THE EFFECT OF UPPER LIMB POST-ACTIVATION POTENTIATION ON INCREASES IN VERTICAL JUMP HEIGHT DUE TO AN ARM SWING

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Post-activation potentiation (PAP) refers to the phenomenon where muscular performance is improved as a result of contractile history. The aim of this study was to investigate the effects of upper limb PAP on vertical jumping. Firstly, countermovement jumps were performed with (CMJAS) and without an arm swing (CMJ). Participants then carried out 10 dumbbell swings with a weight of 15% of the participant's body weight and performed further countermovement jumps with an arm swing at 3 (PAP3mins), 6 (PAP6mins) and 9 (PAP9mins) minute rest periods. There was a significant difference ($p < 0.05$) in jump height, peak vertical GRF and peak concentric power when comparing CMJ to CMJAS. No significant difference was found when comparing a CMJAS to any of the conditions with induced PAP on the upper limbs. This indicates that inducing PAP on the upper limbs does not have a significant effect on jump height.

KEY WORDS: jumping, countermovement, contractile history, upper limb.

INTRODUCTION: Jumping for maximum height is a common skill used in a variety of sports. Many studies have demonstrated that jump height increases by around 10% due to an arm swing (Feltner, Fraschetti & Crisp, 1999;. Lees, Vanrenterghem & De Clercq, 2006). Lees et al., (2006) examined the effects of maximal and submaximal arm swing on jump height. They found that the energy benefit of using an arm swing is closely related to the greatest kinetic energy of the arms during the arm swing. This build-up of energy in the arms is caused by a greater range of motion being adopted at the shoulder and greater effort of the shoulder and elbow muscles. Therefore investigating methods to increase the force produced by the upper limb muscles during the arm swing may enhance the effect of an arm swing during vertical jumping.

One factor which has been shown to produce acute beneficial effects on muscle force production is post activation potentiation (PAP). PAP is the phenomenon whereby muscle force production may be facilitated as a result of previously performing muscle contraction at or near maximum intensity. This is different from a general warm-up since PAP is induced by exercises performed at near maximal muscle activation whereas warm-ups tend to involve lower intensity muscle contractions. PAP has commonly been induced through the use of heavy resistance exercise (HRE) and is thought to have an increased effect on the following exercise. For example, a back squat exceeding 85% of 1 repetition maximum (1RM) has been shown to improve countermovement jump height (Maloney, Turner & Fletcher, 2014). Whilst a number of studies have found that an increase in jump height can occur due to inducing PAP through a range of prior exercise modalities on the lower limbs (French, Kraemer & Cooke, 2003; Rixon et al., 2007; Kilduff et al., 2007; Comyns, Harrison, Hennessy, Jensen, 2007), little is known regarding the influence PAP of the upper limb muscles on the effect of arm swing. In scenarios where athletes are able to induce PAP prior to performing jumps, such as during a break in play or prior to introducing new players into a game situation, the effect of inducing PAP on the upper limbs could be beneficial for subsequent sporting performance. Therefore, the aim of the current study was to investigate the effects of PAP of upper limb muscles on the use of an arm swing during a maximum height countermovement jump in recreational athletes.

METHODS: Following institutional ethical approval, thirteen males volunteered to take part in this study (age: 19.2 ± 0.8 years, height: 1.77 ± 0.09 m, body mass: 71.8 ± 9.9 kg). All participants were provided with a participant information form outlining the study and gave

informed consent to take part. Participants were recruited on the basis that they were physically active and reported to participate in recreational activity at least 3 times a week. All participants were considered to be healthy and free from musculoskeletal injuries.
Prior to testing, participants underwent a standardised warm up that consisted of 5 minutes on a cycle ergometer at 160 rpm. This general warm-up was selected to not have any exercises which could induce PAP in order to separate the warm-up from subsequent PAP exercises. After the warm up, participants began the testing protocol where they were required to perform countermovement vertical jumps from an AMTI force plate (Advanced Mechanical Technology, Inc., Watertown, MA) which captured ground reaction force (GRF) at 1000 Hz. All vertical jumps were performed with maximum effort whereby participants were instructed to stand still on the force plate prior to the start of the jump and then to jump as high as possible. Firstly, participants performed baseline vertical countermovement jumps which included three countermovement jumps without an arm swing (CMJ) (keeping their hands on their hips) and three countermovement jumps where participants were able use an arm swing (CMJAS), all with one-minute rest between each jump. Following the baseline jumps, participants then completed ten ballistic dumbbell swings with each dumbbell's weight set at 15% of the participant's body weight (determined as appropriate following pilot testing of a range of weights) to induce PAP. Participants were instructed to flex the shoulder until the dumbbells were in line with the shoulder, with the elbow extended. Following the dumbbell swings the participants were given three minutes' rest before performing another countermovement jump with an arm swing (PAP3mins). The countermovement jump with an arm swing was then repeated following 6 (PAP6mins) and 9 minutes' rest (PAP9mins).
To determine jump height, peak vertical GRF, peak power and take-off velocity the following analysis of the GRF-time data was completed. Firstly, body weight was subtracted from the GRF at each time point to calculate the net force acting on the centre of mass. This net force was then divided by body mass to calculate the acceleration of the centre of mass at each time point. The velocity of the centre of mass was then calculated by numerical integration of the acceleration-time data and power was subsequently calculated by multiplying the GRF and velocity of the centre of mass at each time point. Finally, displacement of the centre of mass was then calculated by numerical integration of the velocity-time data. Statistical analysis was carried out using SPSS version 22 (SPSS Inc., Chicago, IL). A repeated-measures one-way analysis of variance (ANOVA) was used to determine the effect of arm swing and PAP on peak jump height, peak power, peak vertical GRF and vertical take-off velocity. When significant effects were observed, a Bonferroni Post-Hoc was used to identify where the significant difference occurred. Statistical significance was set at $p < 0.05$.

RESULTS: There was a significant effect in jump height between the different jumping conditions ($p = 0.01$) (Figure 1a). The Boferroni Post-Hoc test identified that this significant difference occurred between the CMJ and all types of jumps that involved an arm swing however there was no significant difference between CMJAS and any of the PAP conditions.
When comparing peak concentric power between the different jumping conditions, a significant effect was found ($p = 0.04$) (Figure 1b). Post-hoc tests revealed there was a significant difference between CMJ and PAP3mins ($p = 0.03$) and PAP9mins ($p = 0.02$). However there was no significant difference between CMJ and CMJAS ($p = 0.06$) and PAP6mins ($p = 0.12$). There was no significant difference between CMJAS and any of the PAP conditions.
A significant effect was found when comparing vertical GRF between the different jumping conditions ($p = 0.04$) (Figure 1c). The significant difference occurred between CMJ and CMJAS ($p = 0.049$), between CMJ and PAP3mins ($p = 0.03$) and between CMJ and PAP9mins ($p = 0.03$). There was no significant difference between CMJAS and PAP3mins ($p = 1.00$), PAP6mins ($p = 1.00$) and PAP9mins ($p = 1.00$). The greatest vertical ground reaction force occurred during PAP3mins at 1742.0 ± 247.7 N.
There was no significant difference found when comparing vertical velocity at take off between the five different jumping conditions ($p = 0.19$) (Figure 1d). PAP3mins created the highest mean vertical velocity at take off at 2.85 ± 0.38 m/s.

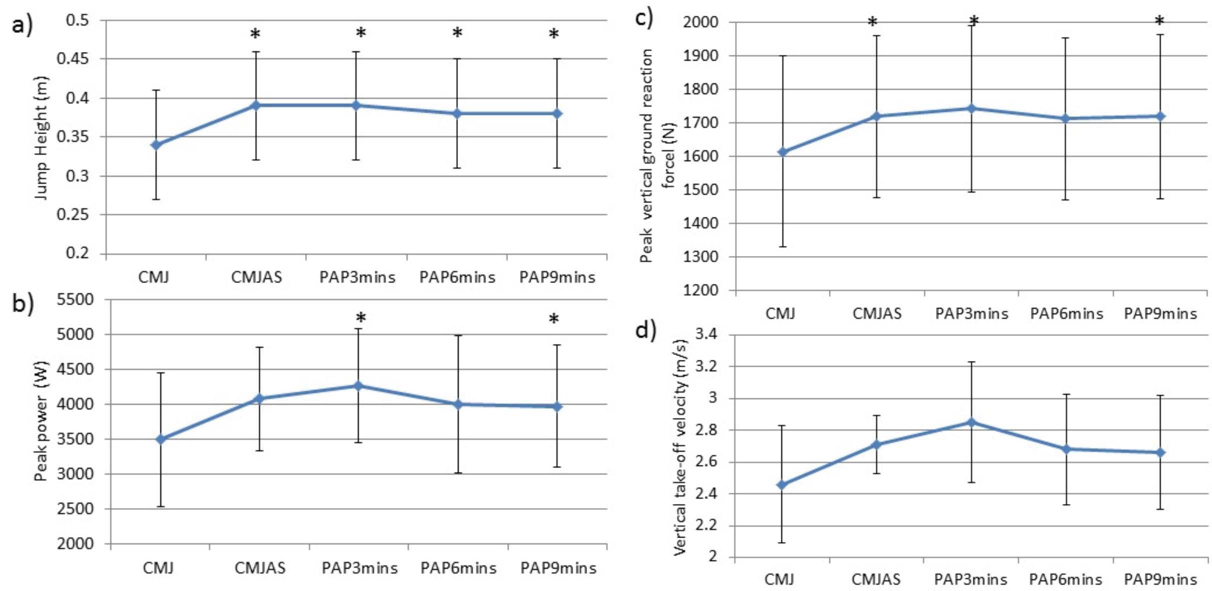

Figure 1: Group means for a) jump height, b) peak power, c) peak vertical ground reaction force and d) vertical take-off velocity during countermovement jump without arm swing (CMJ), countermovement jump with arm swing (CMJAS), three minutes after post activation potentiation (PAP3mins), six minutes after post activation potentiation (PAP6mins) and nine minutes after post activation potentiation (PAP9mins) conditions. * = significant difference compared to CMJ.

DISCUSSION: The results of the current study indicate that a countermovement jump with an arm swing significantly increased jump height, peak concentric power, and vertical GRF when compared to a countermovement jump without an arm swing. However there was no significant increase in vertical velocity at take-off. When comparing CMJAS with the conditions where PAP was induced there was no significant difference in jump height, peak power, peak GRF or vertical take-off velocity. Whilst there were increases in peak power, peak GRF and vertical take-off velocity following PAP3mins compared to the vertical jump with arm swing, there were no significant differences. For PAP6mins and PAP9mins, all variables measured showed a reduction compared to PAP3mins but there were no significant differences. This suggests that the induced PAP on the upper body did not have a significant effect on CMJ performance. For jump height, the results showed that there was a significant difference between the CMJ and all conditions involving an arm swing. Many studies have found that vertical jump performance can increase due to an arm swing (Feltner et al., 1999: Lees et al., 2006). Previous research by Feltner et al. (1999) found that an arm swing increased vertical jump height by 9%, which is slightly less than the 13.7% increase in jump height of due to an arm reported in the current study.

Many studies have focused on the effect of PAP on the lower body with limited research involving the upper body despite the importance of upper body power in many sports (French et al., 2003; Rixon et al., 2007; Kilduff et al., 2007). Therefore the current results cannot be directly compared to studies involving the lower body. In the current study PAP was induced on the upper body whilst most of the muscular effort comes from the lower body during a vertical jump. Lees at al., (2006) found that a more forceful arm swing resulted in an improvement in jump height. Whilst there may have been an increase in force produced by the shoulder muscles following PAP, this increase in force may not have been large enough to significantly increase jump height when compared to CMJAS. Since the majority of force production during a vertical jump is produced by the lower limbs, PAP on the upper limbs alone did not have a significant effect on jumping performance. The upper limbs contribute to a small total of the relative mass of the body, therefore any increases in the velocity at which the arms can be swung during the jump in which PAP has been induced in the upper limbs are likely to only result in a small increase in the total kinetic energy of the body.

There still appears to be some disagreement regarding the most effective exercise modalities for inducing PAP. Whilst some studies report dynamic activities to be most effective (Kilduff et al., 2007), others report dynamic activities are not as effective as lower velocity or isometric activities whereby a dynamic contraction may result in less low frequency fatigue putting the participant at a biomechanical disadvantage (Rixon et al., 2007). Since peak power, peak GRF and vertical take-off velocity were increased for PAP3mins compared to CMJAS, although not significantly, this may warrant further investigation using different types of exercises to induce PAP.
Whilst previous research by Sotiropoulos et al. (2010) has shown that jump height and power production to increase regardless of the load used during a warm up (low: 25 and 35% 1RM or moderate: 40 and 65% 1RM), other studies have found that only higher loads (>80% 1RM) can induce an increase in power performance (Comyns et al., 2007). Additionally these studies mentioned involved inducing PAP by a percentage of 1RM whereas this study used 15% of the participant's body weight. This is one of the main limitations of the current study as a percentage of 1RM may have been a more effective method of determining load to induce PAP. Another limitation is that the study did not examine the change in arm swing speed which may have been an indicator of a possible PAP effect. Future research should investigate different exercise modalities to induce PAP on the upper limbs, such as heavier weights and isometric contractions, as well as examining its effects on different types of athletes, particularly those familiar with playing sports involving a high frequency of jumping activities. In addition, since vertical jumping with an arm swing is a whole body movement, consideration should be given to inducing PAP on the whole body musculature through exercises such as Olympic lifting techniques which may have a greater effect than only inducing PAP on the lower or upper limbs alone.

CONCLUSION: The results from the current study indicated that inducing PAP on the upper body does not have a significant effect on vertical jump performance. This includes jump height, peak concentric power, vertical velocity at take-off and peak GRF. However, these finding should also encourage future research to investigate alternative protocols to measure the effects of PAP on the upper body since the peak power, peak GRF and take-off velocity did show slight increases following PAP after 3 minutes rest.

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