THE EFFECT OF POST-ACTIVATION POTENTIATION ON THE ROUNDHOUSE KICK IN MARTIAL ARTS

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Abstract

Acute enhancement of the contractile properties of skeletal muscle has been observed during explosive movements following heavy resistance exercise (HRE) and explosively loaded exercise (ELE). It is undetermined whether this phenomenon, termed post-activation potentiation (PAP), can augment the kinetic profile of the roundhouse kick (RHK). This investigation aimed to determine whether RHK force and power could be enhanced if preceded by HRE or ELE. Nine resistance trained, competitive martial artists (mean ± SD: age, 22.8 ± 3.1 years; stature, 1.77 ± 0.03 m; body mass, 73.7 ± 8.2 kg) performed 3 RHKs at 6 times (baseline, post-2, 4, 8, 12 and 16 minutes) under 3 conditions (control, HRE and ELE). The initial control condition contained no intervention. The latter HRE, 3 repetition maximum back squat, and ELE, 2 x 5 drop jump (DJ), conditions were performed in a counterbalanced order. Peak force (F_{peak}), peak power (P_{peak}), average force ($F_{average}$) and average power ($P_{average}$) were analysed. No significant differences from baseline were revealed at any time, in any condition ($p > 0.05$). Effect sizes revealed a possibly positive effect on F_{peak} from 4 to 16, P_{peak} at 4, $F_{average}$ and $P_{average}$ at 4 and 8 minutes (0.13 – 0.25) following ELE, P_{peak} at 12 minutes (0.12) following HRE and $F_{average}$ at 8 and $P_{average}$ at 2 and 8 minutes (0.13 - 0.19) in the control condition. A significant enhancement of RHK force and power was not achieved via PAP. Competitive martial artists would unlikely benefit from a PAP protocol for this purpose.

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Chapter 1. Introduction

The roundhouse kick (RHK) is the most applied offensive lower limb attack in striking martial arts (Ouergui, Hssin, Franchini, Gmada, & Bouhlel, 2013). It is an action designed to strike an opponent on the side; whereby the hips perform a rotational movement with the accompanying leg performing an arc motion from the outside towards the inside and from the vertical to the horizontal plane (Ouergui *et al.*, 2013). There is a paucity of kinetic data on the RHK, and of current literature exists such methodological dissimilarity between investigations that there lies a large level of inconsistency between results. That being said, despite differing apparatus for data collection and participant martial arts background, concurrency of findings can be found. Sidthilaw (1996) analysed mean peak forces of low- (knee) and mid-level (hip) RHKs by Thai boxers, as measured by tri-axial accelerometry, to be 6702 ± 3514 and 7240 ± 3477 newtons (N), respectively. Using a different method, by registering the pressure exerted on an airbag upon impact, Chiu, Wang, and Chen (2007) recorded values of 8252 ± 720 N by Taekwondo athletes. Using a combined method of 3D camera analysis, force platforms and tri-axial accelerometry, O'Sullivan *et al.* (2009) recorded RHK (referred to as "turning kick") peak force values of 6400 ± 898 and 6393 ± 1382 N for Taekwando and Youngmudo athletes, respectively.

Although there is currently no research that quantifies the frequency with which this kick is delivered in any striking martial art, when athletes successfully execute this action with the forces described in the previous studies, they possess the capacity to cause soft tissue damage, skeletal fractures and neurological impairment (Sidthilaw, 1996). The level of force applied to an opponent via the RHK may, therefore, be a determining factor in winning or losing a fight. Further to this, employing strategies to augment kicking force could enhance an athlete's competitive performance, increasing their likelihood of winning.

Kicking force can be increased through various long-term training modalities such as resistance training or by developing the skill level in that particular action, but like other explosive movement patterns, it may also be augmented acutely by inducing a potentiated state in the active muscles. This state, referred to as neural potentiation or post-activation potentiation (PAP) is brought about via a combination of neurological and physiological adaptations to muscular contraction (Esformes & Bampouras, 2013). A temporary augmentation in the efficiency of neuromuscular activation due to a greater excitation of the central nervous system and motor neurons leads to an increase in recruitment of motor units (Hanson, Leigh, & Mynark, 2007). Previous muscular contraction also increases the release of calcium ions (Ca^{2+}) from the sarcoplasmic reticulum (Esformes & Bampouras, 2013; Rassier & MacIntosh, 2000). This greater Ca^{2+} concentration leads to the activation of myosin light chain kinase (MLCK) when it binds with the Ca^{2+}-calmodulin complex, causing phosphorylation of regulatory light chains of myosin (RLC) (Rassier & MacIntosh, 2000; Sweeney, Bowman, & Stull, 1993). The result of this is theorised to be an enhancement of the sub-maximal contractile response due to an increased sensitivity of actin-myosin interaction as contractile proteins become more sensitive to Ca^{2+} (Esformes & Bampouras, 2013; Rassier & MacIntosh, 2000). Tillin and Bishop (2009) also consider a reduction in the muscle fibre pennation angle following resisted muscular contraction to be a possible contributing mechanism to the resultant improvement in muscular performance of PAP.

Post-activation potentiation has been shown to benefit explosive power of the upper and lower body in various sporting actions (Wilson *et al.,* 2013). Significant improvements in vertical jump (VJ) height, in the form of countermovement jumps (CMJs) or squat jumps (SJs), have been reported as a result of PAP following heavy resistance exercise (HRE) (Wilson *et al.,* 2013). Mitchell and Sale (2011) found that a 5RM BS increased twitch torque, a direct measure of PAP, by 10.7%, and subsequent CMJ height by 2.9%. Young, Jenner and Griffiths (1998) found that participants increased their externally loaded CMJ (5 continuous repetitions) heights by 2.8% over baseline after 4 minutes following a 5 repetition maximum (RM) set of externally loaded half squats (HS). Weber, Brown, Coburn and Zinder (2008), in a similar investigation, found that a single set of 5 back squats (BS) with 85% of 1RM increased participants' jump height by 5.8% during 7 consecutive SJs, 3 minutes post-intervention. In a study assessing the response to strength (back squat) and power (hang clean) intervention sets with rest periods of 4 or 5 minutes for each condition, individualistic overall improvements of 5.7% (2.72 ± 1.21 cm) in VJ height occurred when the optimal condition of exercise and rest interval was selected (McCann & Flanagan, 2010). Esformes and Bampouras (2013) found both the quarter squat (QS) and parallel squat (PS) to improve CMJ height by 3.5 cm and 4.6 cm, respectively, following 5 minutes of rest.

Heavy pre-loading exercises have also been shown to improve sprint speeds over distances ranging from 20-100 meters (m) (Wilson *et al.,* 2013). Matthews, Matthews, and Snook (2004) discovered that a combination of a 5RM squat and 5 minutes rest thereafter significantly improved participants' sprint speed over 20 m. Contrary to this, McBride, Nimphius, and Erikson (2005) found that 3 repetitions of a squat at 85% of 1RM and 4 minutes rest was not sufficient stimulus and/or rest time to improve running speed over 10 or 20 m, but did report significant improvements at 40 m. Similar to the work of McBride *et al.* (2005), Rahimi (2007) investigated the effects of 3 different squat intervention set (SIS) conditions; whereby participants performed 2 sets of 4 repetitions at 60, 70 and 85% of 1RM. It was found that all conditions improved sprint speed over 40 m, with the 85% condition eliciting the greatest PAP response (Rahimi, 2007). In comparison, Yetter and Moir (2008) found multiple sets of heavy BS induced significant improvements in sprint speed during 40 m trials. In this investigation, the participants sprinted significantly faster in the 10-20 and 30-40 m intervals of three 40 m sprint trials 4 minutes after performing 3 SISs consisting of: 5 repetitions at 30% of 1RM, 4 repetitions at 50% of 1RM and 3 repetitions at 70% of 1RM with 2 minutes separating each load change (Yetter & Moir, 2008). Linder *et al.* (2010) found that when participants were given a longer rest interval of 9 minutes following the performance of a single set of a 4RM HS, significantly reduced 100 m sprint times were achieved.

Not all investigations assessing the effect of heavy pre-load resistive exercises on PAP have encountered positive improvements in aspects of sporting performance; it appears that vast methodological differences between investigations may lead researchers to draw contrasting conclusions on the factors necessary to optimise potentiation (Wilson *et al.,* 2013). Hanson *et al.* (2007) saw no significant improvement to kinetic measures of the VJ in their investigation. This may have been due to the insufficient stimulus of the pre-load intervention selected (Hanson *et al.,* 2007). Participants performed each SIS at a workload of 50% of their maximum, which may have induced the onset of fatigue without causing sufficient physiological or neurological potentiation to overcome this (Hanson *et al.,* 2007). Furthermore, each SIS was performed in a smith machine, rather than using free weights. This may not have caused sufficient muscular activation when performing the SIS as electromyography (EMG) activity of the prime mover and stabiliser muscles have been recorded to be 43% lower when the squat is performed in a Smith machine, rather than with free weights (Schwanbeck, Chilibeck, & Binsted, 2009).

Insufficient physiological and neuromuscular stimulation may also explain why non-significant changes from pre- to post-intervention have occurred in investigations that have used QS or HS in their experimental protocol, such as that of Mangus *et al.* (2006). Research to support this assertion demonstrates that quadriceps and lumbar erector spinae activity peaks at approximately 90º (Escamilla *et al.,* 2001; Gorsuch *et al.,* 2013; Sousa *et al.,* 2007) and that activity of the gluteus maximus is significantly greater during the full squat when compared with squats of slighter depths (Caterisano *et al.,* 2002; Clark, Lambert, & Hunter, 2012). Furthermore, Periera *et al.* (2010) found the activity of the rectus femoris, adductor longus and gracilis to be greatest during the deepest phase of a PS, whilst Jensen and Ebben (2000) found a significantly greater activation of the hamstrings at knee angles of 120-110º and 100-90º than at 160-150º in the eccentric phase of the squat. These investigations demonstrate that greater muscle activation occurs across the posterior and anterior chains when a full squat, rather than a HS or QS is performed. Therefore, this may have been a contributing factor to the absence of a performance enhancing PAP response being achieved in the Mangus *et al.* (2006) investigation.

The work of Mangus *et al.* (2006) and Trimble and Harp (1998) has also identified another characteristic of PAP; its individualistic nature. In both of these studies, half of the cohort exhibited potentiated effects following an intervention, whilst the remainder did not, thereby illustrating the presence of responders and non-responders to this neuromuscular phenomenon. This may be a consequence of the proportions of fibre types in the muscle tissue; with a positive relationship existing between the magnitude of PAP response and percentage of type II fibres (Hamada *et al.,* 2000).

Timing of the intervention is another factor that appears to influence the degree to which PAP may benefit sporting performance. Although various studies have detected significant differences from baseline measurements following a HRE intervention with as little as 3 minutes rest, Kilduff *et al.* (2008) found that 12 minutes was the optimal recovery time to improve muscle performance following a single set of a 3RM squat, with 8 minutes also registering a significant response in CMJ height. Interestingly, 4 minutes, a common rest interval to numerous investigations, registered as a non-significant improvement over baseline (Kilduff *et al.,* 2008).

Despite the equivocal conclusions within the literature, maximal or near-maximal contractile activity can induce a PAP response that may benefit explosive movements (Hodgson, Docherty, & Robbins, 2005). Therefore, as the RHK common to numerous striking martial arts is an explosive action, it could be hypothesised that a similar pre-loading exercise to those used in the aforementioned research could elicit a beneficial response with regard to muscular performance as a result of enhanced neuromuscular activation.

A key issue of performing HRE in a pre-training or pre-competition environment is that it may not be ergonomic for certain sports. An acute increase in the neuromuscular function of an athlete during explosive actions would be most advantageous for a competition; therefore the implementation of HRE in this setting would likely require the transport of heavy equipment. This would be impractical for numerous athletes, clubs and sports. However, this issue could be omitted entirely, as it has been demonstrated that PAP can also be achieved via explosive contraction requiring no external load (Chen, Wang, Peng, Yu, & Wang, 2013). Turner, Bellhouse, Kilduff and Russell (2015) reported improvements in 10 and 20 m sprint performance 4 minutes following 30 repetitions of alternate-leg bounding using body mass and 4 and 8 minutes following using an additional external load of 10% of body mass. Linnamo, Häkkinen, and Komi (1997) reported similar EMG activity in the quadriceps during maximally- and explosively-loaded exercises (ELEs), with markedly more fatigue following the maximally-loaded condition. Hilfiker, Hübner, Lorenz, and Marti (2007) and Chen *et al.* (2013) found VJ height was significantly higher in participants who performed multiple drop jumps (DJs) 1 and 2 minutes prior to testing, respectively. Not only does this suggest that ELE can induce PAP, but unlike HRE, it may not accrue equal magnitudes of fatigue, thus serving to benefit performance by curtailing this detrimental effect (Chen *et al.,* 2013). As ELE has been shown to enhance neuromuscular performance in the explosive VJ and sprinting, the same may be achieved for the RHK.

Therefore, the purpose of this investigation was three-fold. The first objective was to determine whether a PAP response that significantly increases RHK force could be achieved via HRE in the form of a 3RM BS. Secondly, this investigation aimed to determine whether a more practical use of ELE in the form of plyometric DJs could develop a similar PAP effect. The final objective was to establish the optimal rest duration for each condition in order to provide detailed guidelines on when they should be implemented in a sport setting, if indeed, at all.

Chapter 2. Method

2.1 Participants

Nine male, competitive martial artists from 2 mixed martial arts (MMA) clubs volunteered for this investigation. Prior to participation, participants completed a Health Questionnaire (Appendix 1) and provided written, informed consent (Appendix 2). All participants possessed at least 1 year of training experience and 1 competitive performance in a full-contact, striking martial art (MMA, Muay Thai or Kick Boxing). The participants also had at least 2 years prior lower-body resistance training experience. A power analysis (G*Power 3.1.9) revealed that the minimum number of participants required to detect a significant effect would be 3 ($\alpha = 0.05$; $\gamma = 0.8$; $\delta = 0.8$), therefore a sample size of 9 was deemed a suitably statistically powerful cohort.

2.2 Design

The study utilised a repeated measures design in which participants performed 3 experimental conditions (control, HRE and ELE) consisting of maximal effort kicks taken at 6 time-points (baseline, post-2, 4, 8, 12, and 16 minutes). The latter 2 intervention based protocols were conducted in a counterbalanced, cross-over manner following the initial laboratory familiarisation and non-intervention, control protocol visit. Each testing session was separated by 3-7 days, during which each participant was requested to abstain from muscle-damaging resistive exercise to either the legs or core in the prior 48 hours, and refrain from consuming stimulants (e.g. caffeine) on the day of testing. The dependent variables were peak (F_{peak}) and average force ($F_{average}$) and peak (P_{peak}) and average power ($P_{average}$) exerted by the kicking leg. The peak value for each variable at each time-point was selected for analysis. A schematic diagram of the study design can be seen in Figure 2.1.

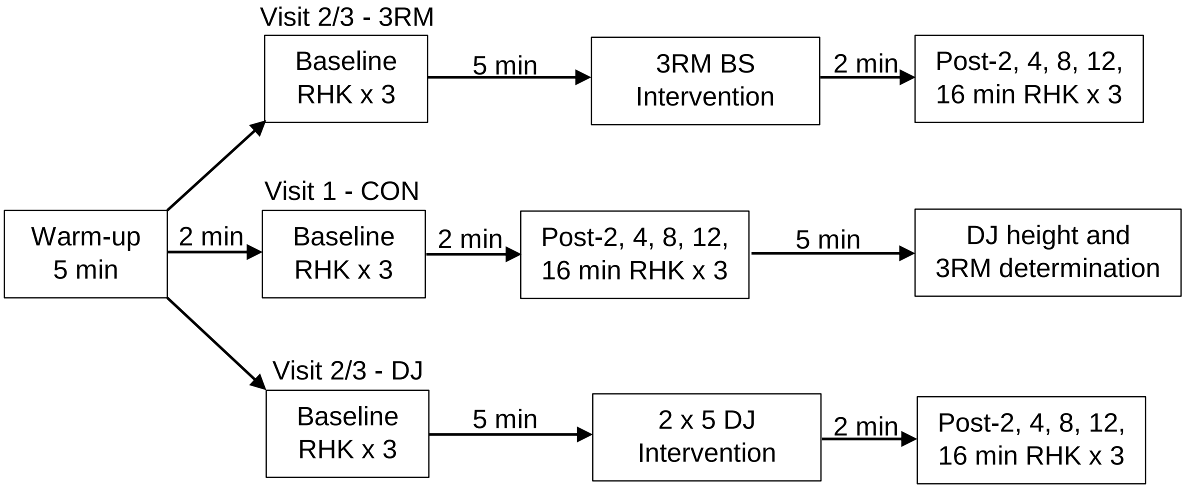

Figure 2.1. Schematic diagram of the study design for control (CON), 3RM and DJ protocols.

2.3 Procedures

Participants visited the lab on 3 occasions. Each testing session commenced with the placement of 3 motion capture markers on the feet. Two markers were attached to the forefoot and heel of the supporting leg and 1 to the heel of the kicking leg. The heel of the kicking leg was selected as the most appropriate marker location for kinetic analysis as it best replicates the path of the impact point during the RHK (i.e. the lowest-most part of the shank), without being obscured or damaged upon contact with the bag. Values for F_{peak}, $F_{average}$, P_{peak} and $P_{average}$ were estimated by post hoc calculations of the 3D motion capture data (Pro-reflex MCU cameras, Qualisys Inc., Sweden). Force (F) was estimated by multiplying the estimated segmental mass (m) of the lower leg and foot (Dempster, 1955) (i.e. the effective mass striking the bag), by the acceleration (a) of the heel marker (F = ma). Power (P) was estimated by multiplying F by the velocity (v) of the heel marker (P = Fv). Average force and power were obtained during the kicking phase; defined as the duration between the event of the lowest position of the support leg heel marker along the Z axis and the event the kicking leg impacted the bag. Two markers were also placed on the bag; 1 located at the base and another at the level of impact on the polar opposite side from the striking target (Figure 2.2.).

As it was crucial for accurate data collection that all participants aimed for the same position on the bag, a standardised target height for all participants was defined. This height was chosen to be 75 percent (%) of the leg length of the average MMA fighter, as profiled by Schick, *et al.* (2010). This value was calculated by halving the mean stature of MMA fighters (174.8 cm), to represent total leg length (Bogin and Varela-Silva, 2010), and taking 75% of this to derive a 'mid-thigh' value (65.5 cm) ($[174.8 \div 2] \times 0.75 = 65.5\ cm$). As no international reference values exist for knee height (Bogin & Varela-Silva, 2010) from which to obtain an average 'mid-thigh' value of the medial distance from knee to hip, 75% of total leg length was deemed representative.

After marker placement, during all 3 visits, the experimental protocol was explained and participants were permitted to simulate testing conditions with submaximal effort kicks until accustomed to the RHK action to be performed during the kinetic capture (Figure 2.2.). An identical warm-up, consisting of 2 minutes of skipping and a mobilisation routine, was implemented at the beginning of all testing bouts.

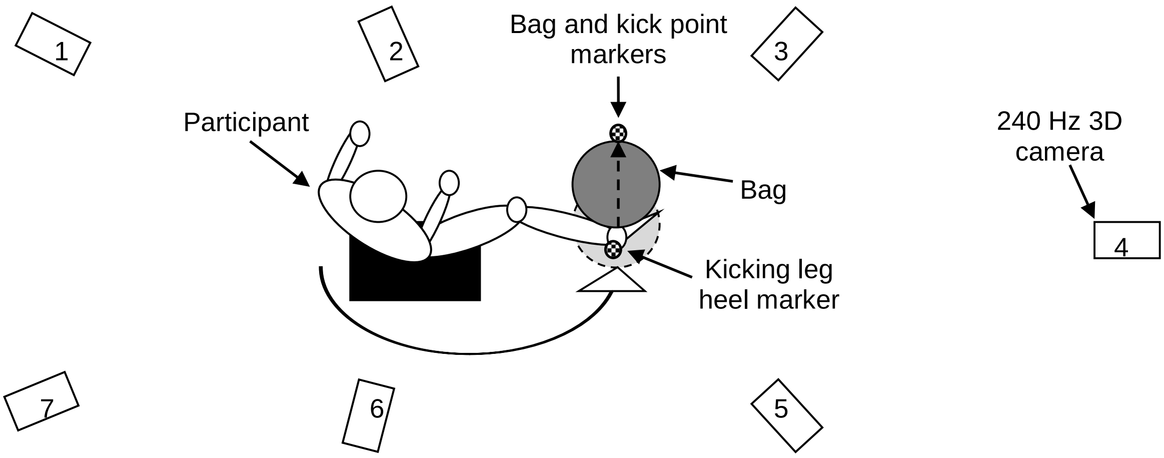

Figure 2.2. Experimental setup.

2.3.1 Visit 1 – Control protocol

After 2 minutes following the standardised warm-up, participants performed 3 maximal effort RHKs each recorded 15 seconds apart to form the baseline measurements. As the control protocol included no intervention, subsequent kicks were performed post-2, 4, 8, 12, and 16 minutes from baseline. The format of the initial session also served to determine the optimal DJ height (Chen, *et al*. 2013) (Appendix 3) and 3RM BS mass (Baechle, Earle, & Wathen, 2008, p. 396) (Appendix 4) to be used during the respective interventions on subsequent visits.

2.3.2 Visit 2/3 – Intervention protocols

The return to the lab for the second and third testing sessions were to perform the respective 3RM or DJ interventions. Following baseline RHKs, during the DJ protocol, participants rested passively for 5 minutes before performing 2 sets of 5 DJs with 15 seconds rest between repetitions and 60 seconds rest between sets. The hands were placed on the hips for each jump to counteract any contribution from an arm swing.

During the 3RM protocol, participants spent the 5 minute duration following baseline kicks preparing for the 3RM back squat. This preparation included 6 repetitions with the 20 kg bar and 6 repetitions with 50% of their 3RM mass, followed by passive rest during the remaining time until 5 minutes post-baseline. At 5 minutes, the 3RM BS was performed. During each repetition, the bar was required to tap safety bars set at a height whereby the thighs were parallel to the ground. In both intervention protocols, subsequent kicks were performed post-2, 4, 8, 12, and 16 minutes from the intervention.

2.4 Statistical Analysis

All statistical analyses were performed using IBM SPSS (SPSS Inc., Chicago, IL, USA) and Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). Descriptive statistics (mean ± SD) were used to determine the characteristics of the cohort. A Shapiro-Wilk test was conducted to analyse the normality of distribution of the dependent variables. A repeated-measure 2-way (3 conditions x 6 times) ANOVA was used to compare the differences between the 3 experimental conditions (Control, 3RM BS and 2 x 5 DJ) and times (pre-test, post-2, 4, 8, 12, and 16 minutes) for each dependent variable of the RHK. When the assumption of sphericity was not met, the Greenhouse-Geisser correction was used. If a significant effect was found, post-hoc paired *t*-tests with Bonferroni corrections were used to detect where the differences lay. Effect sizes and the associated magnitude-based inferences were calculated for the key performance variables of F_{peak}, $F_{average}$, P_{peak} and $P_{average}$ of the kicking leg heel marker in the manner described by Batterham and Hopkins (2006). The study was approved by the University of Chester, Faculty of Life Sciences Research Ethics Committee.

Chapter 3. Results

Mean and standard deviation values for descriptive variables are presented in Table 3.1. The Shapiro-Wilk test determined the experimental data were normally distributed ($p > 0.05$).

Table 3.1. Descriptive characteristics of the cohort (n = 9), presented as means (M) and standard deviations (SD).

Characteristics	Condition	M ± SD
Age (y)		22.78 ± 3.07
Stature (m)		1.77 ± 0.03
Body mass (kg)	Control	73.47 ± 8.28
	DJ	74.10 ± 8.18
	3RM	73.59 ± 8.18
Kicking leg mass (kg)	Control	13.59 ± 1.53
	DJ	13.71 ± 1.51
	3RM	13.61 ± 1.51
3RM mass (kg)		98.89 ± 10.83

3.1 Peak kicking force

A significant main effect of the experimental condition on F_{peak} was revealed, ($F = 5.7$, $p < 0.05$). Subsequent paired *t*-tests determined that F_{peak} during the DJ experimental condition was higher than the 3RM protocol at post-4 minutes from baseline, but after the Bonferroni correction, this did not reach significance ($t = 2.9$, $p > 0.0028$). No significant main effect of time ($F = 0.9$, $p > 0.05$), or condition × time interaction ($F = 1.1$, $p > 0.05$), were found for F_{peak}. Effect sizes (Table 3.2.) demonstrated unlikely and unclear effects on F_{peak} at all time-points relative to baseline in the control condition. There was a possibly positive effect on F_{peak} at post-4, 8, 12, and 16 minutes (ES = 0.17 ± 0.34, 0.18 ± 0.30, 0.13 ± 0.24, 0.18 ± 0.24, respectively) during the DJ condition.

In the 3RM condition, all F_{peak} ES values were unclear except for post-4 minutes, where a possibly negative effect occurred (ES = -0.21 ± 0.38).

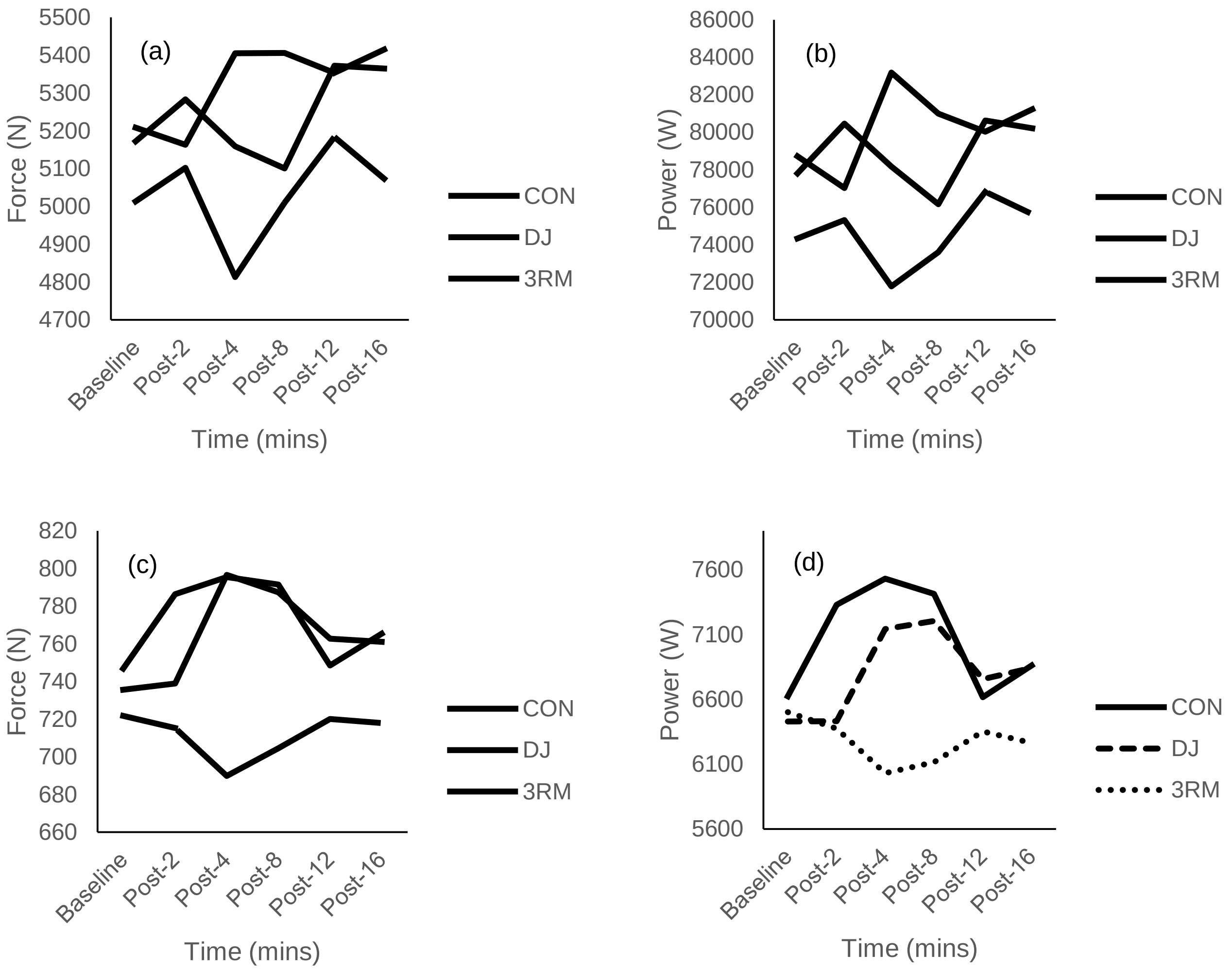

Figure 3.1. F_{peak} (a), P_{peak} (b), $F_{average}$ (c), $P_{average}$ (d) during the control (CON), DJ and 3RM experimental conditions.

Table 3.2. Standardised effect sizes and mechanistic magnitude based inferences for the dependent variables against baseline values during control, DJ and 3RM experimental conditions.

Measure	Condition	Standardised effect sizes and mechanistic magnitude based inferences				
		Post-2	Post-4	Post-8	Post-12	Post-16
F_{peak}	Control	0.07 ± 0.18 Unlikely ↑	-0.07 ± 0.25 Unlikely ↓	-0.14 ± 0.36 Unclear	0.08 ± 0.37 Unclear	0.09 ± 0.27 Unlikely ↑
	DJ	-0.04 ± 0.16 Unlikely ↓	0.17 ± 0.34 Possibly ↑	0.18 ± 0.30 Possibly ↑	0.13 ± 0.24 Possibly ↑	0.18 ± 0.24 Possibly ↑
	3RM	0.09 ± 0.38 Unclear	-0.21 ± 0.38 Possibly ↓	0.00 ± 0.35 Unclear	0.18 ± 0.39 Unclear	0.06 ± 0.41 Unclear
P_{peak}	Control	0.11 ± 0.14 Unlikely ↑	-0.04 ± 0.21 Unlikely ↓	-0.11 ± 0.29 Possibly ↓	0.04 ± 0.28 Unclear	0.02 ± 0.25 Unclear
	DJ	-0.08 ± 0.15 Unlikely ↓	0.20 ± 0.30 Possibly ↑	0.10 ± 0.31 Unclear	0.06 ± 0.21 Unlikely ↑	0.11 ± 0.23 Unlikely ↑
	3RM	0.05 ± 0.27 Unclear	-0.12 ± 0.25 Possibly ↓	-0.03 ± 0.27 Unclear	0.12 ± 0.30 Possibly ↑	0.06 ± 0.31 Unclear
$F_{average}$	Control	0.09 ± 0.23 Unlikely ↑	0.08 ± 0.47 Unclear	0.14 ± 0.31 Possibly ↑	-0.12 ± 0.43 Unclear	-0.06 ± 0.43 Unclear
	DJ	0.01 ± 0.16 Very likely trivial	0.25 ± 0.26 Possibly ↑	0.21 ± 0.37 Possibly ↑	0.11 ± 0.15 Unlikely ↑	0.10 ± 0.15 Unlikely ↑
	3RM	-0.03 ± 0.27 Unclear	-0.17 ± 0.20 Possibly ↓	-0.09 ± 0.19 Unlikely ↓	-0.01 ± 0.32 Unclear	-0.02 ± 0.33 Unclear
$P_{average}$	Control	0.13 ± 0.25 Possibly ↑	0.14 ± 0.47 Unclear	0.19 ± 0.35 Possibly ↑	-0.13 ± 0.45 Unclear	- 0.07 ± 0.42 Unclear
	DJ	0.00 ± 0.14 Very likely trivial	0.21 ± 0.25 Possibly ↑	0.23 ± 0.37 Possibly ↑	0.10 ± 0.14 Unlikely ↑	0.12 ± 0.14 Unlikely ↑
	3RM	-0.04 ± 0.25 Unclear	-0.16 ± 0.20 Possibly ↓	-0.13 ± 0.19 Possibly ↓	-0.05 ± 0.25 Unclear	-0.08 ± 0.28 Unlikely ↓

3.2 Peak kicking power

No significant main effect of the condition (*F*= 4.0, $p > 0.05$), or time ($F = 0.4$, $p > 0.05$), nor a significant condition × time interaction ($F = 1.1$, $p > 0.05$), were found for P_{peak}. Effect sizes showed a possibly negative effect at post-8 minutes from baseline for P_{peak} during the control condition (ES = -0.11 ± 0.29). A possibly positive effect was found at post-4 minutes during the DJ condition (ES = 0.20 ± 0.30). A possibly negative effect at post-4 and possibly positive effect at post-12 minutes were noted for P_{peak} during the 3RM condition (ES = -0.12 ± 0.25, 0.12 ± 0.30, respectively).

Table 3.3. Means (M), standard deviations (SD) and percentage (%) changes from baseline for F_{peak} and P_{peak}.

Condition	Time-point	F_{peak}		P_{peak}	
		M ± SD	% change	M ± SD	% change
Control					
	Baseline	5184.2 ± 923.5	-	78065.1 ± 19906.8	-
	Post-2	5254.5 ± 997.2	2.1	80410.4 ± 20561.8	3.4
	Post-4	5110 ± 1043.7	-0.3	77236.3 ± 23719.5	0.5
	Post-8	5040.2 ± 658.4	-1.4	75553.9 ± 15013.1	-2.1
	Post-12	5267.4± 1165.6	3.9	78920.3 ± 23776.4	3.6
	Post-16	5281.2 ± 859.6	3.7	78476.7 ± 19904.7	3.1
DJ					
	Baseline	5208.5 ± 1019.2	-	78721.5 ± 20373.8	-
	Post-2	5163.4 ± 991.3	-0.9	77021.5 ± 21120.8	-2.2
	Post-4	5405.4 ± 930.8	3.9	83177.4 ± 18174.2	5.7
	Post-8	5406.3 ± 834.7	3.8	80993 ± 17668.1	2.9
	Post-12	5353.2 ± 833.9	2.8	80027.6 ± 18203.2	1.7
	Post-16	5415.1 ± 892.9	4.0	81228.6 ± 18504.8	3.2
3RM					
	Baseline	5013.7 ± 861.5	-	74341.1 ± 19173.1	-
	Post-2	5102.1 ± 965.1	1.8	75311.1 ± 19794.7	1.3
	Post-4	4813.2 ± 1098.6	-4.0	71786.1 ± 20569.4	-3.4
	Post-8	5009.7 ± 1004.4	-0.1	73613.4 ± 20775.1	-1.0
	Post-12	5183.9 ± 853.6	3.4	76824 ± 17736.2	3.3
	Post-16	5073.7 ± 896	1.2	75639.2 ± 18073.5	1.8

3.3 Average kicking force

There was no significant main effect of the condition ($F = 1.2$, $p > 0.05$), or time ($F = 0.4$, $p > 0.05$), on $F_{average}$, nor was there a significant condition × time interaction ($F = 0.89$, $p > 0.05$). Effect sizes demonstrated a possibly positive effect in $F_{average}$ at post-8 minutes (ES = 0.14 ± 0.31) during the control condition. A possibly positive effect in $F_{average}$ occurred at post-4 and post-8 minutes (ES = 0.25 ± 0.26, 0.21 ± 0.37, respectively) during the DJ condition. A possibly negative effect on $F_{average}$ was found during the 3RM protocol at post-4 minutes.

Table 3.4. Means (M), standard deviations (SD) and percentage (%) changes from baseline for $F_{average}$ and $P_{average}$.

Condition	Time-point	$F_{average}$		$P_{average}$	
		M ± SD	% change	M ± SD	% change
Control					
	Baseline	751.2 ± 194.1	-	6717.9 ± 2758.1	-
	Post-2	770.9 ± 194.1	5.3	7118.7 ± 2978.9	10.7
	Post-4	768.2 ± 311.5	6.5	7151.3 ± 4446.7	13.7
	Post-8	781.7 ± 270.3	6.0	7300.6 ± 4031.3	12.0
	Post-12	725.4 ± 206.6	0.2	6313.4 ± 2958.1	-0.1
	Post-16	739.2 ± 232	2.5	6518.4 ± 3174.3	3.6
DJ					
	Baseline	735.6 ± 220.56	-	6429.4 ± 3085.6	-
	Post-2	738.9 ± 215.2	0.5	6431 ± 3179.5	0
	Post-4	796.7 ± 211.6	8.3	7141.8 ± 3101.3	11.1
	Post-8	787.3 ± 289.2	7.0	7205.3 ± 4314.5	12.1
	Post-12	762.8 ± 235.1	3.7	6756.5 ± 3359.7	5.1
	Post-16	761 ± 213.7	3.5	6841.6 ± 3215.6	6.4
3RM					
	Baseline	721.7 ± 174.2	-	6501.7 ± 2667.8	-
	Post-2	715.2 ± 225.9	-0.9	6373.6 ± 3367.9	-2.0
	Post-4	689.8 ± 187.5	-4.4	6031 ± 2755	-7.2
	Post-8	704.6 ± 190.1	-2.4	6113.9 ± 2800.4	-6.0
	Post-12	720.1 ± 216.1	-0.2	6353 ± 3292.7	-2.3
	Post-16	718 ± 199.2	-0.5	6263.8 ± 3092.3	-3.7

3.4 Average kicking power

There was no significant main effect of the condition (*F* = 0.8, *p* > 0.05), or time (*F* = 0.6, *p* > 0.05), on $P_{average}$. There was no significant condition × time interaction (*F* = 1.1, *p* > 0.05). Effect sizes revealed possibly positive effects on $P_{average}$ at post-2 and 8 minutes (ES = 0.13 ± 0.25, 0.19 ± 0.35, respectively) during the control condition. Possibly positive effects during the DJ condition were noted at post-4 and 8 minutes (ES = 0.21 ± 0.25, 0.23 ± 0.37, respectively). Conversely, post-4 and 8 minute values for $P_{average}$, during the 3RM condition, were possibly negative (ES = -0.16 ± 0.20, -0.13 ± 0.19).

Chapter 4. Discussion

The results of this investigation suggest that neither a HRE nor ELE intervention is able to induce a significant PAP response to increase peak and average RHK force and power. No significant improvements over baseline in any of the key dependent variables were found in all 3 conditions at all time-points.

To the author's knowledge, the present investigation was the first to examine whether RHK kicking force and power could be augmented as a result of HRE or ELE preload stimuli. Several previous studies have demonstrated that HRE in the form of a multiple RM squat can improve performance variables associated with certain lower body explosive movement patterns such as CMJs and sprinting (McBride *et al.,* 2005; Mitchell & Sale, 2011; Weber *et al.,* 2008). However, the results of this study show the 3RM intervention to have had the least beneficial effect on performance (Figure 3.1.). A similar lack of a beneficial effect on CMJ performance was found by Hanson *et al.* (2007) who used a Smith machine BS with 50% of maximum, and Magnus *et al.* (2006) who used QS and HS interventions. The key difference in this investigation is that a free-weight PS was used in order to ensure optimal recruitment of the active and stabilising musculature during the squat (Caterisano *et al.,* 2002; Clark *et al.*, 2012; Escamilla *et al.,* 2001; Gorsuch *et al.,* 2013; Jensen & Ebben, 2000; Periera *et al.,* 2010; Schwanbeck *et al.,* 2009; Sousa *et al.,* 2007). Yet, using a greater range of motion in the squat did not have an effect on RHK force or power.

The lack of a significant improvement in RHK performance variables may be due to the insufficient similarity between movement patterns during the BS exercise and a maximal effort RHK (Hanson *et al.,* 2007). Whereas other investigations have effectively utilised the BS exercise to improve CMJ or sprint performance, which are unidirectional, ballistic, stretch-shortening cycle (SSC) actions, perhaps the kinetics of the dynamic, transverse action of the RHK cannot be positively influenced by inducing a neurologically potentiated state in the agonistic muscles active during the BS (Mitchell & Sale, 2011). Furthermore, the success of some investigations in achieving a PAP effect in the CMJ as a result of a BS intervention may illustrate the similarity between these two movement patterns, and by extension the dissimilarity between the DJ and RHK. McGill, Chaimberg, Frost and Fenwick (2010) discovered a large degree of muscle activation in the upper and lower erector spinae, rectus abdominis, internal oblique and latissimus dorsi during the RHK, which may not receive sufficient activation to develop neural potentiation during BS or CMJ interventions. The role of the trunk muscles, potentially unstimulated by each intervention of the present investigation, may partially explain the inability for the 3RM or DJ protocol to significantly enhance kinetic measures of the RHK in this investigation.

Although there were no significant differences in the dependent variables between baseline and all other time-points, and between each respective intervention condition and control, Figure 3.1. demonstrates a consistent increase above baseline in the DJ condition at post-4 minutes that plateaus until post-16 minutes for F_{peak} and post-8 minutes for $F_{average}$ and $P_{average}$. Magnitude based inferences reveal a possibly positive effect in all of these cases (Table 3.2.). Both the control and DJ conditions appear to follow a similar response for $F_{average}$ and $P_{average}$ from post-4 minutes to post-16 minutes, with both conditions eliciting a possibly positive effect on average measures that peak at post-8 minutes from baseline or intervention, respectively. Despite a percentage mean change from baseline of greater than 10% occurring at some time-points (Table 3.4.), the vast standard deviation in all cases creates a large pooled variance that reduces the effect size and broadens the confidence limits. Much of the literature on PAP has reported performance improvements in ballistic measures from 2 to 5% (Maloney, Turner & Fletcher, 2014). However, due to the highly individualised responses of each participant in the present investigation, the percentage changes found in force and power (Table 3.3. and 3.4.) are unlikely to have occurred as a result of a PAP response due to a HRE or ELE intervention. It may be the case, as suggested by Mangus *et al.* (2006) and Trimble and Harp (1998), that there are responders and non-responders to PAP, and that we are yet to identify the variables that define the specificity of this phenomenon.

One variable that has been put forward as potential determining factor of PAP is strength. Seitz, Villarreal and Haff (2014) found that stronger individuals (relative 1RM BS ≥ 2 × body mass) expressed an earlier and more pronounced PAP response than their weaker counterparts (relative 1RM BS < 2 × body mass). The cohort in this investigation had a relative 1RM BS of 1.45 × body mass (Baechle *et al.,* 2008, p. 394), thus possibly expressing a similarly suppressed PAP response when compared with individuals able to squat ≥ 2 × body mass (Seitz *et al.,* 2014). It is likely that, as participants were working close to maximal effort in the present study (~93% 1RM, Baechle *et al.,* 2008, p. 394), fatigue did indeed accumulate, but due to low relative strength levels, and possibly a lower proportion of type II muscle fibres, a sufficient magnitude of PAP was not achieved to overcome this (Hamada *et al.,* 2000). This could suggest the existence of a strength threshold necessary to illicit a significant neural potentiated state from both HRE and ELE and concurrently illustrating a limitation of this investigation in acquiring stronger participants.

The present study did not establish a performance improvement indicative of a PAP response as a result of HRE or ELE, however, like many other investigations in the field of neural potentiation, neither did it contain a direct measure of PAP (Pearson and Hussain, 2013). Mitchell and Sale (2011) utilised twitch torque, a direct measure of neural potentiation, to determine that a 5RM squat intervention did indeed induce PAP associated with an enhancement of explosive jump performance. However, using an isometric conditioning contraction, Pearson and Hussain (2013), revealed an increase in twitch torque with an accompanied plateau or decrement in jump height and power. It must be noted that these values did not reach significance, but the lack of association between twitch torque and jump performance may suggest other studies without a direct measure of PAP may be observing other phenomena that cause performance improvements during explosive actions (Maloney *et al.*, 2014; Person and Hussain, 2013).

Maloney *et al.* (2014), propose that an increase in lower limb stiffness, as indicated to improve SSC abilities, and shown to follow HRE, could be an accompanying mechanism that augments post-intervention measures of explosive actions. This is a vital consideration when assessing the influence an intended neural potentiation intervention protocol, which may concurrently induce stiffness, has on RHK force and power. McGill *et al.* (2010) discovered the occurrence of a “double peak” in muscle activity during the RHK while assessing the paradoxical nature of muscular contraction and joint velocity in an open kinetic chain action. During each kick, the muscles underwent a pulse of activation. Contraction occurred to initiate movement, applying force and inducing stiffness. This was followed by a rapid relaxation phase during flight to enhance limb acceleration. Immediately before contact, a second contraction was initiated, to reinstate stiffness and increase the effective mass, to transfer maximal force upon impact (McGill *et al.,* 2010). Perhaps the rate of muscle relaxation, allowing greater joint acceleration during the flight phase of a RHK, is a significant factor in determining kicking force and power. It may be that the intentional or otherwise inducement of neural potentiation or stiffness hinders, or has no effect on, this feature of RHK force and power application. Future investigations in the field of PAP should incorporate direct measures of neural potentiation along with performance indicators (Mitchell & Sale, 2011; Pearson & Hussain, 2013) in order to determine the degree to which explosive actions are augmented via PAP or other mechanisms (Maloney *et al.,* 2014).

There is a paucity of kinetic data on the RHK, and the investigations incorporating estimations of force obtain these values from differing methodologies. The F_{peak} values (5182.53 ± 935 N) obtained via 3D motion capture of acceleration data and estimated leg mass recorded in the present investigation differ considerably from the values obtained by Falco *et al.* (2009) (1477.90 ± 674.31 N), Estevan, Falco, Álvarez and Molina-García (2012) (1237.47 ± 367.99 N) and Chiu *et al.* (2007) (8252 ± 720 N) via impact upon a force plate or air bag. However, the values are more comparative with those obtained by Sidthilaw (1996) (knee: 6702 ± 3514, and hip: 7204 ± 3477 N) and O'Sullivan *et al.* (2009) (Taekwando: 6400 ± 898, and Youngmudo: 6393 ± 1382 N) via tri-axial accelerometry. This suggests that, due to 3D analysis not adding to the degree of disparity between previously implemented kinetic measurement techniques, it could be an approach utilised in future investigations. However, the lack of information pertaining to the reliability and validity of this method is a limitation of this investigation. Therefore, forthcoming research should assess the reliability of this method in acquiring these data before this can be assured.

The findings of this study suggest that increasing RHK force and power via PAP cannot be achieved with a 3RM BS or DJ intervention. It may be that these interventions lack the relevant movement specificity to potentiate the force generating muscles during the RHK, or that other mechanisms are, at least somewhat, responsible for the production of force and power of this dynamic action. Therefore, competitive athletes would unlikely benefit from implementing a pre-competition PAP protocol to increase RHK force and power.

Chapter 5. References

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