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USING THE SPLIT SQUAT TO POTENTIATE BILATERAL AND UNILATERAL JUMP PERFORMANCE

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ABSTRACT

The purpose of this study was to examine if a split squat conditioning exercise with no or light loads could potentiate unilateral and bilateral jump performance. Twelve semi-professional rugby players (age: 22.3 ± 1.4 years; height: 1.84 ± 0.05 m, mass: 92.4 ± 9.6 kg) from the English National League 1 performed a series of unilateral and bilateral countermovement jumps (CMJ) and broad jumps (BJ) over the course of two testing days. Both testing days involved performing baseline jumps before completing two sets of ten repetitions of a split squat, this completed with either bodyweight (testing session 1) or a 30kg weighted vest (testing session 2). A five-minute recovery period was permitted both following the warm up and following the completion of the split squat exercise. Significantly larger bilateral jump scores were reported following completion of the bodyweight split squat: CMJ (p = 0.001, ES = 0.44, [mean difference 2.517]), BJ (p = 0.001, ES = 0.37, [mean difference 3.817]), and the weighted vest split squat; CMJ (p = 0.001, ES = 0.8, [mean difference 4.383]), BJ (p = 0.001, ES = 0.68, [mean difference 6.817]). The findings of this study demonstrate that no or light loads of a split squat conditioning exercise are able to potentiate bilateral jump performance in semi-professional rugby players without the need for expensive weight room equipment. As such, this may provide coaches with a viable option of enhancing bilateral jump performance as part of a warm up or on-field conditioning practice.

Key Words: Post-activation potentiation, countermovement jump, broad jump, split squat

INTRODUCTION

Power is an essential fitness component across many individual and team sports and can be the difference between successful and unsuccessful moments in match scenarios (7, 8). Although possessing a high level of power does not guarantee crossover to sporting success, greater power outputs have been able to distinguish between different levels of playing ability (2, 19). A common method of increasing power is through the use of post-activation potentiation (PAP) whereby muscular performance can be enhanced by its contractile history in the form of a conditioning exercise (CE) (27, 33). Such examples include performing squats prior to a countermovement jump (CMJ) (30, 33, 35) or resisted sprint methods (36) prior to sprint training. It is thought that at a physiological level, the two mechanisms suggested to create PAP are the phosphorylation of myosin regulatory light chains (1), which subsequently increase myofibrillar sensitivity to calcium secretion from the sarcoplasmic reticulum, and recruitment of higher order motor units (24). Essentially, this may enhance an athlete's capacity for increased force production enabling a subsequent increase in performance for a given task.

Much research has been conducted on PAP in recent years, with multiple factors such as exercise selection (9, 30), strength level (29), training age (34, 37), intensity and volume of the CE (6, 11, 12, 31, 35) and rest periods (15, 16) all examined to derive the most practical solution for enhancing performance in strength and conditioning (S&C) practice. A common theme throughout the literature has been to focus on using traditional bilateral exercises as the CE. Such examples include power cleans (30), back squats (29, 35, 38), and isometric squats/pulls (4, 18, 23). However, at the sub-elite level, numerous potential barriers exist which may hinder an athlete's ability to express enhanced performance such as optimal technique and mobility. In addition, finance could even be considered a logistical constraint. For example, not all clubs, players, and coaches will have access to weightlifting platforms and expensive power racks. With this in mind, it would be prudent to identify alternative methods of enhancing muscular performance for the sub-elite athlete without the requirement for expensive weight room equipment or extensive external loads. While this has been discovered in ballistic movements such as CMJ's (10, 11), and drop jumps (13), this still may be available from more traditional strength training exercises.

As such, there would appear to be a distinct lack of research on the effects of less commonly-used CE's on eliciting PAP. The split squat exercise is typically associated with reduced loads when compared to bilateral equivalents (33), and due to its split-stance positioning, the necessity to rely on such expensive equipment to elicit adaptation could be argued to be less, in principle. Thus far, studies which have used less intense CE's have generated conflicting results. In studies performed by Smilios et al. (31) and Sotiropoulos et al. (32), light (25-35% 1RM and 30-60% 1RM respectively) intensities have shown to improve CMJ height and mechanical power after using jump squats and half squats as the CE. In contrast, Comyns et al. (6) observed no changes in jump height when using 30-65% 1RM back squats. As previously mentioned, the common denominator for these studies was the use of a bilateral CE in the methodology and as such, any conclusions to be drawn from this pool of PAP studies cannot be assumed if a split-stance CE was to be used.

Therefore, the primary aim of this study is to determine whether the split squat can potentiate bilateral and unilateral jump performance in semi-professional rugby players. A secondary aim is to decipher if there is a difference between bodyweight and light resistance conditions (using a weighted vest) in the split squat, assuming a potentiation effect occurs. If a significant difference in jump performance was noted, as hypothesised, this would enable a practically viable means of eliciting PAP during on field warm-ups or conditioning practice.

METHODOLOGY

Experimental Approach to the Problem

This study was designed to determine whether no and light loads of the split squat exercise could be used to potentiate bilateral and unilateral jump performance in semi-professional rugby union players. This investigation was warranted given the lack of literature surrounding the use of split-stance strength exercises for PAP. For the dependent variables; the CMJ, dominant and non-dominant limb single leg countermovement jump (SLCMJ), broad jump (BJ), and dominant and non-dominant limb single leg broad jump(SLBJ) were measured at both time points (pre and post). These specific variables were chosen for their simple and reliable field-based methods of assessing lower body performance. Load (bodyweight or 30kg weighted vest) on the split squat were chosen due to their relative ease by which subjects would be able to perform the task (both technically and irrespective of mobility issues). Furthermore, given its split-stance positioning, unloaded or wearing a 30kg weighted vest still represented a high relative intensity.

Subjects

Twelve semi-professional rugby players (age: 22.3 ± 1.4 years; height: 1.84 ± 0.05 m, mass: 92.4 ± 9.6 kg) playing in the English National League 1 took part in this study. All athletes had at least three years resistance training experience and were experienced with both the bilateral and unilateral CMJ and BJ from club training sessions, thus negating any requirements for familiarisation. The athletes were asked to refrain from any exercise and to avoid consuming any alcohol and/or caffeine 24 hours prior to the testing. In addition, players were advised to abstain from eating anything within two hours prior to each testing session in order to standardise procedures across the squad. The study was approved by the London Sports Institute Ethics Committee at Middlesex University, London, UK.

Procedures

Testing occurred over two days, separated by 48 hours between sessions. All players undertook a standardised warm up consisting of a 4-minute slow jog and 3 x 20m shuttle runs, followed by a variety of dynamic stretches that aimed to mobilise key lower body joints such as the ankles and hips. Such exercises included multi-planar lunges, inchworms and glute bridges. Subjects then performed two baseline jumps of each variation (bilateral and unilateral CMJ and BJ), these interspersed by 30 seconds of recovery and a 3-minute rest period between CMJ and BJ variations. Subjects were encouraged to jump "as explosively as possible" for each attempt. Following 5-minutes of rest, subjects completed the split squat intervention (session 1: bodyweight; session 2: 30kg weighted vest). After an additional 5-minute rest period, post-testing jumps were completed, these conducted in the same order and process as baseline testing (17). The best jump scores acquired from each jumping variation were used for subsequent data analysis.

Countermovement Jumps. Subjects were instructed to dip to a self-selected depth before jumping vertically as explosively as possible with hands fixed on their hips at all times to standardise procedures. Jump height was determined using the iPhone app 'My Jump' which has recently been shown to be a reliable method for measuring this variable (3). Subjects were asked to perform both trials bilaterally first, followed by alternating unilateral trials.

Broad Jumps. Subjects were instructed to dip to a self-selected depth before jumping forward as explosively as possible with hands fixed on their hips at all times to standardise procedures. All jumps were performed alongside a tape measure fixed to the floor. Jump distance was determined by measuring the rear-most point of the heel closest to the start line and was measured to the nearest millimetre. Subjects were asked to perform both trials bilaterally first, followed by alternating unilateral trials.

Split Squat. Two different conditions of the split squat were utilised in the testing days. Testing day one consisted of players performing two sets of 10 repetitions (on each leg) of the bodyweight split squat (see Figures 1 and 2), with a rest period of 1-minute between sets. One complete set included both legs performing the split squat exercise. Subjects were instructed to control the descent on each leg so as to prevent the rear knee from "banging" on the floor, whilst the ascent was encouraged to be performed as explosively as possible. Depth was determined as sufficient when the femur achieved parallel with the ground. Testing day two followed the same procedures; however, a 30kg weight vest was worn.

INSERT FIGURES 1 AND 2 ABOUT HERE

<u>*Statistical Analysis*</u>

Data was analyzed for normality using the Shapiro-Wilk test. To assess for reliability within conditions at baseline, coefficient of variation (CV) was used. To assess for reliability between conditions at baseline, intraclass correlation coefficient (ICC) was used. To examine for changes in jumping performance, a 2 x 2 repeated measures ANOVA (condition: bodyweight and 30 kg, time: pre and post) was conducted for each dependent variable, with Bonferroni post hoc statistical analysis used to determine, where required, significance between time points within conditions, and between conditions within time points. Statistical significance was set at $p < 0.05$. Further data analysis included calculating the smallest worthwhile change (SWC), which was determined by multiplying 0.2 by the pooled standard deviations of pre and post-test measurements (14), and the standard error of measurement (SEM). In addition, Cohen's d effect sizes (ES) were calculated for magnitude of change in jump performance by subtracting the pre-test mean from the post-test mean and dividing by the standard deviation. Classification of ES are reported in line with suggestions by Rhea (25), (trivial = <0.25, small = 0.25-0.50, moderate = 0.5-1.0 and large = >1.0).

RESULTS

All baseline data was normally distributed ($p > 0.05$). Table 1 provides a summary of reliability and percentage change data analysis. All ICC's demonstrated high levels of rank order consistency (ICC = 0.992-0.997) and the CV calculations were < 10% for all jumps across both split squat conditions. Tables 2 and 3 show the mean pre and post results for all CMJ and BJ variables across both split squat conditions.

CMJ. ANOVA identified a significant interaction effect of condition and time [$F_{(1,22)} = 8.553$, $p = 0.008$, ES = 0.28]. Bonferroni post hoc analysis identified significance between time points for both the bodyweight condition ($p = 0.001$, ES = 0.44 [mean difference 2.517]), and the weighted vest condition ($p = 0.001$, ES = 0.8 [mean difference 4.383]).

SLCMJ. ANOVA identified no significant interaction effect of condition and time for either the dominant limb [$F_{(1,22)} = 2.984$, $p = 0.098$, ES = 0.119] or the non-dominant limb [$F_{(1,22)} = 1.102$, $p = 0.305$, ES = 0.048].

BJ. ANOVA identified a significant interaction effect of condition and time [$F_{(1.22)} = 10.828$, $p = 0.003$, ES = 0.33]. Bonferroni post hoc analysis identified significance between time points for both the bodyweight condition ($p = 0.001$, ES = 0.37 [mean difference 3.817]), and the weighted vest condition ($p = 0.001$, ES = 0.68 [mean difference 6.817]).

SLBJ. ANOVA identified no significant interaction effect of condition and time for either the dominant limb [$F_{(1.22)} = 2.046$, $p = 0.167$, ES = 0.085] or the non-dominant limb [$F_{(1.22)} = 0.462$, $p = 0.504$, ES = 0.021].

INSERT TABLES 1-3 ABOUT HERE

DISCUSSION

The present study observed the effect of a body weight and weighted split squat (30kg weighted vest) on bilateral and unilateral CMJ and BJ performance. Results revealed that the bodyweight split squat was able to enhance both bilateral and unilateral jump performance, although the bilateral variations were the only two noted as statistically significant. Similarly, for the weighted split squat condition significant improvements were seen in bilateral jumps, with non-significant improvements identified within unilateral jump tests.

The notion that a bodyweight CE can potentiate muscular performance would appear to bring about conflicting results. The findings from the present study that a bodyweight split squat is able to elicit a significant effect on bilateral jump performance are in contrast to Esformes et al., (9), who used a variety of bodyweight plyometric jumps in an attempt to potentiate the CMJ and found no difference compared to a control group. Although the type of CE was different, the rest interval (5 minutes) and load stimulus (bodyweight) was comparable with the current study. However, Masamoto et al., (20) also used bodyweight plyometric exercises in PAP research and noted a significant improvement in maximal lower body strength. To the author's knowledge, this is the first study that has looked at using a split-stance bodyweight compound exercise in an attempt to acutely enhance jump performance. With this in mind, direct comparisons with existing research are not possible.

In contrast, Healy and Harrison, (12) used an isometric unilateral glute activation protocol in an attempt to potentiate single leg drop jump performance and found no significant improvements. It may have been that there was limited capacity for potentiation from a unilateral isometric protocol, whereas the present study used a compound exercise conducted within an isotonic nature. Wilson et al. (37) found that if the CE is not biomechanically similar to the jump involved, then it is less likely to have a potentiating effect. This is in conjunction with the findings of numerous other studies which have found improvements in jump performance when using comparable movement patterns, such as half squats (5, 10, 26). The nature of using a multi-joint, split-stance movement pattern would have stimulated multiple muscle groups such as the glute complex, hamstrings and quadriceps (22), thus activating the relevant musculature used throughout jumping exercises, highlighting task-specificity.

For the weighted split squat condition, the findings of this study identify that a light load was sufficient enough to potentiate bilateral jump performance, although only non-significant mean improvements were identified for unilateral jumps. The bulk of research investigating the effects of PAP on jump performance would appear to support the use of high loads, due to increased central nervous system stimulation and motor unit recruitment (5, 26). However, the popularity of research surrounding PAP has resulted in researchers investigating the effects of light loads on performance outcomes, given their practicality for applied practitioners (31, 32). More specifically, Sotiropoulos et al. (32) used loads of 25-35% of subjects' 1RM back squat and witnessed a 3.95% increase in jump height. Furthermore, the nature of the CE was biomechanically similar to the jump, thus the notion of specificity was kept within the methodology. The same could be argued for the present study, whereby the CE was still a squat pattern – simply performed in a staggered stance, thus shifting the focus to that of a unilateral nature, with similar mean improvements identified within the present study (> 4%). Therefore, it is apparent that the use of heavy loads is not the only way to obtain potentiation, given how similar relative loads are acknowledged as much greater when performed within unilateral movement patterns.

Interestingly, the present study identified significant increases in bilateral jump performance, with non-significant mean increases in unilateral jump performance; this similar between conditions. Understanding why lack of significant differences were noted for the unilateral jump tests may be partially explained by the variation seen in unilateral CMJ performance elsewhere in the literature (21). For example, Maulder and Cronin, (21) revealed a much wider disparity between limbs for the SLCMJ compared to the SLBJ, potentially indicating that the SLCMJ is a more complex movement pattern to perform. This may bring to light a greater element of task complexity for unilateral jump tests, this aiding in drawing conclusions to the lack of significance found. Although, mean increases of between 3-5% were identified following the completion of the bodyweight split squat for unilateral jump tests, with 7-13% mean improvements found following the 30kg weighted split squat. However, it should be noted that whilst all post-intervention jumps occurred in the same order for each testing session, there was a time-disparity between when the CMJ and BJ were tested. Consequently, it is feasible that subjects were still "fatigued" at the time of CMJ testing, negating any potentiation effect. This falls in line with reviews by Wilson et al. (37) and Seitz and Haff (28), who both identified a window of opportunity between 7-10 minutes following a CE whereby performance was enhanced. Given the rest periods permitted between jumps within the present study, this may have direct implications on recovery and any potentiation experienced. Therefore, these results illustrate that whilst task-specific and hindered by training experience relative to the task performed, the use of no or light loads on a split-stance CE can enhance both bilateral and unilateral jump performance. However, task complexity may have hindered any significant unilateral enhancements in jump performance, and thus training state should be a consideration for practitioners should these methods wish to be replicated.

Whilst the authors controlled and standardised key variables, specific limitations did arise, for example loading of the weighted vest. Within the present study a standardised load of 30kg was used, thus providing a varied training stimulus to each athlete relative to their strength levels (37). This in turn meant that the load was not relative to the individual, by virtue of either a percentage of each subject's 1RM for the chosen exercise, or through comparable measures to bodyweight. However, the key purpose of the present study was to identify whether no or light loads could offer an alternative method for enhancing lower body jump performance without the use of typical weight room equipment, thus the application of this study can still be considered across the applied S&C field given its minimalistic approach to equipment and space required. Furthermore, the use of a rear foot-elevated split squat could also aid as a practical alternative for harnessing PAP, given how a raised back foot would have increased the intensity without the added requirement of more load (thus increasing practicality). Finally, the warm up was of a relatively low intensity and the findings do make the assumption that there was no further increase in muscle temperature, thus potentiation occurred as a result of the selected methods. It could be argued however, that the warm up was standardised, and as such, it is essential that coaches ensure their athletes are thoroughly warmed up prior to attempting any of the aforementioned methods, thus increasing the likelihood that any improvements are a true representation of PAP.

PRACTICAL APPLICATIONS

This study has demonstrated that the split squat, when completed both as a bodyweight exercise and when loaded with a 30kg weighted vest, is an effective exercise when aiming to enhance bilateral jump performance within both vertically and horizontally orientated jump tasks. The findings demonstrate viable methods of implementing PAP as part of an on-field warm up or training protocol, highlighting its efficacy for sub-elite rugby athletes. Consequently, practitioners could use the methods employed within the present study in numerous ways to enhance their practice, for example through providing time and cost efficient alternative methods for potentiation through bodyweight and lighter loads, thus negating the requirement for expensive gym equipment (Olympic weightlifting platforms or squat racks). Future research should look to standardise the timings of post-testing jumps, with an additional element of individualisation of loading relative to each and every athlete (1RM or relative to BW), as this may bring to light optimal loads on an individual level which may lead to further significant enhancements to jump performance.

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Table 1: Data analysis for all variables under both the bodyweight and 30kg split squat conditions

Variable	ICC	CV (%)	SWC	SEM (cm)	% Change (pre-post)
CMJ (BW)	0.992	5.3	1.06	1.61	7.39
CMJ (30)		9.04	1.81	1.60	12.82
SLCMJ (BW – D)	0.993	4.24	0.85	0.88	4.07
SLCMJ (30 – D)		6.44	1.29	0.78	14.42
SLCMJ (BW – ND)	0.994	3.16	0.63	0.96	4.50
SLCMJ (30 – ND)		6.12	1.22	0.90	7.72
BJ (BW)	0.996	3.74	0.75	7.55	5.13
BJ (30)		6.39	1.27	7.07	9.16
SLBJ (BW – D)	0.997	4.04	0.81	7.71	5.00
SLBJ (30 – D)		5.73	1.01	8.34	8.62
SLBJ (BW – ND)	0.995	4.85	0.97	7.81	6.91
SLBJ (30 – ND)		6.07	1.16	7.32	8.21

CMJ = Countermovement jump; SLCMJ = Single leg countermovement jump; BJ = Broad jump; SLBJ = Single leg broad jump; BW = Bodyweight; D = Dominant; ND = Non-dominant

ICC = Intraclass correlation coefficient; CV = Coefficient of Variation; SWC = Smallest worthwhile change; SEM = Standard error of the mean

Table 2: Pre and post-intervention CMJ scores for the bodyweight and 30kg split squat conditions.

	CMJ (SD)		D SLCMJ (SD)		ND SLCMJ (SD)	
	Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*
Split Squat (BW)	34.08 (5.89)	36.6* (5.57)	14.74 (2.48)	15.34 (3.06)	14.45 (2.86)	15.1 (3.32)
Split Squat (30Kg)	34.16 (5.38)	38.54* (5.55)	14.63 (2.33)	16.74 (2.70)	14.63 (2.88)	15.76 (3.13)

* Denotes statistically significant from equivalent baseline measurement ($p < 0.01$)

CMJ = Countermovement jump; SLCMJ = Single leg countermovement jump; BW = Bodyweight; D = Dominant; ND = Non-dominant; SD = Standard deviation

N.B: All scores are reported in centimetres

Table 3: Pre and post-intervention BJ scores for the bodyweight and 30kg split squat conditions.

	BJ (SD)		D SLBJ (SD)		ND SLBJ (SD)	
	Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*
Split Squat (BW)	189.13 (26.56)	198.83* (26.17)	142.76 (25.39)	149.90 (26.69)	140.38 (26.49)	144.98 (27.07)
Split Squat (30Kg)	188.95 (26.09)	206.26* (24.49)	141.22 (25.31)	153.39 (28.89)	140.15 (27.08)	151.66 (25.36)

* Denotes statistically significant from equivalent baseline measurement ($p < 0.01$)

BJ = Broad jump; SLBJ = Single leg broad jump; BW = Bodyweight; D = Dominant; ND = Non-dominant; SD = Standard deviation

N.B: All scores are reported in centimetres

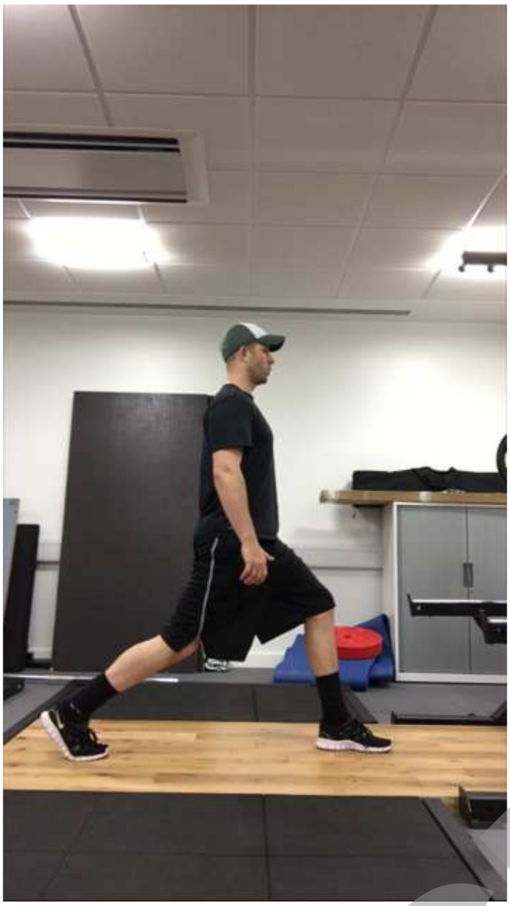

Figure 1: Start position of the split squat exercise

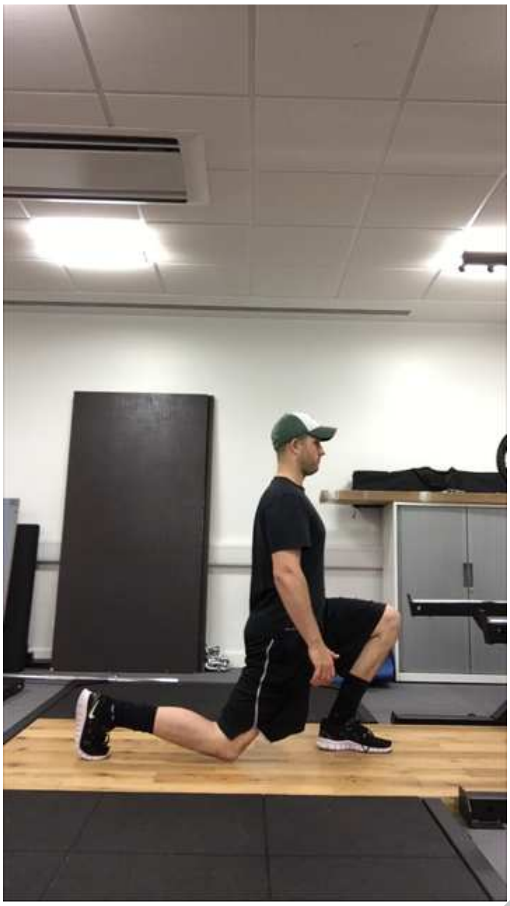

Figure 2: Bottom position of the split squat exercise