RM values for both participants were inaccurate. To account for possible fatigue due to underestimation, main testing involved the individuals’ 5 RM half-squat value being calculated from 1 RM trials. At 1 RM load, the athlete can perform more trials before fatigue negatively affects performance.

Orientating the goniometer at the correct locations (see section 3.3.1) on one participant proved difficult as he wore loose fitting tracksuit bottoms. For main testing, it was decided that participants should wear the correct attire of t-shirt, sport shorts and comfortable trainers.
The other pilot testing day, separated by three days to avoid fatigue, aimed to trial the Illinois agility run (described in section 3.4). The sample of males followed the warm up routine identical to that in section 3.4, and were demonstrated the correct running path. One problem arose from following the original protocol and using the timing gates in place of a standard stop watch. The Illinois Agility run traditionally requires the athlete to begin from lying face down behind the start line, and on command jumps to their feet and negotiates the course. From several time trials, it was observed that a break in the timing gate beam unintentionally occurred. On one occasion a subject bending down to get in the ready position, initiated recording by breaking the beam with his head. Secondly, the larger of the two individuals knocked the tripod holding the reflective plate out of synch, whilst jumping to his feet. Later testing trialled the commencement of the run from a standing position one metre behind the start gate. This eradicated any measuring error due to unintentional beam breaks, and was standardised for the main testing sessions using a clearly defined mark.

3.4 Experimental Procedure

3.4.1 Familiarisation & 1RM determination

Subjects reported to the laboratory on three different occasions over a one week period, with each experimental session held three days apart to avoid fatigue. All trials were performed at the same time of day, to minimise diurnal variations. Consumption of water was permitted during each test. Room temperature was maintained between 20 and 24 °C (Oregan Scientific BAA913HG). Session one was completed the week before main testing, familiarising the eleven males with experimental apparatus, and to determine the load to be used during the potentiation protocols by obtaining individuals’ one repetition maximum (1RM) half-squat.

During familiarisation, subjects’ stature and mass were determined, using a fixed stadiometer (SECA, UK) and calibrated electronic weighing scales (SECA, UK),
measured to the nearest 0.1 kg and 0.1 cm, respectively. They first performed a warm-up routine identical to the one performed during the subsequent main trial. This consisted of 3 minutes low intensity work (60 rpm at a resistance of 1 kg) on a Monark 874 E weighted cycle ergonometer (Monark, Varberg, Sweden). One dynamic stretch for each muscle group, designed to activate functional movement in the legs and trunk, preceded an activity specific warm up. This included 12 repetitions of the back-squat without load, in order for the investigator to assess technique and evaluate knee angle with a goniometer. To measure knee angle precisely, the goniometer was centered at the lateral femoral condyle, and pointed one end towards the greater trochanter at the hip and the lateral malleolus at the ankle (Chiu et al., 2003). Brackets were subsequently positioned below the bar to prevent any knee flexion above 90 degrees. This was followed by two sets of 5 repetitions using a resistance that was 40 and 60 % of subjects’ perceived maximum. Five minutes after the warm-up subjects began their first test condition.

The 1RM half-squat test was performed using methods previously described by Hoffman (2006). A 5 minute rest period was imposed between all attempts to allow subjects adequate time to replenish phosphocreatine (PC) and adenosine triphosphate stores (ATP). All trials remained standardised by using the same Smith machine in the physiology laboratory. The benefit of performing the half squat on the Smith machine is that the bar is forced to travel over a predefined path and has the safety aspect of adjustable brackets. The squat exercise required the athlete to set under the bar, in an upright position, looking forward, grasping firmly the bar with both hands and placing it across the posterior Deltoid, resting on the Trapezius muscle at a self selected location. Foot position was kept constant for all half-squats, by marking the position of the heel that suited each subject. In their own time, the athlete descended to the parallel position which was attained when the greater Trochanter of the femur reached the same level as the knee (Chiu et al., 2003). The correct depth of each dynamic half-squat was kept constant by making a specific mark for each subject on the frame of the Smith machine. The athlete then ascended until full knee extension, trials not meeting the range of motion
criteria were discarded. Once satisfied with participants’ technique, subject one’s perceived maximum was loaded onto the Smith machine. Two spotters assisted in lifting the bar from the support rack and followed the bar in case intervention was required. If this attempt was successful the weight was increased by 5-10 kg and the subject attempted another repetition. This procedure continued until the subject failed to complete 1 repetition with good technique. One repetition maximum values were obtained within 5 attempts. These values were used to calculate individuals’ 5 RM (to the nearest 2.5 kg), using guidelines for developing power in multiple effort power events (rugby, soccer, tennis), based on 5 reps at 85% of 1 RM (Baechle & Earle, 2000). The 5 RM back-squat was chosen for the dynamic condition as it represented a typical lower body maximal resistance exercise (Jenson and Ebben, 2003), and a training intensity that had previously been reported to enhance performance of a subsequent explosive sports activity (Young et al., 1998).

3.4.2 Agility Trials Pre-Stimulus

Experimental session two required subjects to report to an indoor athletics centre (Mondo Sportflex Super X Classic surface), to determine agility performance, and having followed guidelines regarding preparation, previously mentioned in section 3.3.1. Recruits were requested to complete 3 minutes low intensity jogging, and a range of dynamic stretches (as in section 3.3.1), as a warm up. Agility was assessed using the Illinois agility run previously described in Davis et al. (2005). Figure (3.4.2) indicates the correct running pattern, which was demonstrated by the researcher and each athlete was allowed to jog through the cones once before the test trials began. Smart Speed Timing gates (Fusion Sport, Brisbane, Australia) were placed at the start and finish lines at a height of 1.0 m, and synchronised by the researcher. Protocol for agility data collection were kept standardised, participants commenced from a standing start 1 m behind the timing gates, on a clearly visible mark. Subjects were then free to begin testing when ready; Smart Speed’s remote timing unit automatically recorded the time when the athlete crossed the start and finish lines.
Figure 3.4.2 Representation of the adapted Illinois Agility Run. Players sprinted 10 meters, went around the cone and returned to the centre cone level to the starting line. They then swerved in and out of the four markers, returning to the centre cone once again. Two 10 m sprints finished the agility course.

Throughout all trials subjects were verbally encouraged to perform at maximal effort, and were given continual feedback on technique. Andreacci et al. (2001) demonstrated that frequent verbal encouragement at the beginning, leads to significantly greater maximum effort in a treadmill test than when no encouragement is given or when the encouragement is infrequent.
3.4.3 Main Testing Session

Exactly one week after the familiarisation session subjects returned to the laboratory for the main trial. This commenced with the same three-stage warm up programme as in familiarisation. Participants were tested one after the other, each following identical protocol. Five minutes post warm up, subject one set themselves under the Smith machine, and indicated when the spotters should lift the load from the brackets. 5 repetitions at the individuals’ calculated load were carried out, repetitions not meeting the range of motion, were repeated. From the completion of the fifth repetition, each subject started an individual stopwatch and had exactly 4 minutes before the commencement of the agility run. This intra-complex rest interval was administered on the basis of previous research who found a positive effect on the potentiation of the lower body (Young et al., 1998). The rest interval also allowed for the short walk to the indoor athletics centre, where the agility course was laid out identical to the previous session.

3.5 Reliability

Reliability concerns the degree to which replicated measures provide both consistent and accurate scores, and are influenced by measurement error and undependability. Reliability will be high due to the nature of the study design, having fewer testing errors occur in a laboratory setting. However being a false environment, more errors in terms of performance are expected (Bland, 2000).

Maximal testing raises issues regarding reliability of repeating trials, especially several days between sessions, as in the case of the present study. Only the subject will know if they are exerting maximal effort, however some untrained participants will not know how far to push themselves. To attempt to minimise this, verbal encouragement was implemented throughout. All measurements involve some error; some were due to performance inconsistency by the tester and the athlete. Reliability was kept consistent in terms of ‘stability’ by measuring variables with
the same equipment (i.e. Smith machine, goniometer, timing gates) on different occasions (Bland, 2000).

Furthermore the timing gates minimised investigator error by a system called error correction processing (ECP), which examined all events (such as the leading hand, torso, and trailing hand) passing through the single beam gate, and used the start of the longest break i.e. the torso (Fusion Sport, Brisbane, Australia).

3.6 Statistical Analysis

Conformation that all dependant variables were normally distributed was assessed via a Kolmogorov-Smirnov test (see section 5.1). Normal distribution was accepted at a significant level greater than $p > 0.05$. Data were expressed as the mean and ± SD. Statistical analyses were conducted using Statistical Package for the Social Sciences (SPSS for Windows version 12.0, SPSS, Inc., Chicago, IL). For all statistical comparisons, the Alpha level of significance was set at $p > 0.05$ (95 % confidence level). A paired-samples T-test was administered to assess the acute positive effects of a pre conditioning half-squat on a subsequent agility test. A paired-samples T-test was used because there were two related observations and the aim is to observe if the means on these two normally distributed interval variables differ from one another.

Additional comparisons to determine if an individual’s power to weight ratio might influence agility score. A Pearson’s correlation for each subject’s power-to-weight ratio and the potentiated agility test score were administered. The relationship between power-to-weight ratio and the participants’ agility score post-stimulus were the analysed variables (section 5.3).

Each agility score, pre and post-stimulus, were also assessed in terms of the percent potentiation, a commonly used measure to assess the relative change in
performance following postactivation potentiation. Percent potentiation greater than 100% indicates PAP, equal to 100% indicates no potentiation, and less than 100% indicates postactivation depression (Chiu et al., 2003) (fig.3.6). Appendix C, shows subjects’ percent potentiation in tabulated form.

\[
\text{% Potentiation} = \frac{\text{Potentiated Variable}}{\text{Un-potentiated Variable}} \times 100
\]

**Fig. 3.6** Percent Potentiation Equation (Chiu et al., 2003)

### 3.7 Ethical Guidelines

As a researcher it is our responsibility to ensure the investigation does not detrimentally affect the physical, psychological and social well being of the participants. As stated in the consent form (Appendix D), participation is entirely voluntary and withdrawal at any time will not incur retribution. Before providing written informed consent, subjects completed a PAR-Q and received a clear explanation of the protocol, including a demonstration of the correct half-squat technique, and the risks and benefits of participation. In compliance with the provisions of the Data Protection Act (1984), all data sheets were identified via subject number, kept separately from consent forms and stored in locked cabinets within locked office facilities within the Cardiff School of Sport. Participants were assured that only the researcher and supervisor, would be the only people to have access to personal information and results.
CHAPTER IV

RESULTS
4.0 RESULTS

4.1 One-Sample Kolmogorov-Smirnov Test

<table>
<thead>
<tr>
<th></th>
<th>Agility Pre-Stimulus</th>
<th>Agility Post-Stimulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Normal Parameters(a,b)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>15.6718</td>
<td>15.5055</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>.38654</td>
<td>.44523</td>
</tr>
<tr>
<td>Most Extreme Differences</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absolute</td>
<td>.223</td>
<td>.164</td>
</tr>
<tr>
<td>Positive</td>
<td>.133</td>
<td>.133</td>
</tr>
<tr>
<td>Negative</td>
<td>-.223</td>
<td>-.164</td>
</tr>
<tr>
<td>Kolmogorov-Smirnov Z</td>
<td>.740</td>
<td>.545</td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
<td>.644</td>
<td>.928</td>
</tr>
</tbody>
</table>

a  Test distribution is Normal.
b  Calculated from data.

The Kolmogorov-Smirnov significant values displayed in table 4.1 are; 0.74 for Agility Pre-Stimulus and 0.545 for Agility Post-Stimulus. If the p-value is less than 0.05, there is insufficient evidence to suggest the distribution is not normal, therefore this data can be described as normally distributed (p>0.05), and no violations of the test assumptions have been made. As a consequence the researcher can proceed with the assumption of normality, and continue with the T-test.
4.2 Paired Samples Statistics

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agility Pre-Stimulus</td>
<td>15.6718</td>
<td>11</td>
<td>.38654</td>
<td>.11655</td>
</tr>
<tr>
<td>Agility Post-Stimulus</td>
<td>15.5055</td>
<td>11</td>
<td>.44523</td>
<td>.13424</td>
</tr>
</tbody>
</table>

The dependant variables being compared are identified in table 4. , the Mean, N, Standard Deviation, and Standard Error of the Mean for each variable are given.

4.3 Paired Samples Correlations

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Correlation</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agility Pre-Stimulus &amp; Agility Post-Stimulus</td>
<td>11</td>
<td>.967</td>
<td>.000</td>
</tr>
</tbody>
</table>

Here the correlation between each of the pairs of variables is given in table 4. . This is a repeated-measures analysis using the same sample twice. The correlation value of .967, as expected has a high degree of correlation between the two sets of scores. This being greater than 0.05 effectively means that there is no significant differences in the test re-test scores was observed. Therefore the H¹ can be rejected and the null hypothesis can be accepted.
### 4.4 Paired Sample Test

<table>
<thead>
<tr>
<th>Paired Differences</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Std. Deviation</td>
<td>Std. Error</td>
</tr>
<tr>
<td>Agility Pre-Stimulus - Agility Post-Stimulus</td>
<td>.16636</td>
<td>.12118</td>
<td>.03654</td>
</tr>
</tbody>
</table>

Here the descriptive statistics for the difference between each pair of variables is given. The T-test results displayed in table 4.4. The output shows an n of 11 and a mean of .16636. This statistical analysis produced a t-value of 4.553, and an asymp. Sig. (2-tailed) value of (p-value) of 0.001. Consequently there is no significant difference in agility scores pre and post stimulus (p<0.05).

The t-statistic for the coefficient is the ratio of the coefficient to its standard error. It can be tested against a t distribution to determine how probable it is that the true value of the coefficient is really zero. Df represents the degrees of freedom (4.553). The mean difference (.16636) is what is actually being tested against zero. The result is insignificant t(11) = , p = .001. We reject hypothesis 1 in favour of the alternative null Hypothesis.
Figure 4.5 Means & Standard Deviation for Pre and Post-Stimulus Agility Scores

Graphical representation of the 11 recruits’ mean, Pre and Post-Stimulus Agility test scores, with standard deviation. The graph shows a decrease in mean time post-stimulus, however a larger standard deviation.
Each variable was also assessed in terms of the percent potentiation, a commonly used measure to assess the relative change in performance following postactivation potentiation. Percent potentiation equal to 100% indicates no potentiation, greater than 100% indicates PAP, and less than 100% indicates postactivation depression. 10 out of the 11 subjects observed a positive percentage potentiation, the anomaly to the results produced a negative potentiation, by performing the post-stimulus agility run, slower.
Figure 4.7 The Relationship between Power-to-Weight Ratio and Agility Post-Stimulus

Relationship indicates a general trend between the two sets of data, with the exception of two anomalies. Data points on the regression model appear to be in strong correlation with the line of best fit. The results agreed with previous research and this study’s hypothesis, the subjects with a lower power-to-weight ratio recorded slower agility times. Therefore the relatively stronger individuals recorded faster agility times (Appendix C).
CHAPTER VI
DISCUSSION
5.0 DISCUSSION

Results from the current study do not support the hypothesis that performance and muscle activation increases after a pre-conditioning contraction. Therefore conflicts with the findings of Young et al. (1998) and other research (Gullich & Schmidtbleicher, 1996; Baker, 2003; Chiu et al., 2003; French et al., 2003; Gourgoulis et al., 2003), and the general suggestion that increased neural activation is the mechanism underpinning complex training. Findings are however in agreement with certain studies (Ebben et al., 2000; Hrysomallis & Kidgell, 2001; Jones & Lees, 2003), who reported no improvement of power in subsequent performance. The results would also correspond with the findings of Radcliffe & Radcliffe (1999), who established that different warm up treatments (squat, snatch, tuck jumps, and loaded CMJ’s) induced no significant effects (p>0.05) on CMJ performance, after a 3 minute recovery.

While no statistical significance was found, suggesting that complex training did not enhance agility performance, it was also noted that no adverse effects occurred with the additional exercise. This supported Ebben et al. (2000), who appeared to show no detrimental effect of heavy resistance exercise on the plyometric activity for a 20 minute period. A possible fatiguing effect mentioned in previous research (Hrysomallis & Kidgell, 2001), was therefore not observed.

5.1 Relationship between PAP & Fatigue

Previous sources have suggested that the plyometric component of complex training should be performed immediately after the high load resistance training component (Ebben & Watts, 1998; Verkhoshansky & Tatyan, 1973). Findings are inconsistent regarding the intra-complex rest interval, suggesting that in the applied training setting it may be beneficial to be individually determined. The improvement window seems to differ between subjects and it would be important to individually determine this window of opportunity.
The findings of the present study could therefore be consistent with previous research which has shown a sufficient recovery period is required to attenuate fatigue and realise PAP (Gullich and Schmidtbleicher, 1996; and Young et al., 1998). Additionally, the time course of jump height potentiation fits the PAP fatigue relationship model (Figure ?, Sale, 2002), whereby fatigue is more dominant immediately after a pre-conditioning contraction but then dissipates at a faster rate than PAP, resulting in an increase in subsequent performance at some point in time during the recovery period. In addition, the completion of the agility run, 4 minutes post-stimulus, could have had a fatiguing effect and masked any potential improvement.

5.2 Power-to-Weight Ratio

Relative strength for each subject was calculated as their 1 RM mass back-squat, divided by body mass. The hypothesis that higher relative power-to-weight individuals would observe a greater response to potentiation was accepted. This would therefore appear that subjects with a small power-to-strength ratio are unable to convert their strength to power, possibly due to an inability to effectively utilise their higher-order MU during explosive movements. A preconditioning contraction however, is expected to increase the recruitment of higher order MU, which might explain the greater potentiation effect observed in those subjects with a small power-to-strength ratio. Consequently, other subject characteristics such as subject’s strength (Gourgoulis et al., 2003), fibre-type distribution (Hamada et al., 2003), and training status (Sale, 2002; Chiu et al., 2003) may have influenced the results of the present study.
5.3 Effect of the Pre-conditioning Exercise

Even though previous research has utilised a 5 RM back squat effectively (Young et al., 1998), the nature of the stimulus may not have been sufficient to elicit the potentiation effect in the case of the present study. Findings would seem to agree with a section of Gullich & Schmidtbleicher’s (1996) results, which stated that sub MVC’s (below 1 RM) produced no change in the RFD.

The pre-conditioning contraction type effect might be associated with the greater neural activation, and subsequently greater muscle fibre activation, expected to occur during isometric MVC’s (Duchateau et al., 1984). If more muscle fibres are contracting during the isometric MVC’s, this may result in greater RLC phosphorylation and/or increase in compliance, therefore potentiating subsequent activity, regardless of MVC volume. On the other hand, a relatively high volume of dynamic contractions may be required to achieve the same PAP and/or compliance responses as isometric contractions. A possible cause of the group affects on the mean change in Agility test may be associated with the mechanisms of PAP. RLC phosphorylation has its greatest effect at relatively low concentrations of Ca\(^{2+}\) but has little or no effect at saturating Ca\(^{2+}\) levels (Vandenboom et al., 1993; Sale, 2002; and Hodgson et al., 2005).

5.4 Subject Characteristics

A further factor that differed from previous studies (Gullich & Schmidtbleicher, 1996; Young et al., 1998; Chiu et al., 2003; Rixon et al., 2007) was the training status of the sample. These studies recruited elite athletes (or split subjects into training level groups), compared to the present selection of males that were essentially team sports players participating at a recreational or amateur level. Although the subjects used were active, recreationally trained, they may not have had enough strength to elicit changes from the 5 RM pre-conditioning contraction. Young, Jenner & Griffiths (1998) found that there was a positive correlation
between the load used in the potentiation protocol and the performance enhancement in a squat, suggesting that stronger individuals may receive a greater potentiation benefit. Future studies should look at this to see if pre-existing strength affects the results of a potentiation protocol. Additionally, the eleven males were of different strength and power abilities and this may have been a factor in the inter-subject variations observed.

Despite the statistically insignificant potentiations observed in the present study, there was a large degree of subject variability with respect to each subject’s response to the treatment. This subject variability was consistent to the findings of past research (Gullich & Schmidtbleicher, 1996).

Finally, it is possible that the group affects measured in this study are not the result of physiological states (e.g., fresh or fatigued), but are instead caused by a learning effect that may have occurred during each main trial. Consequently, the implication of the group affects observed in the present study are not entirely clear, and the effects of a pre-conditioning contraction on subsequent activity during different physiological states requires further investigation.

5.5 Subsequent Agility Performance

Researchers employing a 3-4 minute rest interval between stimulus and ESA have recorded significant positive potentiations (Gullich & Schmidtbleicher, 1996; Young et al., 1998; McBride et al., 2005). Comparing results with these similar study designs, the present findings contradict that evidence. McBride et al. (2005) observed a significant potentiation in 40 m sprint times following a back-squat pre-conditioning contraction, however no such potentiation was found in the present findings, even though protocol was similar.

The complex training theory however cannot be completely disregarded by the current study. The results imply that performing the agility run 4 minutes post
stimulus, does not create optimal conditions for power development. There is however strong theoretical evidence to suggest that a 3-4 minute intra-complex rest interval is required for significant enhanced performance to be realised (Gullich & Schmidtbleicher, 1996; and Young et al., 1998).

5.6 Technical Error of Measurement (TEM)

The major limitation that the present study incurs is a measure of absolute variability during agility testing. Due to time constraints and equipment availability, trials for pre-stimulus agility scores were limited to one. Replicating the pre-stimulus trial three or more times, would allow for an average time and standard deviation from the mean, to be calculated, and a consequent TEM to be expressed (fig. 5.6).

\[
\text{TEM} = \sqrt{\frac{\sum d^2}{2n}}
\]

**Figure 5.6** Equation for measuring Technical Error of Measurement (d = difference between replicated measures, n = number of subjects).

The resulting value is expressed as a percentage or in units of measurement, in this case, seconds. A subsequent trial will fall within this value (± calculated value), with a certainty of 68% (Altman, 1991).

The trial-to-trial difference values calculated by Vescovi & Mcguigan (2007) for the Illinois agility run, were 0.2 s. Similarly the test - retest TEM for the Illinois agility run, was recorded at 2.02% by Young et al. (2001). With this in mind, participants test re-test time can be hypothesised for the present study. Only two participants recorded significantly faster agility times in relation to the TEM of 2.02%. The means of the sample, counteracted the two significant values, which could be assumed were the cause of potentiation in the muscle.
Despite the insignificant mean potentiations observed in the present study, there was a large degree of subject variability with respect to each subject’s response to the treatment. 10 out of the 11 subjects appeared to increase agility performance and only one decreased performance score, despite being proved insignificant, it would seem that the difference in scores would not be down to testing error expected with the agility test, but actually the potentiation of the muscle. However, even with these hypothesised significant values, it is possible that the faster agility times were the result of other limiting factors such as, increased compliance in the series elastic components of the musculotendinous structures, as opposed to a PAP response. Optimal stiffness of the series elastic components for performance of an activity that relies predominantly on storage of elastic energy during the eccentric contraction is toward the compliant end of the elastic continuum (Wilson et al., 1991). Additionally the mechanism of this increase agility performance is a subject of speculation because the study did not test the level of neuromuscular activation. Gullich & Schmidtbleicher, (1996) suggested that morphological changes in skeletal muscle are unlikely in such a short time, but high frequency stimulation of motor neurons associated with the heavy squat set may increase the probability of individual MU activation. According to Gullich & Schmidtbleicher (1996), such short term changes leading to positive performance alterations are most probably caused by neuronal factors of speed and strength mechanisms.

Repeating the experimental procedure again, would allow for the problems associated with quantifying the potentiated scores, to be rectified. Gathering an average agility score pre-stimulus, by implementing a three or five trial protocol, would allow for a technical error of measurement (TEM) to be recorded. TEM is a measure of absolute variability, expressed in units of measurement (in this case, seconds) or %, between an observed value and true score (with 68 % certainty).
CHAPTER VII
CONCLUSION
6.0 CONCLUSION

It has been proposed that a MVC will induce PAP, resulting in an enhancement of various movement mechanics, consequently improving performance, or the training stimulus, of a subsequent ESA. However, although research investigating the effect of an MVC on a subsequent twitch contraction has consistently recorded PAP, evidence verifying the same effect during an ESA is equivocal. The reason for this is primarily due to the differences in experimental protocol implemented by the various studies.

Factors such as MVC type, volume, recovery period following the MVC, subject characteristics, and type of ESA executed after the MVC have a large influence on the interaction between PAP and fatigue, ultimately determining the effect of an MVC on subsequent performance. Due to the contrasting results of past research, to date there are no empirically established guidelines for the utilisation of PAP in training or performance. Furthermore, the effects of an MVC on the activation of higher-order MU, a variable associated with one of the proposed mechanisms of PAP, are unclear.

To conclude, the present findings produced no significant evidence to support the hypothesis that performance and muscle activation increases after a preconditioning contraction, however a treatment effect cannot be ruled out.

6.1 Limitations

Conclusions from the current study however, are only representative of how the analysed sample responded to the treatment. The more heterogenous the sample, the higher the correlation in terms of reliability. The present study was homogenous in design, whereby the sample was not representative of the whole population; the recruits were limited to 20-23 year old male sports students at UWIC, and further limited to only those with previous explosive sport participation,
resistance training experience, and availability on testing days. This meant that only a small sample size (n = 11) were analysed, and undermined the statistical power of the results. Generalising to other populations therefore did not apply. Subjects were unpaid volunteers, so motivation during performance would have been mostly intrinsic. However, subjects will be encouraged to give maximal effort at all times. Therefore coaches should be aware of how the individual athlete may react to the complex method.

Equipment restrictions and time constraints meant that testing times were limited, and the experimental procedure had to adhere to these factors. Muscle biopsies were not taken so subject muscle fibre type distribution was not known. As a result, the differences in agility times, pre and post-stimulus were an observed response.

The Illinois Agility Run may be heavily influenced by the ability to sprint quickly over short distances instead of measuring the ability to change directions. In addition, the duration of the original test is approximately 16 – 18 s; therefore performance may have metabolic limitations (Vescovi & Mcguigan, 2007). The length of time between test and re-test of the agility runs, may also have had an affect on the reliability, the longer the time to re-test, the weaker the correlation.

Findings of the study are limited to the lower body muscle groups observed, type of pre-conditioning stimulus and subsequent power exercise, intra-complex rest interval incurred, and the sample population recruited. In addition the use of a Smith machine may not provide as much muscular tension as compared to free weight squats using an Olympic bar.

Within the limitations of this study, complex training implemented acutely in the form of a warm up, may not offer ergogenic advantages. The results however offer no detrimental effects associated with resistance exercise.
6.0 Practical Applications and Future Research

Before any conclusions can be made as to the efficacy of exploiting PAP as a warm up for explosive agility activities, further scientific research is required. Future research should aim to investigate the manipulation of these inter-dependent variables, while taking into account the additional effects of factors such as subject characteristics and type of subsequent activity. Furthermore, considering that field and court sports generally include these changes of direction in response to a stimulus, for example another player’s movement, or the ball, it would seem vital to provide testing and training that mimics this demand to increase specificity.

The overall purpose should be to establish specific guidelines explaining how to optimise the effects of contractile history and utilisation of PAP, for the benefit of both acute performance and training. Investigations should assess the specific mechanisms of PAP and fatigue following a pre-conditioning contraction, and analysis of their combined effects on subsequent ESA’s in subjects of different physiological states.
REFERENCES
REFERENCES


Fusion Sport, Brisbane, Australia. *Error correction processing (ECP)*. No Date. (online) http://fusionsport.com/portal/content/view/16/79/. Accessed on 12.02.08


APPENDIX A
### Table A. Subjects’ Characteristics

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (years)</th>
<th>Stature (cm)</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21</td>
<td>181.5</td>
<td>76</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>178.6</td>
<td>92.3</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>175.6</td>
<td>77.9</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>175.8</td>
<td>73.1</td>
</tr>
<tr>
<td>5</td>
<td>21</td>
<td>187.1</td>
<td>66.3</td>
</tr>
<tr>
<td>6</td>
<td>23</td>
<td>176.1</td>
<td>67.8</td>
</tr>
<tr>
<td>7</td>
<td>21</td>
<td>169</td>
<td>73</td>
</tr>
<tr>
<td>8</td>
<td>20</td>
<td>181.6</td>
<td>74.4</td>
</tr>
<tr>
<td>9</td>
<td>21</td>
<td>171.2</td>
<td>66.3</td>
</tr>
<tr>
<td>10</td>
<td>21</td>
<td>168.6</td>
<td>73.2</td>
</tr>
<tr>
<td>11</td>
<td>22</td>
<td>174.5</td>
<td>71.6</td>
</tr>
<tr>
<td><strong>Means</strong></td>
<td><strong>20.9</strong></td>
<td><strong>176.3</strong></td>
<td><strong>73.8</strong></td>
</tr>
<tr>
<td><strong>SD</strong></td>
<td><strong>0.9</strong></td>
<td><strong>5.7</strong></td>
<td><strong>7.2</strong></td>
</tr>
</tbody>
</table>
APPENDIX B
Table B. Table Showing Subjects’ Agility Scores Pre and Post-Stimulus

<table>
<thead>
<tr>
<th>Subject</th>
<th>Agility Pre-Stimulus (secs)</th>
<th>Agility Post-Stimulus (secs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14.96</td>
<td>14.77</td>
</tr>
<tr>
<td>2</td>
<td>15.92</td>
<td>15.72</td>
</tr>
<tr>
<td>3</td>
<td>15.72</td>
<td>15.39</td>
</tr>
<tr>
<td>4</td>
<td>15.89</td>
<td>15.64</td>
</tr>
<tr>
<td>5</td>
<td>15.03</td>
<td>14.69</td>
</tr>
<tr>
<td>6</td>
<td>15.88</td>
<td>15.84</td>
</tr>
<tr>
<td>7</td>
<td>15.85</td>
<td>15.88</td>
</tr>
<tr>
<td>8</td>
<td>16.12</td>
<td>16.08</td>
</tr>
<tr>
<td>9</td>
<td>15.41</td>
<td>15.29</td>
</tr>
<tr>
<td>10</td>
<td>16.01</td>
<td>15.77</td>
</tr>
<tr>
<td>11</td>
<td>15.6</td>
<td>15.49</td>
</tr>
<tr>
<td>Means</td>
<td>15.67</td>
<td>15.51</td>
</tr>
<tr>
<td>StDev</td>
<td>0.39</td>
<td>0.45</td>
</tr>
</tbody>
</table>
Table C. Power-to-Weight Ratio & Agility Post-Stimulus Score

<table>
<thead>
<tr>
<th>Subject</th>
<th>Weight (kg)</th>
<th>1 RM (kg)</th>
<th>Power-to-Weight Ratio</th>
<th>Agility Post-Stimulus Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>76</td>
<td>170</td>
<td>2.24</td>
<td>14.77</td>
</tr>
<tr>
<td>2</td>
<td>92.3</td>
<td>160</td>
<td>1.73</td>
<td>15.72</td>
</tr>
<tr>
<td>3</td>
<td>77.9</td>
<td>180</td>
<td>2.31</td>
<td>15.39</td>
</tr>
<tr>
<td>4</td>
<td>73.1</td>
<td>160</td>
<td>2.19</td>
<td>15.64</td>
</tr>
<tr>
<td>5</td>
<td>66.3</td>
<td>140</td>
<td>2.11</td>
<td>14.69</td>
</tr>
<tr>
<td>6</td>
<td>67.8</td>
<td>140</td>
<td>2.06</td>
<td>15.84</td>
</tr>
<tr>
<td>7</td>
<td>73</td>
<td>150</td>
<td>2.05</td>
<td>15.88</td>
</tr>
<tr>
<td>8</td>
<td>74.4</td>
<td>120</td>
<td>1.61</td>
<td>16.08</td>
</tr>
<tr>
<td>9</td>
<td>66.3</td>
<td>140</td>
<td>2.11</td>
<td>15.29</td>
</tr>
<tr>
<td>10</td>
<td>73.2</td>
<td>150</td>
<td>2.05</td>
<td>15.77</td>
</tr>
<tr>
<td>11</td>
<td>71.6</td>
<td>180</td>
<td>2.51</td>
<td>15.49</td>
</tr>
</tbody>
</table>

| Means   | 73.8        | 153.6     | 2.38                   | 15.51                      |
| StDev   | 7.2         | 18.6      | 0.19                   | 0.45                       |
APPENDIX D
Physical Activity Readiness Questionnaire (PAR-Q)

Please Circle the answers to the following questions:

1. Has your Doctor ever said you have heart condition and that you should only do physical activity recommended by a Doctor? Yes / No

2. Do you feel pain in the chest when you perform physical activity? Yes / No

3. In the past month have you had chest pain when you were not doing physical activity? Yes / No

4. Have you recently been absent from lectures due to illness? Yes / No

5. Do you lose your balance because of dizziness or do you ever lose consciousness? Yes / No

6. Do you have a bone or joint problem that could be aggravated by physical activity? Yes / No

7. Have you any muscle injury condition that may require further rest between exercise? Yes / No

8. Is your Doctor currently prescribing drugs for blood pressure or a heart condition? Yes / No

9. Do you know of any other reason why you should not partake in physical activity on medical grounds? Yes / No

If you have answered yes to any of the above, please add details below:

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

Signed ________________________  Date ________________________
UWIC Participant Consent Form

Participant Name: ______________________
Contact Tel: ______________________
Title of Project: Effect of postactivation potentiation upon agility performance
Name of Researcher: Robert Davey

As part of my undergraduate dissertation experimental procedure, titled ‘Effect of postactivation potentiation upon agility performance’, I require between 10-15 subjects and wondered if you would be kind enough to help me with my research. The study aims to test the physiological phenomenon that explosive strength of a muscle or group of muscles is enhanced following maximal or near maximal contractions; this is termed Postactivation Potentiation.

Participation is entirely voluntary, and at any stage of the process, you are free to withdraw without retribution. If you do withdraw the researcher may wish to retain the data that has been recorded from you but only if you agree, otherwise your records will be destroyed.

The criterion for selection requires a history of competitive participation in an explosive sport (i.e., sprinting, rugby, soccer, tennis), previous resistance training experience and an ability to squat at least 1.5 times your body mass. Participation entails attending three testing sessions, over a one week period:

- First test session familiarises subjects with testing procedures and will obtain individuals 1 repetition maximum (RM) half-squat, in order to calculate 5 repetition maximum.

- Second session will measure the participant’s fastest Illinois agility run from two trials.
Third session combines the two protocols; participants will carry out 5 half-squat repetitions, followed 4 minutes later by the same agility run.

This research will provide the participants with the latest scientific strategy for optimising their muscular power to improve both acute performance and training. Furthermore, subjects will have their lower body strength and agility scientifically tested.

This study requires subjects to perform at maximal effort during the back squats, and agility test. Consequently, subjects will experience feelings of discomfort due to fatigue. There is also a possible risk of delayed onset muscle soreness, or muscle injury. Every effort will be made to minimise any risk associated with these tests, by having all participants perform familiarisation sessions and a thorough warm-up and cool-down during each testing session. Subjects will also be continually coached on correct postures and techniques for all test exercises.

In compliance with the provisions of the Data Protection Act (1984), data sheets will be identified via subject number will be kept separately from consent forms, and stored in locked cabinets within locked office facilities within the Cardiff School of Sport. Myself and dissertation tutor Dr. Joseph Esphormes, will be the only people to have access to personal information and results.

Your participation in this study does not prejudice any right to compensation that you may have under statute of common law. The Ethics Committee at the University of Wales Institute Cardiff requires that all participants are informed that, if they have any complaint regarding the manner, in which a research project is conducted, it may be given to the researcher or, alternatively to the Dissertation Supervisor Dr. Joseph Esphormes. All study participants will be provided with a copy of the Consent Form for their personal records.
- I confirm that I have read, and understand the information sheet for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactory.

- I fulfil the criteria for participation.

- I understand that my participation is voluntary and that I reserve the right to withdraw at any time without reason, or retribution.

(Tick where appropriate)

________________________________________________________________________________________
(Signature of Participant) Date

________________________________________________________________________________________
(Signature of Experimenter) Date

If you have any questions concerning the research, please feel free to ask the researcher at any time. Further information regarding this study may be obtained from:

Robert Davey Tel: 07825393181
Sport & Exercise Science Undergraduate, UWIC

Dr. Joseph I. Esformes, PhD., CSCS.
Lecturer in Physiology
University of Wales Institute, Cardiff
Cardiff School of Sport
Cyncoed Road
Cardiff, CF23 6XD, UK
Tel: +44 (0) 29 2041 7060