Lunging exercise potentiates a transient improvement in neuromuscular performance in young adults

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Published

2015

Journal Title

Journal of Strength and Conditioning Research

Version

Accepted Manuscript (AM)

DOI

10.1519/JSC.0000000000000913

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ABSTRACT

High-load resistance-based exercise is a common approach to facilitating improved neuromuscular performance via post-activation potentiation. Popular field-based warm-up activities, however, have been largely overlooked despite their specificity and practicality for sports performance. Therefore, the aim of this study was to investigate the effect of repeated bouts of alternating lunges on neuromuscular performance determined by a maximal vertical jump. Forty-three healthy young adults (24 women and 19 men: age 25.6 ± 4.4 years) participated in the study. Maximal vertical jump (VJ) performance was quantified by jump height (cm), relative impulse (N·s/kg), flight time (s) and normalized peak vertical ground reaction force (GRFz, BW) at baseline and following each of six sets of 20 alternate split lunges. A rating of perceived exertion (1-10 scale) was recorded from participants prior to each VJ. Jump height was greater than baseline for the first four trials (3.1-3.8%, $p < 0.05$), but no different to baseline on subsequent trials. Although there were no improvements for relative impulse over repeated trials, the sixth trial was significantly smaller than baseline (2.35 ± 0.38 vs. 2.26 ± 0.35 N·s/kg, $p \leq 0.001$). Similarly, no improvements were observed for flight time, although the first, fourth, fifth and sixth trials were reduced compared to baseline performance ($p \leq 0.01$). No differences were observed for peak vertical GRF ($p > 0.05$). In conclusion, a regime of lunging exercise resulted in a transient improvement in maximal vertical jump performance. Measures of flight time, impulse, and GRFz, however, did not mirror the performance gain in jump height.

Key words: countermovement; exercise; muscle power; vertical jump.

INTRODUCTION

Neuromuscular performance involves the complex interaction of local muscle factors and neurophysiological function. In particular, the performance characteristics of a muscle are affected by its contractile history and neural excitability. Voluntary muscle contractions performed prior to physical performance measures have been shown to increase performance in a phenomenon known as post-activation potentiation (PAP) [28]. Consequently, PAP may have important implications for pre-event conditioning and warm-up regimes across a range of sports, particularly for those requiring fast or powerful manoeuvres. It is possible however, that performance benefits may be garnered through participation in relatively simple activities if applied at optimal exercise dosages, and thus, such characteristics should be investigated.

A variety of exercises have successfully elicited PAP in upper and lower body tasks, including knee extensions [3], bench press [2, 19], and numerous squat variations [1, 4, 11, 18, 24-27, 32, 33]. Historically, high load squats (>80% 1RM) are the most common exercise for PAP elicitation, although results have been inconsistent [11, 15, 20, 22, 23, 25, 26, 29]. The degree of PAP is influenced by a variety of factors, including stimulus intensity [2], training status [7, 16] and time interval between potentiation and performance measurement [4, 8, 22, 25]. Interestingly, there has been little investigation of the use of low to moderate load exercise as a method for eliciting PAP and improving performance.

High load gym-based activities are a popular method of eliciting PAP for the purpose of enhancing vertical jump performance [11, 15, 20, 22, 23, 25, 26, 29]. Given that such gym-based activities require specialised equipment that may not be easily accessible or practical for some athletes, it is important to investigate the effects of simple body-weight manoeuvres.

If successful, simple lower body field-based activities may in fact serve as appropriate warm-up activities in addition to providing performance benefits in the in the form of PAP. Furthermore, such activities may be more economical (i.e. given there is no requirement for equipment) and safer to perform in light of reduced load [14]. To date, only a few studies have investigated the capacity of simple field-based warm-up activities to elicit PAP [5, 6, 31]. Those studies, however, report vertical jump performance benefits of low load (<20% bodyweight) and/or bodyweight exercises, although the optimal number of bouts or repetitions for PAP development remains unresolved.

The aim of this study was to investigate the effect of repeated bouts of alternating lunges and determine if PAP could be observed in the form of maximal vertical jump performance. We hypothesised that lunging exercise would result in progressive improvements in measures of jump performance (i.e. jump height, flight time, GRFz and relative impulse) as a result of PAP.

METHODS

Experimental Approach to the Problem

A within-subject laboratory-based study design with repeated measures was implemented to test our hypothesis. We recruited apparently healthy young adults to perform repeated bouts of alternating split lunges to test its effect on maximal vertical jump (VJ) performance. Dependent measures included jump height, peak vertical ground reaction force, impulse, and flight time.

Subjects

Forty-three healthy adults (24 women and 19 men) aged between 18 and 35 years volunteered for the study. Participants were excluded if they had any musculoskeletal or medical impairment that might impact their ability to perform physical activity or jumping tasks. Prior to jump testing, each participant's height and body mass was measured using a wall-mounted stadiometer (HART Sport & Leisure, Australia) and digital scale (Soehnle Co., Switzerland), respectively. Body mass index (BMI) was calculated per the accepted formula (BMI = weight/height^2, kg/m^{-2}). Participants were 1.71 ± 0.09 m tall and weighed 65.7 ± 10.3 kg. Based on BMI, most participants (37/86%) were classified as healthy (BMI <25 kg/m^2) while the remaining participants (6/14%) were classified as overweight (BMI 25-30 kg/m^2) (Table 1). Participants were classified as moderately active, with a median Tegner score of 5 (range: 3 to 9). Seventy-two percent of the sample was Tegner level 3, 4, or 5. Thus, the vast majority of participants were either infrequent or only recreational participants in lower limb specific sports. Each participant gave written informed consent and experimental procedures were approved by XXXX XXXX Committee (Approval number: XXXX-XX-XX-XXXX).

[Table 1]

Procedures

Maximal jump height was determined from a Yardstick VJ device (Swift Performance Equipment, Brisbane, Australia). Prior to testing baseline VJ performance, all participants were familiarised with the laboratory and testing procedures, and given an opportunity to practice a maximum of five VJs. Of the five practice jumps, the best performance was adopted as the baseline score. Practice jumps were necessary to ensure participants were familiar with the VJ device used to measure jump height, and to be able to successfully jump from and land on the force plate (AMTI, Watertown, MA, USA) used to collect ground reaction force data. Three-dimensional ground reaction forces were collected at 1000Hz, and later used to calculate performance measures.

For each maximal VJ, participants were instructed to remove their shoes, stand stationary on the force plate with their preferred arm raised and non-preferred arm by their side, then squat down to a self-selected depth and jump directly upward as high as able. Participants were instructed to keep their preferred arm vertical for the duration of the jump to limit the influence of arm swing and to allow for accurate measurement of jump height using the Yardstick device. If participants did not comply, the jump was deemed a mis-trial and another jump was performed.

Following baseline determination of VJ performance and prior to each subsequent jump trial, participants performed 20 lunges at a rate of approximately 0.5Hz. Each participant was instructed to perform alternating split lunges with their hands on their waist, and lunge down to the floor (but not touching) so that both legs achieved approximately 90 degrees of hip and knee flexion with trunk remaining upright. Additionally, for each lunge, participants were asked to step forward rather than jump and to push back through their heel to return to the starting position. Following each bout of lunges, participants were allowed a 30-second rest where RPE (1 = very light to 10 = maximal) was measured before performing a maximal VJ. A 30-second rest period has been used previously in trials eliciting PAP [9].

Data Analyses

Ground reaction force data were analysed from the point of stationary standing to the point of landing, using custom-written software in Matlab version 7.8.0 (The MathWorks, Natick, MA). Normalised peak ground reaction force in the vertical direction (GRFz) was determined by extracting the peak value between the point of stationary standing and take-off, and dividing by body mass. Flight time was calculated as the time interval between the point of take-off (determined by a GRFz of zero) to the point of landing (determined by the rapid increase in GRFz from zero). Relative impulse was determined using the impulse-momentum method, where the integration of the force-time curve (GRFz) between stationary standing and the point of take-off is calculated [21]. Relative impulse was subsequently determined by dividing impulse by body mass.

Statistical Analyses

Statistical analyses were undertaken using SPSS for Windows version 21.0 (IBM, Chicago, IL, USA). All descriptive statistics are reported as mean ± standard deviation. Between-trial differences in impulse, jump height, peak ground reaction force and flight time were investigated using a repeated measures analysis of variance (ANOVA). The threshold for statistical significance was set at $p < 0.05$, and effect sizes (ES) are reported as Cohen's *d*.

RESULTS

Repeated bouts of alternating split lunges resulted in an initial increase in jump height followed by a decline across subsequent trials (Figure 1A). Jump heights recorded for the first (43.2 ± 9.2 cm; $p = 0.03$; ES = 0.30), second (43.6 ± 9.6 cm; $p = 0.005$; ES = 0.39), third (43.7 ± 9.5 cm; $p = 0.002$; ES = 0.41) and fourth (43.2 ± 9.6 cm; $p = 0.03$; ES = 0.30) trials were higher than the baseline trial (41.9 ± 10.1 cm). Jump height subsequently returned to baseline levels for the fifth (42.9 ± 9.4 cm; $p = 0.11$; ES = 0.23) and sixth trials (42.1 ± 9.6 cm; $p = 0.74$; ES = 0.05).

With respect to flight time, the first (0.441 ± 0.063 s; $p = 0.007$; ES = 3.44), fourth (0.440 ± 0.069 s; $p = 0.004$; ES = 3.62), fifth (0.437 ± 0.069 s; $p = 0.002$; ES = 4.60) and sixth (0.433 ± 0.074 s; $p < 0.001$; ES = 5.71) trials were shorter than the baseline trial (0.451 ± 0.067 s). Flight time for the second (0.449 ± 0.061 s; $p = 0.48$; ES = 0.70) and third trials (0.447 ± 0.068 s; $p = 0.18$; ES = 1.33) did not differ from baseline values (Figure 1B).

No improvements in jump performance were observed based on relative impulse (Figure 1C). Relative impulse for the sixth trial, however, was significantly smaller than baseline (2.35 ± 0.38 vs. 2.26 ± 0.35 N·s/kg, $p < 0.001$; ES = 0.55). No significant differences in normalized peak GRFz were observed (Figure 1D).

[Figure 1]

When VJ data were analysed by gender, no differences in temporal outcomes were observed. Further, when data were analysed based on BMI, there were no differences in VJ gains between participants in the highest and lowest BMI groups. Mean RPE scores recorded immediately following each bout of alternating split lunges increased with each successive trial (Figure 2). Median RPE was 1 after the first bout, but reached 8 following the last trial.

[Figure 2]

DISCUSSION

Our aim was to determine the effects of repeated bouts of alternating split lunges on maximal VJ performance in healthy young adults. We found an initial increase in jump height for the first four trials before performance returned to baseline for remaining trials. Although no improvements in performance were observed for relative impulse and flight time, the sixth (i.e. final) trials were significantly poorer than the baseline performance. Interestingly, no between-trial differences were observed for normalised GRFz.

In accordance with our hypothesis, there was an initial increase in jump height over baseline for the first four bouts of alternating split lunges. This is in agreement with previous investigations that show low load exercises are sufficient to elicit a PAP response [5, 6]. For instance, Chattong and colleagues [6] employed box jumps using handheld weights at 0, 5, 10, 16 and 20% of the participants bodyweight and found no difference in box jump performance between load intensities. However, when performance data was combined for these different load intensities there was an overall improvement in vertical jump performance. This highlights that box jumps loaded with less than 20% bodyweight is sufficient to elicit PAP [6]. Similarly, Burkett and colleagues [5] found that a single set of weighted box jumps (using a weighted vest at 10% of bodyweight) resulted in significant improvements in vertical jump performance [5]. Others have also utilised similar types and intensities of exercise, with comparable results to our study. Thompsen et al. [31] examined the effect of three different warm-up protocols on VJ and long jump performance. Of the three protocols examined, only the ten minute unloaded dynamic exercise protocol and the ten percent body weight loaded dynamic exercise protocol led to significant improvements in jump performance. While both protocols contained lunging exercises of a similar intensity to ours and a protocol that was similar in overall duration, jump performance was only examined on one occasion two minutes post warm-up, hence it is difficult to determine if a shorter or longer protocol would produce similar effects and at what point performance may be detrimentally affected. The results from our study suggest that between two and four sets of bodyweight lunges is sufficient to produce a positive effect on VJ performance.

Previous investigations have demonstrated that bodyweight exercises may be capable of producing similar magnitudes of performance gains as high load gym-based exercises. The 3.1-3.8% improvements we observed in jump height following repeated bouts of lunging are comparable to the 2.5-5.5% improvements seen with high load squat variations (>80% 1RM) and isometric contractions [1, 3, 30]. In further support of our data, previous studies of low load box jumps have reported gains in vertical jump performance [5, 6]. When calculated from their findings, the net improvements were 1.3% [6] and 3.3% [5]. Furthermore, it has been proposed that low load dynamic exercises produce cumulative performance gains through PAP [28]. Repeated bouts of lunging in the current study, however, did not result in cumulative performance gains, but rather, an initial gain after the first bout, followed by maintenance of benefit for several bouts thereafter. Indeed, previous researchers have alluded to this complex interaction between the intensity and duration of the potentiating exercise, and the length of the recovery between the potentiating exercise and the performance task [28]. For example, the positive effects of PAP may be counteracted by fatigue if potentiation exercises are performed for too long or at an excessively high intensity. While the current study has provided preliminary data for such interaction, further dose-response studies are necessary to determine the optimum number of sets and repetitions, as well as the most appropriate recovery period.

Predictably, in the current study following the attainment of maximal VJ performance, there was a decrement in jump height, relative impulse and flight time for the final trials. In fact, the observed performance decrement was associated with a corresponding increase in RPE across trials. Such an inverse relationship between RPE and performance has been observed previously [10, 13] and is an important phenomenon to monitor. Interestingly, previous investigations that have attempted to examine the relationship between PAP and performance related gains by altering recovery times have demonstrated mixed results [25]. Both Comyns and colleagues [9] and McCann and Flanagan [25] investigated different rest intervals in conjunction with high intensity externally loaded PAP regimes. Both found that although performance gains were highly individualised, rest intervals between 30 seconds and 4 minutes tended to be most fruitful.

We reported multiple force plate based performance measures given the inconsistencies identified in previous reports. In the current study, jump height was the only measure responsive to positive performance changes. Our measure of ground reaction force (GRFz), however, appears to be limited in its ability to measure neuromuscular performance during a VJ. No significant differences were observed in GRFz over the six trials, which is in agreement with Comyns and colleagues [9], where no improvements were observed in maximal single leg VJ after a bout of squats. Similarly, Esformes and colleagues [31] found no improvements in peak GRFz, relative GRFz, or rate of GRFz application during VJ performance following both a plyometric and a free weight resistance based exercise protocol. Furthermore, GRFz has been shown to be a poor predictor of VJ performance [24]. Certainly our data further supports that peak and relative GRFz lack sensitivity to performance gains in jump height.

Interestingly, in contrast to other performance measures, there was a decrement in flight time after the first bout of split alternating lunges. This decrease may be attributed to jumping inexperience and or changes in jumping technique. Variation in jumping technique, particularly knee flexion has been shown to be greater during landing than take off [21], ranging from 0.38% to 11.36% [17], which may, in turn, affect variance in flight time and reduce its sensitivity to detect changes in VJ performance. Indeed, large variations in flight time without corresponding variations in jump height have been observed previously [9].

Several limitations warrant consideration. Firstly, while we attempted to control for jump technique through the provision of strict instructions and a standard jump measurement device, we did not measure joint kinematics or timing in the current study. It is possible that improvements in jump performance not mirrored by GRF measures were to some extent a product of refined movement patterns. Secondly, as we did not control for differences in body weight or strength during the lunging protocol, the relative intensity of the lunges likely differed between individuals. While this makes comparisons with other studies difficult, we felt it was important to maintain the highly practical nature of the PAP regime by having participants perform unloaded lunges. Thirdly, although our participants were considered moderately active, many were relatively untrained in terms of jumping. It is possible that the substantial gains we observed in jump height bear relation to the low initial values and a rapid learning effect. Additionally, the decrement in jump performance may have been related to the increase in RPE in our untrained volunteers. It is possible that with longer rest periods, improvements over the later few trials may have been observed. Identification of such an association requires further investigation. Finally, it could be argued that lunging exercise lacks a certain degree of specificity to a maximal vertical jump and that a squat manoeuvre or similar might be more specific. Despite this, we observed performance improvements and propose that a more specific exercise would result in similar or greater performance gains.

In conclusion, a regime of lunging exercise resulted in a transient improvement in maximal vertical jump height. No net improvements, however, were observed for flight time, impulse, or GRFz. Despite no improvements in performance for these measures, a significantly poorer performance was observed for relative impulse and flight time for the final trial when compared to baseline performance. Nonetheless, our data suggest that low load dynamic exercises, such as split alternating lunges, may be sufficient to elicit PAP in healthy young adults.

PRACTICAL APPLICATIONS

A regime of lunging exercise resulted in a transient improvement in neuromuscular performance as determined by jump height for a maximal VJ. This indicates that low load dynamic exercises conducted shortly before performance (i.e. 30 seconds) may be sufficient to elicit PAP and careful consideration should be given to the warm up protocols for maximal vertical jump tasks and similarly powerful athletic activities.

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Tables

Table 1: Participant characteristics (mean ± SD) (n=43).

Variable	Mean ± SD	Range (min-max)
Age (yrs)	26 ± 4	20-37
Height (m)	1.71 ± 0.09	1.60-1.90
Weight (kg)	65.7 ± 10.3	47.3-87.6
BMI (kg/m^2)	22.4 ± 2.5	18.1-28.2

Key: BMI, body mass index

Figures

Figure 1: Maximal vertical jump performance at baseline and following each bout of alternating split lunges for A) Jump height, B) Flight time, C) Relative impulse, and D) Normalised peak vertical ground reaction force (GRFz) (n = 43).

*different to baseline ($p < 0.05$)

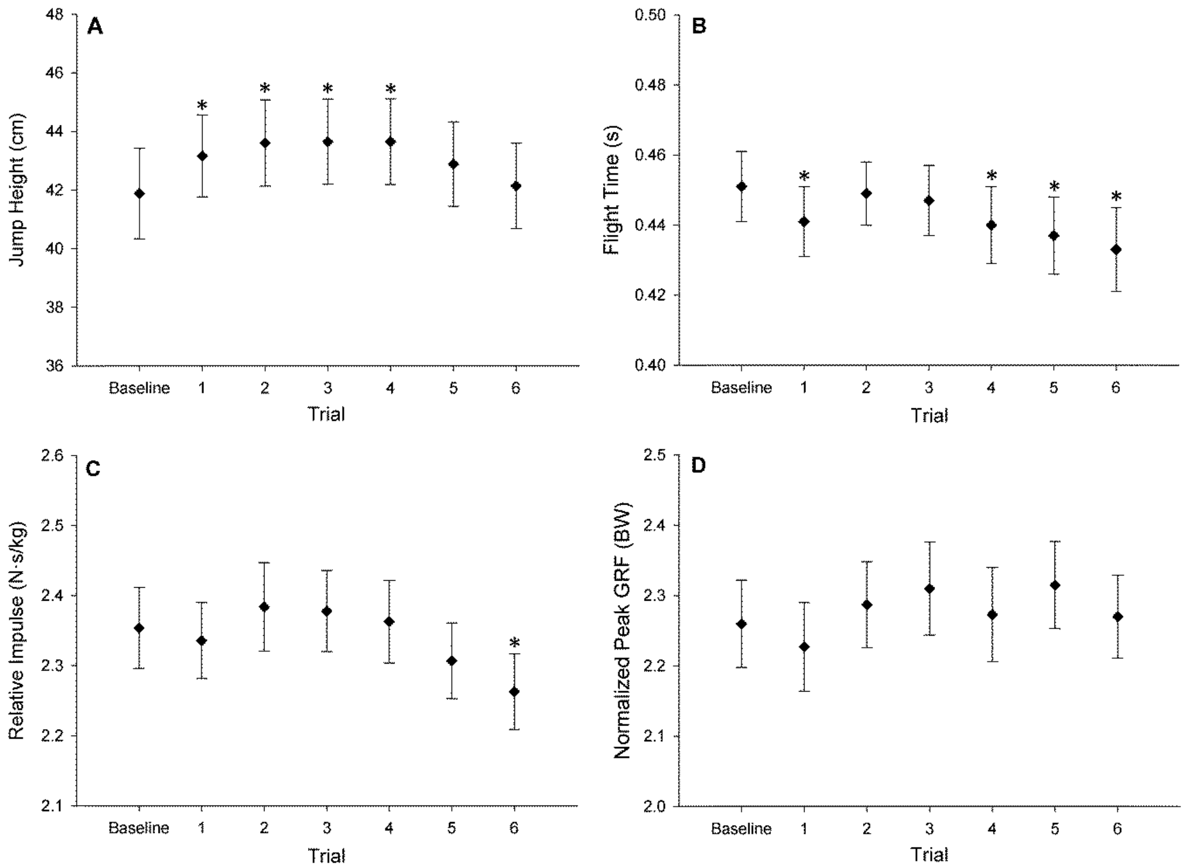

Figure 2: Box-and-whisker plot of ratings of perceived exertion following each bout of alternating split lunges (n=43)