## Introduction

Post-activation Potentiation (PAP) is a phenomenon characterized by an increase in muscular power after a conditioning activity (34,55,68). It has been widely used by athletes to acutely enhance muscular power in training and competition. PAP is induced from manipulating the rest periods, load and volume of the exercises used as conditioning activities (CA) before the start of a ballistic exercise (50,54-56). The concept of PAP can be addressed through several mechanisms such as the rise in myosin light chain phosphorylation, the increase in higher order motor unit recruitment, and the influence of change in muscle pennation angle (63).

PAP has been attained by performing various modes of exercise including: the lifting of free weights of maximal or near maximal intensity between 60-90% of 1 repetition maximum (1RM) (7,15,17,19,21,25,45,59,70); performing resisted sprints such as sled pulls or pushes (58,65,67,69); lifting heavy weights with 15-30% of total load contributed by variable resistance (VR) (6,11,48,49,53,57,60,70); performing a ballistic movement with VR (2,41); performing maximal isometric voluntary contractions (24,27,29,52) and performing plyometric exercises (3,8,26,36,41,47). The athletes' strength level and the logistical demand required for the performance of each mode of exercise to induce PAP will differ. For example, stronger athletes who are more fatigue resistant would respond better to PAP exercises that involve lifting of free weights at near maximal intensity (55,68); performing resisted sprints to induce PAP might be more feasible during field training; and using plyometric, isometric and VR exercises to induce PAP can be an option in situations where free weights are not available. It is important for practitioners to consider the available information in the literature in order to prescribe the most suitable method to induce PAP. Therefore, the purpose of the review is to explore the available literature on the effects of different modalities for inducing a PAP response resulting in improved sport related performance, highlight the advantages and disadvantages of each PAP method and provide information pertaining to gaps in current literature. Magnitudes of changes in performances are presented as percentage change in the main text and effect sizes are presented in the tables. Effect sizes were calculated by the following formula:

$$Cohen's\ d = \frac{M_2 - M_1}{Pooled\ SD}$$

Where $M_1$ = mean of group/condition 1 (e.g. control group), $M_2$ = mean of group/condition 2 (e.g. experimental group), $SD_1$ = standard deviation of group/condition, $SD_2$ = standard deviation of group/condition 2. The pooled SD is calculated based on the sample SDs by using the equation below.

$$Pooled\ SD = \sqrt{\frac{(SD_1^2 + SD_2^2}{2}}$$

Effect size was deemed: (i) trivial effect size if $d < 0.20$; (ii) small effect size if $d = 0.20 - 0.49$ and; (iii) moderate effect size if $d = 0.50 - 0.80$; (iv) large effect size if $d = 0.8$ (16). However, as some studies presented their data in graphical form only, it was not possible to calculate the effect sizes for the results of these studies.

**Free Weights Exercises**

Free weights exercises are the most common CA used to elicit PAP. These comprise of exercises such as the deadlift, back squat and weightlifting (power cleans and its derivatives) (Table 1). A study by Arias et al. (5) had participants perform1 x 5 deadlift at 85% 1RM prior to performing a CMJ at 15 s and for intervals of every 2 min intervals thereafter; up to 16 min, after completion of the deadlift. Jump height was found to have decreased at all time intervals, with a significant decrease at 15s ($p < 0.05$). The authors suggested that the significant drop at 15s was due to the dominance of fatigue during the early stage of recovery (5). In addition, Arias et al. (5) noted that the intervals selected to perform the CMJ was only 2 minutes, and this may have caused fatigue accumulation which subsequently affected the ability for the muscles to achieve the potentiation effect from deadlifts. In contrast, Strokosch et al (60) showed that standing broad jump (SBJ) performance improved by 4.64% to 5.35% ($p < 0.05$) after performing 4 x 2 deadlift at 85% of 1RM with a recovery period of 90s. One possible reason for this increase could be due to the inclusion of variable resistance that Strokosch et al (60) used for part of the loads lifted during the deadlift exercise. The addition of variable resistance to free weights exercise has been shown to be more effective at inducing PAP than free weights exercise alone (48,49). This will be discussed in the later section of the review.

An extensively examined CA used to improve CMJ height acutely is the back squat exercise (55). Studies using squats to potentiate CMJ performance have resulted in 2% to 12.7% improvement in jump height by using loads between 60-84% (medium) and >85% (high) of 1RM; single and multiple sets; along with with rest intervals ranging from 15s to 10 min (7,17, 21, 25, 45, 55, 68). Apart from the intensity level, squat depth was also shown to affect the extent of a back squat to optimally potentiate lower limb muscles (12,21). For example, Esformes and Bampouras (21) conducted a study to compare the PAP effects of quarter (QS) and parallel squat (PS) performed for 3 x 3RM load of each exercise. The study concluded that PS was superior to QS (12.8% vs

9.7%, $p < 0.05$) due to the increased activation of the gluteus maximus from a lower squat depth, resulting in a greater magnitude of PAP effect. This finding was in line with the study by Caterisano et al. (12), who reported that gluteus maximus produced a greater percent contribution in muscle activation during PS than QS.

Apart from CMJ, the effect of the squat as a CA on sprint running performance has also been studied (17,59). Crewther et al. (17) showed that 1 x 3 squat at 3RM load did not lead to an improved sprint time after 15 s, and every 4 min intervals up to 16 min ($p > 0.05$). However, Seitz et al. (59) showed an improvement in sprint time (2.16%, $p < 0.05$), and average acceleration (4.59%, $p < 0.05$) when back squats were performed with a similar intensity and volume, with a recovery period of 7 min, was used as the CA. A possible reason for the conflicting findings between the two studies could be due to the difference in strength levels of the participants. Participants in the study by Seitz et al. (59) were elite rugby players with relative 1RM back squat of 2.02 times per kg of bodyweight as opposed to the sub-elite group of rugby players with only 1.73 times per kg of bodyweight (derived by dividing average participants body mass by the estimated 1RM squat based on the 3RM squat using the 1RM estimation chart (30) in the study by Crewther et al. (17). It has been shown that individuals with greater maximum strength responded better to PAP stimulus (15,25,28,55,68). For example, Gourgoulis et al. (28) found that physically active men who could squat more than 160 kg had a 4% ($p < 0.05$) increase in CMJ height while individuals who squat less than 160 kg showed no significant change in CMJ. The possibility of a greater composition and cross-sectional area of type II muscle fibres in stronger individuals could have resulted in a greater phosphorylation of myosin light chain leading to an increased PAP effect

(1,43). Additionally, stronger individuals are more fatigue resistant, which influenced the level of neuromuscular fatigue and potentiation post-CA (14,31).

Several studies have also investigated the effectiveness of weightlifting as a form of PAP stimulus. The study by Dolan et al. (19) showed that when performed as a CA, 3 x 3 hang clean and jerk at 80% 1RM resulted in enhanced shotput performance acutely by 3.6% ($p < 0.05$). This result was similar to the findings of Harris et al. (32) who showed a ~5.33% ($p < 0.05$) acute improvement in shot put throw velocity after performing power jerks (2 x 2 at 50% and 75%  and 2 x 3 power jerks at 85% 1RM) as CA. In addition to shot put performances, weightlifting as a PAP activity was also found to benefit CMJ performance (15,45). Participants in the study by McCann and Flanagan (45) also showed acute improvements in jump height by about 2% ($p < 0.05$) after performing 1 x 5 hang cleans at 5RM load as a CA. Similarly, Chiu and Salem (15) found that performing snatch pulls as PAP stimulus resulted in 5.9% ($p < 0.01$) improvement in CMJ. Based on the findings of the mentioned studies, it is evident that weightlifting is an effective method to induce PAP, however, there are several factors to consider when performing weightlifting. Firstly, due to the complexity of the movement, coaches might require more time to teach athletes the lifting technique before weightlifting can be used for inducing PAP. Secondly, similar to all free weights exercise, lifting equipment is required for the performance of weightlifting; therefore, this might not be a possible option during competitions, or field training where equipment is not available.

Performing heavy free weights exercises such as weightlifting and squats at 50-90% 1RM has been shown to induce PAP effect and resulted in improved jump and sprint performances.

Factors to consider when performing these exercises as CA to induce PAP, include load and volume of exercise, individuals' strength level, rest period, range of movement and availability of equipment.

**Table 1.** Summary of selected studies using free weights to elicit PAP.

| **Study** | **Subjects** | **Training Status & Strength Level** | **Intervention (sets x reps @ % RM)** | **Performance Measure** | **Rest** | **Effect Size** | **Results** |
|---|---|---|---|---|---|---|---|
| Arias et al. (5) | 15 males | Training Status: Resistance trained<br><br>Strength Level: 1RM DL: 1.9x BW | 1 x 5 @ 85% 1RM DL | VJ | 15s, 2, 4, 6, 8, 10, 12, 14 & 16 min | NA | ~7.5% ↓ in JH at 15s than at 2-16 min post DL. |
| Bauer et al. (7) | 60 males | Training Status: Resistance trained<br><br>Strength Level: 1RM BS: 1.8x BW | MI: 3 x 6 @60% 1RM BS<br>HI: 3 x 4 @ 90% 1RM BS | CMJ | 15s, 1, 3, 5, 7, 9 & 11 min | NA | MI vs HI<br>3 min: 4.37% vs 3.65%<br>5 min: 3.18% vs 2.99% |
| Chiu & Salem (15) | 13 males in power sports | Training Status: Well trained<br><br>Strength Level: NA | Two waves x 2 reps @ 70, 80, 90, 100% 1RM SP<br>Pre VJ, wave 1, mid VJ, wave 2, post VJ | VJ | 3 min | Mid: 1.62<br>Post: 1.75 | Mid: 5.77%<br>Post: 5.90% |
| Crewther et al. (17) | 9 male rugby players | Training Status: Sub-elite<br><br>Strength Level: 3RM: 1.56x BW | 1 x 3RM BS | CMJ, sprint, sled pull | 15s, 4, 8, 12 & 16 min | 4min: 0.31<br>8 min: 0.32<br>12 min: 0.27 | CMJ:<br>4 min: 3.8%<br>8 min: 3.5%<br>12 min: 3%<br><br>No change in sled pull and sprint time |

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| de Villarreal et al. (18) | 12 First Division male volleyball players | Training Status: Competitive & resistance trained<br><br>Strength Level: NA | WP2: 2 x 4 80% 1RM HS, 2 x 3 85% 1RM HS<br><br>WP 3: 2 x 4 80% 1RM HS, 2 x 2 90% 1RM HS, 2x1 95% 1RM HS<br><br>WP 6: 3 x 5 30% 1RM HS | CMJ, DJ and loaded CMJ | 5 mins, 6 h | NA | WP 2: ↑ DJ (2.98%), ↑ CMJ power (11.39%)<br><br>WP3: ↑ DJ (5.47%), ↑ CMJ power (9%)<br><br>WP 6: No significant change in all measures. |
| Dolan et al. (19) | 6 male and 7 female track & field athletes | Training Status: Collegiate<br><br>Strength Level: NA | 1 x 3 @ 80% 1RM hang clean & jerk | Shot put | 8 min | 0.20 | Shotput distance: 3.6% |
| Esformes & Bampouras (21) | 27 male rugby union players | Training Status: Sub-elite<br><br>Strength Level: 3RM QS: 2.3x BW<br>3RM PS: 2.1x BW | 1 x 3RM QS and PS | CMJ | 5 min | QS: 0.99<br>PS: 1.23 | CMJ height:<br>QS: ↑ ~9.72%<br>PS: ↑ ~12.77% |
| Fukutani et al. (25) | 8 Olympic weightlifters | Training Status: Elite<br><br>Strength Level: 2.37x BW | HC: 1 x 3 @ 90% 1RM BS<br>MC: 1 x 3 @ 75% 1RM BS | CMJ | 1 min | HC: 0.59<br>MC: 0.22 | CMJ height:<br>HC: ↑ ~10.86%<br>MC: ↑ ~5.26% |
| Harris et al. (32) | 10 throwers | Training Status: Collegiate<br><br>Strength Level: NA | 2 x 2 power jerk @ 50% & 70% 1RM, 3 x 2 power jerk @ 85% 1RM | Shot put | 3 min | 0.28 | Throw velocity ↑ 5.3% |

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| Low et al. (39) | 16 youth soccer players | Training Status: Adolescents<br><br>Strength Level: NA | 1 x 3 @ 91% 1RM BS on 6 repeated sprints (35m) | Sprint | 8 min | Sprint 1: <0.2<br>Sprint 2: 0.36 | Sprint times:<br>Sprint 1: -0.39%<br>Sprint 2: -1.65%<br><br>No change in sprints 3 to 6. |
| Lum (40) | 8 male and 8 female kayakers | Training Status: Adolescents<br><br>Strength Level: 1.4x BW | 2 x 5 @ 60% 1RM BS | VJ | 8 min | | No change in CMJ height. |
| McCann and Flanagan (45) | 14 volleyball players | Training Status: Collegiate<br><br>Strength Level: NA | 1 x 5RM BS and hang clean at two rest periods | VJ | 4 & 5 min | 4 min: 0.09<br>5 min: 0.05 | 4 min: ↑ 2.16%<br>5 min: No significant. difference |
| Seitz et al. (54) | 13 junior rugby league players | Training Status: Elite<br><br>Strength Level: 1RM BS: 2.02x BW<br>1RM PC: 1.17x BW | 1 x 3 @ 90% 1RM BS vs<br>1 x 3 @ 90% 1RM power clean | Sprint | 7 min | ST; v; ā:<br>PC: 0.92, 0.84, 1.0.<br>BS: 0.66, 0.63, 0.7. | ↑ in ST; v; ā:<br>PC: 3.05%, 3.22%, 6.61%, respectively.<br>BS: 2.16 %, 2.25%, 4.59%, respectively |
| Weber et al. (66) | 12 in-season track & field athletes | Training Status: Collegiate<br><br>Strength Level: NA | 1 x 5 @ 85% 1RM BS and 5 SJ (control) on 7 SJ | SJ | 3 min | mJH<br>BS: 0.44<br>SJ: -0.23 | Changes in mJH; pJH; pGRF:<br>BS: 5.8%, 4.7%, 4.6%, respectively<br>SJ: -2.7%, -4%, -1.3%, respectively |

**Abbreviations: ā = average acceleration, BS = back squat, BW = body weight, CMJ = countermovement jump, DL = deadlift, HC = heavy condition, HI = high intensity, HS, = half squat, JH = jump height, MC = moderate condition, MI = medium intensity, mJH = mean jump height, NA = not available, pGRF = peak ground reaction force, pJH = peak jump height, PS = parallel squat, QS = quarter squat, SJ = squat jump, SP = snatch pull, ST = sprint time, v = velocity, VJ = vertical jump.*

Table 2. Summary of selected studies that included resisted sprints to elicit PAP.

| **Study** | **Subjects** | **Training Status & Strength Level** | **Intervention (sets x reps @ % RM)** | **Performance Measure** | **Rest** | **Effect Size** | **Results** |
|---|---|---|---|---|---|---|---|
| Seitz et al (58) | 20 rugby league players | Training Status: Well trained<br><br>Strength Level: NA | 75%: 1 x 15m sled push with 75% body weight.<br><br>125%: 1 x 9m sled push with 125% body weight. | Sprint | 15 s, 4, 8, 12 min | 75%: 15s (0.07), 4 min (-0.22), 8 min (-0.42), 12 min (-0.36)<br><br>125%: 15s (0.64), 4 min (0.53), 8 min (0.41), 12 min (0.34) | 75%: ↓ 20-m sprint time after 4 (0.95%), 8 (1.8%) and 12 min (1.55%).<br><br>125%: ↑ 20-m sprint time at all time point (1.36-2.59%) |
| van den Tillar & Heimburg (65) | 15 female handball players | Training Status: Well trained<br><br>Strength Level: NA | 7 x 20m sprints alternating between unresisted sprint and sled pull with 5 kg body weight. | Sprint | 5-6 min | NA | ↑ average sprint time (7.3%). |
| Whelan et al. (67) | 12 physically active men | Training Status: Recreational<br><br>Strength Level: NA | 3 x 10m sled pull with 20-30% body weight. | Sprint | 1.5 min | NA | No significant change. |
| Winwood et al. (69) | 22 rugby athletes | Training Status: Resistance trained<br><br>Strength Level: NA | 75%: 1 x 15m sled push with 75% body weight.<br><br>150%: 1 x 7.5m sled push with 125% body weight | Sprint | 4, 8, 12 min | 75%: 4 min (0.09), 8 min (0.24), 12 min (0.22)<br><br>150%: 4 min (-0.13), 8 min (-0.01), 12 min (-0.01) | 75%: ↓ 15m sprint time after 12 min (0.7%).<br><br>125%: No change in sprint time. |

*NA = not available,*

**Resisted Sprint**

Performing resisted sprints in the form of sled pulls and pushes as a CA for sprint performance has been investigated in several studies (58,65,67,69) (Table 2). Seitz et al. (58) showed that 1 x 15m sled push with 75 % body weight resulted in significant improvement in 20m sprint time after 4 (0.95%, $p < 0.05$), 8 (1.8%, $p < 0.05$) and 12 (1.55%, $p < 0.05$) min intervals of recovery. Conversely, sprint time was slower after 1 x 9m sled push with 125 % body weight (1.36% – 2.59%, $p < 0.05$). Similarly, Winwood et al. (69) showed significant improvement (0.75%, $p < 0.05$) in 15m sprint time 12 min after participants performed 1 x 15m sled pull with 75 % body weight, but performing 1 x 7.5m sled pull with 150% body weight resulted in slower sprint time (0.90% - 1.64%, $p > 0.05$). Seitz et al. (58) suggested that the heavier (>75% body weight) sled push and pull might have led to changes in sprinting technique such as increased trunk lean angle or hip joint angle while performing unresisted sprint, which ultimately caused disruption to normal acceleration kinematics. Despite the findings by Seitz et al. (58) and Winwood et al. (69), Whelan et al. (67) showed that 3 x 10m sled pull with 20-30% body weight separated by 90 s recovery time, failed to improve 10m sprint performance. The authors indicated that 20-30% body weight could have been too light to induce PAP (67). Current findings on the use of sled pull or push as CA indicate that performing this exercise for 1 x 15 at 75% body weight is optimal for inducing PAP.

The performance of resisted sprints in the form of sled pulls and pushes may prove valuable for inducing PAP during field training as resisted sprints are commonly practiced by athletes during sports training (65,67). However, this method of CA might only be suitable for athletes training on field or artificial turf surfaces as performing sled pulls or pushes on other surfaces could cause damages to the ground and sled. In addition, the acute effects of resisted sprint on other dynamic performances such as jumping and change of directions has not been investigated; therefore, the current data only supports the use of resisted sprints as CA to improve sprint performance.

**Variable Resistance Exercise**

Variable resistance exercise involves altering the resistance placed on the musculoskeletal system throughout the range of motion to match an exercise strength curve (46). The inclusion of VR allows for greater loading beyond the "sticking point" which will occur as a result of mechanical disadvantage early in the concentric phase of an exercise. Thus, the maintenance of maximal force development throughout the range of motion will be required (4). Examples of commonly used VR equipment include elastic bands and chains (48,49).

**Table 3.** Summary of selected studies that included variable resistance to elicit PAP.

| Study | Subjects | Training Status & Strength Level | Intervention (sets x reps @ xx% RM) | Performance Measure | Rest | Effect Size | Results |
|---|---|---|---|---|---|---|---|
| Aandahl, et al. (2) | 5 women and 11 men | Training Status: Elite,<br><br>Strength Level: NA | 10 kicks with elastic resistance tubes post warm up protocol | Roundhouse kick | 5 to 8 min | NA | Kick velocity: ↑ 3.3% |

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| Baker & Newton (6) | 13 rugby league players | Training Status: Elite<br><br>Strength Level: 1RM BP: 1.33x BW | BP: 2 x 3 @ 75% 1RM<br><br>BP + CH: 2 x 3 @ 60% 1RM | BP and BP + CH | 2 min | PCV: 0.52-0.82<br>MCV: 0.84-0.92 | BP + CH : ↑10% in PCV and MCV |
| Buttifant & Hrysomallis (11) | 12 semi-pro male footballers | Training Status: Sub-elite<br><br>Strength Level: 3RM BxS: 1.47x BW | BxS: 3 x 3RM<br><br>Banded BS: 3 x 3 BS with bands | Weighted JS (20kg) | 5 and 10 min | BxS vs banded BS:<br>5 min: 0.66, 0.59<br>10 min: 0.68, 0.67 | ↑ in mean power (BxS vs banded BS:<br>5 min: 12%, 12%<br>10 min: 14%, 13% |
| Lim et al. (38) | 11 swimmers | Training Status: Well-trained<br><br>Strength Level: NA | 5 x resistance band pull mimicking freestyle stroke | 50m swim | 8 min | 25m split time: 0.35 | ↓ time to 25 m |
| Lum (41) | 11 male judo athletes | Training Status: Elite<br><br>Strength Level: NA | ULB: 2 x 5 SBJ and RB pull<br><br>LB: 3 x 5 SBJ | HPT and SJFT | 5 and 7 min respectiv ely | PP: 0.1<br>No. of throws:<br>LB: 0.6<br>ULB: 0.7 | ↑ PP by ~4.55% in ULB<br><br>↑ no. of throws by ~3.85% in LB and ULB |
| Mina et al. (48) | 16 men | Training Status: Recreational<br><br>Strength Level: NA | FWR: 2 x 3 @ 85% 1RM BS<br><br>EB: 2 x 3 @ 85% 1RM BS with elastic band | 1RM FWR BS | 5 min | 1.88 | ↑ 1RM BS by 7.7% after EB |
| Mina et al. (49) | 16 men | Training Status: Recreational<br><br>Strength Level: NA | FWR: 2 x 3 @ 85% 1RM BS<br><br>CLR: 2 x 3 @ 85% 1RM BS with elastic band | 1RM FWR BS | 5 min | 1.45 | ↑ 1RM BS by 6.2 % after CLR |
| Scott et al. (53) | 20 rugby league players | Training Status: Elite<br><br>Strength Level: HBD: 1.78x BW | 3 x 70% 1RM, with 0-23% from VR using HBD and BS | CMJ | 30, 90 and 180 s | NA | ↑ JH at 30s in HBD (+9.45%) and BS (+8.98%) |

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| | | BS: 1.42x BW | | | | | compared to control. |
| Seitz et al. (57) | 14 rugby league players | Training Status: Elite<br><br>Strength Level: NA | 4 x 2 @ 85% 1RM PBS with VR | SBJ | 90 s | 0.58-0.81 | ↑ 4.0 to 5.7% in SBJ distance |
| Strokosch et al. (60) | 12 rugby league players | Training Status: Elite<br><br>Strength Level: 1RM BS: 1.59x BW<br>1RM DL: 2.11x BW | 4 x 2 @ 85% 1RM PBS or DL with VR | SBJ | 90 s | PBS: 0.64-1.03<br>DL: 0.80-0.96 | PBS: ↑ 3.82% to 6.01%<br><br>DL: ↑ 4.64% to 5.35% |
| Wyland et al. (70) | 20 males | Training Status: Recreational<br><br>Strength Level: NA | 5 x 3 @ 85% 1RM BS without and with VR | 9.1m Sprint | 0, 1, 2, 3, 4 min post BS | 0.83 | Sprint time ↓ by 3.5% at 4 min for VR condition |

**Abbreviations: BB = barbell, BP = bench press, BS = back squat, BxS = box squat, CH = chain, CLR = chain loaded resistance, CMJ = countermovement jump, DL = deadlift, EB = elastic band, FW = free weights, FWR = free weights resistance, HBD = hex bar deadlift, HPT = high pull test, JS = jump squat, LB = lower body, MCV = mean concentric velocity, NA = not available, PBS = paused box squat, PCV = peak concentric velocity, PP = peak power, RB = resistance band, RF = rectus femoris, SBJ = standing broad jump, SJFT = special judo fitness test, ULB = upper lower body, VMO = vastus medialis obliques and VR = variable resistance.*

As shown in Table 3, the use of VR to induce PAP has been investigated in recent studies. For example, Mina et al (48) reported an increase in squat 1RM performance (+7.7%, $p < 0.01$) after participants performed a VR CA that involved 2 x 3 squat at 85% 1RM with 35% of load from elastic bands at the top range of the movement. This increase in squat 1RM was greater than when participants performed 2 x 3 squat at 85% 1RM without VR. This finding was supported by a later study by Mina et al. (49) that showed a 6.6% ($p < 0.01$) improvement in squat 1RM performance after performing 2 x 3 squat at 85% 1RM with 35% of load contributed by chains at the top range of the movement. The authors indicated that this could be due to the greater muscle activity in the quadriceps femoris during the eccentric phase. One limitation of these studies was that the load at the bottom range of the movement for the VR condition were not reported. Therefore, how PAP is affected by the load at the bottom range of the movement is still unknown.

A study by Seitz et al. (57) showed significant improvement in SBJ performance of 4.0 to 5.7% ($p < 0.05$) after performing four sets of two repetitions of paused box squats (85% 1RM, ~15% from VR) with 90s of rest. This finding was supported by Strokosch et al. (60) who reported a 3.82 to 6.01% improvement in SBJ performance after performing the same VR paused box squat protocol as Seitz et al. (57). One novel finding by Seitz et al. (57) and Strokosch et al. (60) was that the recovery time required to induce PAP after performing free weights exercises with the inclusion of VR was only 90 s in contrast to >5 min for free weights alone. It was suggested that VR exercises may induce less fatigue than traditional resistance exercises when the same load is lifted (57), thus requiring shorter recovery time to induce PAP.

The effects of including variable resistance to induce PAP in upper body muscles have also been explored. Baker and Newton (6) conducted a study comparing the effects of 2 sets of 3 repetitions of bench press at 75% 1RM with 17.5 kg contributed by chains, and bench press at 75% 1RM without chains. The bench press with chains condition resulted in ~10% increment in peak and mean concentric velocity when comparing against free weights bench press ($p < 0.05$). The authors suggested that the improvement in performance was most likely due to greater muscle stiffness and faster stretch shortening cycle (6).

Apart from attaching to barbells, VR alone could also be used to induce PAP by performing sport specific dynamic movements (2,38,41). Lum (41) investigated the effects of including resistance band pulls (RBP) that mimics the entry phase of a judo throw, in the warm up routine for judo athletes, on the high pull test (HPT) and for special judo fitness test (SJFT) performance. In this study, participants underwent three different conditions. During the control condition, participants performed their usual pre-competition warm up. In the intervention condition, participants performed half the volume of the pre-competition warm up and either three sets of 5 repetitions of SBJ, or 2 sets of 5 repetitions of SBJ and RBP for each exercise. Results showed that in comparison to the controlled condition, the SBJ and RBP condition led to a significantly higher total number of throws (3.85%, $p < 0.01$), while the SBJ only condition led to a higher number of throws in only the first series of the test (8%, $p < 0.05$). Moreover, only the condition that included SBJ and RBP resulted in significantly higher peak power in HPT (5.8%, $p < 0.01$), as compared to the control condition. Although there could be a possibility that the greater PAP effect in SBJ and RBP condition as compared to SBJ alone condition could be attributed to the greater volume of work done in SBJ and RBP condition, other studies have also shown the positive effect of performing VR exercises on acute sports movement performance. Aandahl et al. (2) also noted an increase of 3.3% ($p < 0.05$) in the velocity of a roundhouse kick in trained martial arts practitioners after performing 10 roundhouse kicks with elastic bands in comparison to control condition where participants performed 10 roundhouse kicks with no additional resistance. Finally, a recent study by Lim et al. (38) showed that swimmers had a faster 25m split time while performing a 50m freestyle time trial after they completed a swim (750m) with 1 x 5 resistance band pull (mimicked freestyle stroke) warm up protocol as compared to a normal swim warm up protocol (1500m) ($p < 0.05$). Although these studies have shown that PAP can be induced when variable resistance equipment is used to perform sports specific movement, none of these studies provided recommendations on the optimal resistance level to use.

Current studies have shown that including variable resistance to free weight exercises resulted in a superior PAP effect as compared to free weights alone. Current recommendations for including VR to free weights lifting are ~ replacing 15 to 35% of load with VR and 1.5 to 7 min of rest in between CA and activity of interest. Exercises using VR alone has also been shown to induce PAP, but there is currently no recommendation for the optimal resistance level to use. Therefore, further studies should be conducted to address this issue, as performing VR exercises to induce PAP could be a viable option in situations where there is no access to free weights, such as during field training or competitions.

**Isometric Exercises**

Isometric exercise is characterized by the contraction of muscles without a change in joint angle (42). It can be performed for a single joint such as isometric knee extension, or multi-joint such as isometric back squat (51). Maximal voluntary isometric contraction is often used to induce PAP where individuals maximally contract their muscles for a specific duration of time (3-10s) (24, 27, 29, 51). It can be performed by exerting force against a stationary object such as a wall or a fixed bar, to attain maximal isometric contraction. While some studies showed that performing isometric contraction to induce PAP led to improvement in drop jump (DJ), CMJ and in knee extension performances (24,29), others have shown conflicting results on the effectiveness of isometric contractions as a form of PAP CA (27, 51).

French et al. (24) investigated the effects of performing 3 x 3s or 3 x 5s isometric knee extensors at maximal voluntary contraction (MVC) on CMJ, DJ, 5s sprint cycling and isokinetic knee extension performance. Significant improvement was shown in DJ flight height (5.0%, $p < 0.05$), ground reaction force of DJ (4.9%, $p < 0.05$), as well as isokinetic knee extension (6.1%, $p < 0.05$) after performing 3 x 3s protocol, while no significant change in all measures was observed in the 3 x 5s protocol (-1.73% to -3.05%, $p > 0.05$). While French et al. (24) showed no improvement in jump performance after the 3 x 5s isometric leg extension protocol, Gullich and Schmidtbleicher (29) showed that a 3 x 5s isometric leg press at MVC, with 1-5 min rest between repetitions, resulted in improved CMJ (3.3%, $p < 0.05$) and DJ (4.1%, $p < 0.05$) height. One possible reason for the conflict in results between the two studies could be due to a shorter rest period (~5s) in French et al. (24)'s study, which resulted in a lack of recovery to express the potentiation effect. Another possible reason could be that the leg press exercise in the study by Gullich and Schmidtbleicher (29) increased activation of more muscles required for jumping performance, as compared to the leg extension exercise in French et al. (24). Furthermore, as both the leg press and jumping are multi-joint activities, performing leg presses may be more likely to induce a PAP effect, than leg extensions, due in part to mechanical specificity.

Although the above studies have shown the positive PAP effect of maximal isometric contraction, there are several other studies that showed conflicting findings (27, 51). Gossen and Sale (27) investigated the effects of performing 1 x 10s isometric knee extension at MVC, with 20-40s rest, on the performance of dynamic knee extensions. No significant difference in peak velocity, peak torque, peak power and work to peak power between isometric and control condition was observed

($p > 0.05$). Similarly, Robbins and Docherty (52) showed no significant difference in CMJ power output between a 3 x 7s isometric back squat at MVC with 4 min rest between repetitions and control condition ($p > 0.05$). The lack of significant findings in the study by Gossen and Sale (27) and Robbins and Doherty (52) could be due to the length of contractions. The isometric conditions that induced PAP effect were only 3-5s per repetition (24, 29), while those in Gossen and Sale (27) and Robbins and Doherty (52) were 10s and 7s, respectively. The increased duration of isometric contraction at MVC could have caused a higher level of fatigue that overwrote any PAP effect induced.

The study by Lim and Kong (37) investigated the acute effects of maximal isometric contraction in comparison to dynamic squat on sprint performance. In this study, participants had to perform 3 different conditions including 3 x 3s isometric leg extension at MVC, 3 x 3s isometric squat at MVC and 3 repetitions of dynamic squat at 90% 1RM prior to attempting a 30m sprint. The results showed no PAP effect following the interventions ($p > 0.05$). However, the authors found that different interventions had varying effects among different participants. For example, the authors included figures that showed sprint performance was improved after performing different CA for different participants. This indicates that an individualized protocol might be required for different individuals to attain PAP effect.

Current findings on the effects of maximal isometric contraction on PAP show that a maximum contraction duration of 3 – 5s per repetition for 3 repetitions with a 1-5 min recovery period seems to be the optimal dosage for inducing PAP. In addition, performing isometric contraction using multi-joint exercise, at joint positions similar to the initiation of the propulsion phase of the tested movement would be recommended as this provides for mechanical specificity. Furthermore, current findings showed no difference in PAP effect between performing isometric and free weights exercise. Therefore, isometric exercise is also a viable option for inducing PAP in situations where free weights are not available. To our knowledge, no study has investigated the effects of upper body isometric contraction on inducing PAP. Therefore, future studies should aim to fill this gap in the literature.

**Table 4.** Summary of selected studies using isometric contraction to elicit PAP.

| Study | Subjects | Training Status & Strength Level | Intervention | Performance Measure | Rest | Effect Size | Results |
|---|---|---|---|---|---|---|---|
| French et al. (24) | 14 track and field athletes | Training Status: Resistance trained<br><br>Strength Level: NA | 3 x 3s vs 3 x 5s isometric MVC of knee extension | CMJ, DJ, 5s cycle sprint, isokinetic knee extensions | 0 – 5s | NA | 3s MVC:<br>↑ by 5.03% for DJ flight time & by 4.94% for DJ GRF, ↑ 6.12% peak torque<br><br>5s MVC:<br>↓ 3.05% peak torque |
| Gossen & Sale (27) | 10 subjects (6 m, 4 f) | Training Status: Moderately active<br><br>Strength Level: NA | 1 x 10s isometric MVC of KE | Dynamic KE | 20s and 40s | NA | No significant difference in peak velocity, peak torque, peak power and work to peak power between PAP trial and CON trial |
| Gullich & Schmidtbleicher (29) | 34 speed-strength athletes | Training Status: Competitive<br><br>Strength Level: NA | Leg press:<br>3 x 5s or<br>5 x 5s isometric MVC | CMJ, DJ | 1 – 5 min | NA | 3 x 5s : ↑ CMJ height by 3.3%, ↑DJ flight time by 4.1%. |

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|---|---|---|---|---|---|---|---|
| | | | | | | | 5x5s: No significant change in all measures. |
| Lim & Kong (37) | 12 track sprinters | Training Status: Resistance trained<br><br>Strength Level: 1RM BS = 1.5x BW | KE:<br>3 x 3s isometric MVC<br><br>BS: 3 x 3s isometric MVC | 30-m sprint | 4 min | Isometric KE: 0.46<br>Isometric BS: 0.65 | No significant difference between isometric and control conditions. |
| Robbins & Docherty (52) | 16 men | Training Status: Resistance trained<br><br>Strength Level: NA | BS: 3 x 7s isometric MVC | CMJ | 4 min | NA | No significant difference occurred in any of the power output measurements |

**Abbreviations: BS = Backsquat, CMJ = Countermovement Jump, DJ= Drop Jump, GRF = Ground Reaction Force, CON = Control, KE = Knee Extension, MVC = Maximal Voluntary Contraction, NA = not available, RI = Rest Interva.*

**Plyometrics Exercises**

Plyometric exercises are movements that involve the stretch shortening cycle (SSC), characterized by a rapid eccentric movement followed by a short amortization phase and a ballistic concentric movement (8). Lower body plyometrics exercises include activities such as DJ, hurdle jump and CMJ while upper body plyometrics include exercises such as bench press throw and ballistic push up. The use of plyometric exercises as PAP CA has been studied and shown to be effective in inducing PAP leading to improved jump (3, 10, 13, 18), sprint (3, 8, 9, 23, 64), judo (41, 47), throwing (61) and sport specific performances (26). However, some studies have also shown no significant changes in sprint time (62) and jump height (20, 40) after performing plyometric exercises.

A study by Bonfim Lima et al. (8), investigated the effects of performing 2 x 5 drop jumps from a height of 75cm on 50m on sprint performance. Significant improvement was shown in 50m sprint time after 10 min (2.4%, $p < 0.05$) and 15 min (2.4%, $p < 0.05$). Similarly, Bryne et al. (9) examined the acute effect of performing 1 x 3 DJ from individualized optimal height (i.e. drop height that resulted in the highest DJ height) of either 20cm, 30cm, 40cm, 50cm or 60cm on 20m sprint performance and reported that there was a significant reduction in 20m sprint time (2.93%, $p < 0.05$). In addition, Abade et al. (3) investigated the effects of plyometric exercises as a form of rewarm up protocol that was performed after a period of 6 min passive recovery from a traditional soccer warm up regime, on subsequent sprinting performance. The protocol involved 4 x 5 jumps over 40cm barrier and one-foot runs in agility ladder. Results showed that the plyometric CA led to improvement in both 10m (-2.9%, $p < 0.05$) and 20m (-3.4%, $p < 0.05$) sprint times while no change was observed in the control condition which involved passively resting for 12 min. Despite the positive effects of plyometric exercise as a PAP CA shown in these studies, Till and Cooke (62) showed that performing 5 double leg tuck jumps did not improve 10 and 20m sprint time after 4, 5 and 6min of recovery period ($p > 0.05$). A possible reason for this finding could be due to the lack of mechanical specificity as sprinting involves both horizontal and vertical propulsion while tuck jumps involved only vertical propulsion (64). Therefore, it is possible that the direction at which force is produced is also an important factor to consider when performing plyometric exercises as a form of PAP CA.

Studies have also been conducted to investigate the effectiveness of weighted plyometric exercises on inducing PAP (23, 44, 64). Turner et al. (64) compared the effects of weighted (10% body weight) and unweighted bounding on 20m sprints. Results showed that the unweighted condition led to an increase 10m sprint acceleration at 4 min (1.8%, $p < 0.05$), while in the weighted condition resulted in improvement in the 10m sprint acceleration at 4 min (2.2%, $p < 0.05$) and 8 min (2.9%, $p < 0.05$) and improvement in 20m sprint velocity at 4 min (2.3%, $p < 0.01$) and 8 min (2.6%, $p < 0.01$). However, the change in sprint performance might not be a real improvement as Turner et al (64) reported that the typical error calculated from baseline measures for 10m and 20m sprint acceleration were 3.4% and 2.6% respectively. As the magnitude of improvement in sprint velocity were within the typical error range, this change could have been due to fluctuation in participants performance. A recent study by Ferreira Junior et al. (23) who used the same plyometric CA as the one in Turner et al. (64), found no significant differences in 100m dash time (0.89%, $p > 0.05$) between intervention and control conditions in high school track and field athletes. There was also no significant difference in all split times (0-30m, 30-50m, 50-70m and 70-100m) except 70 – 100m where intervention condition using weighted plyometric resulted in faster split time (~2.5%, $p < 0.05$) as compared to control condition. Based on the findings of these two studies, the use of loaded and unloaded plyometric exercise to improve sprint performance acutely is not recommended.

The use of plyometric CAs has been shown to improve jumping performance (3, 10, 13, 18). For example, Burkett et al. (10) compare 3 warm up protocols on CMJ performance. The warm up protocols included a submaximal jump protocol where participants were required to perform 1 set of 5 jumps of 75% of their maximum jump height; a weighted jump protocol where participants were required to perform 1 x 5 jumps with 10% of their body weight onto a 63.5cm high box; and a stretching protocol which involved 14 stretches to the lower body with each stretch held for 20 s. It was reported that weighted box jump protocol resulted in 3.3% ($p < 0.05$) higher jump height as compared to no warm up, while submaximal jump (0.9%, $p > 0.05$) and stretching conditions (0.7%, $p > 0.05$) did not. Although it was not stated whether the weighted jump protocol was performed with maximal or submaximal effort, the authors indicated that the extra 10% weight provided some form of overloading. The authors explained that, based on the theoretical Treppe concept, each successive loaded jump resulted in the recruitment of increasing amounts of motor units that led to greater force production (10). When the resistance was removed, more motor units were recruited, producing an even larger power output, or increase in the jumping ability (10).

The effects of plyometric CA on sports related performance is not limited to sprint and jump performances, as plyometric CA have also been shown to elicit PAP effect on other sports movements such as judo throws, tennis serve, and track and field throws (36, 41, 47, 61). Studies by Miarka et al, (47) and Lum (41) investigated the effects of plyometric CA on Special Judo Fitness Test (SJFT) performance. Miarka et al. (47) showed that 10 x 3 box jump resulted in significantly higher total number of throws performed as compared to control condition (12%, $p < 0.05$). Similarly, Lum (41) showed that the addition of 3 x 5 SBJ into a judo warm up protocol resulted in 8% ($p < 0.05$) more throws performed during the first series of Special Judo Fitness Test as compared to judo warm up alone.

The beneficial acute effect of plyometric CA on track and field throws performance was evident in the study by Karampatsos et al. (36). In this study, throwers performed 3 consecutive CMJ 1 min prior to their throw attempt during a competition. The results showed that mean throwing distance improved (2.66%, $p < 0.05$) when the attempt was preceded by the 3 CMJ as compared to not performing the CMJ. In support of this finding, Terzis et al. (61) showed that 5 consecutive

DJ from a height of 40cm resulted in improved underhand shot throw distance (4.6 – 7.4%, $p < 0.01$).

There is a paucity of studies investigating the effects of upper body plyometric CA on sports related performance in the current literature. To our knowledge, only the study by Gelen et al. (26) has compared the effects of various upper body warm up on sports performance. The study compared the effects of 4 different upper body warm up protocol, plyometric, traditional, dynamic exercise and static stretching, on tennis serve performance. The plyometric condition included 6 different types of ballistic exercises, the traditional condition included 6 upper body dynamic exercises, the dynamic exercise included shoulder, wrist and trunk rotation exercise with tennis racket, and the static stretch condition included 7 upper body stretching exercises. The results showed that the plyometric (3.4%, $p < 0.05$) and dynamic exercises (1.3%, $p < 0.05$) condition resulted in significantly higher ball velocity than traditional warm up. While plyometric condition resulted in in significantly higher ball velocity than dynamic (2.1%, $p < 0.05$) and stretching conditioning (3.9%, $p < 0.05$) as well.

The comparison of various mode of plyometric CA was studied by de Villarreal et al. (18). In this study, the PAP effects of loaded CMJ (3 x 5 jumps with optimal loaded CMJ), DJ (3 x 5 DJ from optimal height) and volleyball standard warm up, which included various plyometric exercises, was compared. It was shown that loaded CMJ and specific volleyball standard warm up protocol resulted in improved CMJ height (4.1% and 6.9 %, respectively, $p < 0.05$), DJ height (4.18% and 4.49%, respectively, $p < 0.05$) and maximal power output (2.4% and 10.9%, respectively, $p < 0.05$) 5 min post CA. While only loaded CMJ protocol improved CMJ height (9.0%, $p < 0.05$) 6h post

CA. The authors suggested that the lack of improvement in CMJ and DJ height after performing DJ as CA may be related to the high level of neuromuscular fatigue associated with the DJ exercise, together with the short recovery period (i.e., 5 min) between the end of the plyometric exercise and the beginning of the performance. The results showed that loaded CMJ and the specific volleyball standard warm up protocol can be used to induce PAP to enhance acute jump performance, while only loaded CMJ protocol may be used to enhance acute jump performance for an extended period of time (18).

The effectiveness of plyometric CA in inducing PAP in children was evident in the study conducted by Faigenbaum et al. (22). In this study, participants who performed a warm up with moderate- to high-intensity dynamic movements, such as high knee skip and high knee run exercises, had improved shuttle run timing and CMJ height by 1.8% ($p < 0.05$) and 5.5% ($p < 0.05$) respectively. In addition, the inclusion of 3 drop jumps from a 15cm box after performing dynamic exercises, resulted in greater improvement in CMJ height (6.1%, $p < 0.05$) and long jump (1.9%, $p < 0.05$) performance. These findings indicate that the use of plyometric CA can be used to improve acute sports related performances in children.

As plyometric exercises are associated with preferential recruitment of type II motor units, it has been reported that plyometric CA is a slightly more effective method to induce PAP, as compared to free weights exercise (55). In addition, plyometric CA may induce lower levels of fatigue than the lifting of free weights, hence allowing greater potentiation effect while reducing the time needed for maximal PAP effect (36, 55). The review by Seitz and Haff (55) reported that a greater PAP effect can be achieved earlier after plyometric CA (0.3-4min) as compared to the lifting of moderate to high intensity weights (≥5min). This was also evident in the study by Karampatsos et al. (36) who showed that a 1 min recovery period after 3 repetitions of CMJ, was sufficient to enhance throwing performance (2.66%, $p < 0.05$). In addition, plyometric CAs have been suggested to have greater biomechanical specificity to sprinting as compared to the lifting of free weights. Plyometric CAs generally have similar ground contact times to the acceleration phase of a sprint (33). Furthermore, plyometric CA requires minimal logistics, do not require specific skills sets, activate several muscles groups simultaneously and can be performed quickly. Therefore, it is an ideal way to induce PAP and improve athletic performances (35).

Based on the studies reviewed, current literature suggests that by performing plyometric upper and lower body exercises before sports activities could positively enhance subsequent sports related performance by 1.31% - 12%. It has also been found that the enhancement in performance can occur almost immediately after the CA (20s – 1 min). However, with a higher volume of CA, such as multiple series or sets of plyometric CA, a longer rest period has been suggested (2 – 7 minutes).

**Table 5.** Summary of selected studies using plyometric to elicit PAP in sprint performance.

| Study | Subjects | Training Status & Strength Level | Intervention | Performance Measure | Rest | Effect Size | Results |
|---|---|---|---|---|---|---|---|
| Abade et al. (3) | 22 males soccer players | Training Status: Elite U19<br><br>Strength Level: NA | 4 x 5 jumps over 40cm barrier, one foot runs in agility ladder with 10 rungs | 10 & 20m sprint | NA | 10m sprint: 0.7<br>20m sprint: 0.9 | ↓10m sprint time by 2.9%<br>↓20m sprint time by 3.4% |
| Bonfim Lima et al. (8) | 10 male sprinters | Training Status: High-level professional<br><br>Strength Level: NA | 2 x 5 drop jumps (height of 0.75m) | 50m sprint | 5, 10, and 15 min | 10 min: 0.86<br>15 min: 0.91 | ↓ 50m sprint time at 10 min by 2.4% and at 15 min by 2.7% |
| Bryne et al. (9) | 29 males | Training Status: Physically active<br><br>Strength Level: NA | DYN: 5 mins jog + 10 dynamic stretches<br>DYNDJ: DYN + 1 x 3 depth jumps @individualized optimal height (0.20m, 0.30m, 0.40m, 0.50m or 0.60m) | 20m sprint | 1 min | (CON vs DYN & DYNDJ)<br>DYN: 0.66<br>DYNDJ: 1.49<br><br>(DYN vs DYNDJ)<br>DYNDJ: 0.80 | ↓ 20m sprint time by 2.2% in DYN vs CON<br>↓ 20m sprint time by 5.01% in DYNDJ vs CON<br>↓ 20m sprint time by 2.93% in DYNDJ vs DYN |
| Faigenbaum et al. (22) | 60 children (27 girls, 33 boys; mean age = 11.3 ± 0.7 years) | Training Status: Active<br><br>Strength Level: NA | SS = 5 mins of static stretches on lower body<br>DY= 10 mins of dynamic exercises<br>DYJ= 10 mins of dynamic exercises + 3 DJs from 15cm boxes | Shuttle run | 2 min | DY: 0.29<br>DYJ: 0.43 | ↓ shuttle run timing by ~1.8% in DY and ~-2.7% in DYJ as compared to SS |

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|---|---|---|---|---|---|---|---|
| Ferreira Junior et al. (23) | 11 track and field male athletes | Training Status: High School<br><br>Strength Level: NA | 3 x 10 alternate leg bounding with additional 10% body mass load | 100m dash, split time @0-30m, 30-50m, 50-70m and 70-100m | 7 min | 0.51 | ↓ split time at 70-100m (2.5%) |
| McBride et al. (44) | 15 football athletes | Training Status: NCAA division III<br><br>Strength Level: NA | 1 x 3 loaded countermovement jump @30% 1 RM | 40m sprint | 4 min | NA | No significant change in all measures |
| Till and Cooke (62) | 12 professional academy soccer players | Training Status: Professional & resistance trained<br><br>Strength Level: NA | 1 x 5 double leg tuck jumps | 20m sprint | 4, 5 and 6 min | NA | No significant change in all measures |
| Turner et al. (64) | 23 men | Training Status: Plyometric trained<br><br>Strength Level: NA | 3 x 10 alternate leg bounding in weighted (10% body mass) and unweighted | 20m sprint, split time @ 0-10m, 10-20m | ~15s, 2, 4, 8, 12, and 16 min | NA | Weighted:<br>↑10 m sprint velocity at 4 (2.2%) and 8 (2.9%) min.<br>↑ 20m sprint velocity at 4 (2.3%) & 8 (2.6%) min<br><br>Unweighted:<br>↑ 10m sprint acceleration at 4 min (1.8%) |

**Abbreviations: DYN, DY = Dynamic exercises, SS = Static Stretching, DYNDJ= Dynamic exercises + depth Jump, DYJ = Dynamic exercises + drop jump, NA = not available.*

**Table 6.** Summary of selected studies using plyometric to elicit PAP in jumps performance.

| Study | Subjects | Training status & Strength level | Intervention | Performance Measure | Rest | Effect Size | Results |
|---|---|---|---|---|---|---|---|
| Abade et al. (3) | 22 elite males U19 soccer players | Training Status: Elite U19<br><br>Strength Level: NA | 4 x 5 jumps over 40cm barrier, one foot runs in agility ladder with 10 rungs | CMJ & AJ | N. A | CMJ: ~0.4<br>AJ: ~0.5 | ↑ CMJ (~3.8%) and Abalakov jump (~4.8%) performances |
| Bonfim Lima et al. (8) | 10 male sprinters | Training Status: High-level professional<br><br>Strength Level: NA | 2 x 5 drop jumps (height of 0.75m) | CMJ | 5, 10 and 15 min | Post 15 min vs CON: 0.99<br>vs pre-test: 0.74<br>vs post 5 min: 1.16 | ↑ CMJ height at post 15 min by 5.5% as compared to CON<br><br>↑ CMJ height at post 15 min by 4% as compared to pre-test<br><br>↑ CMJ height at post 15 min by 6.1% as compared to post 5 min |
| Burkett et al. (10) | 29 football athletes | Training Status: Collegiate<br><br>Strength Level: NA | 1 x 5 jumps with 10% BW onto a 63.5cm high box | VJ | 2 min | Vs no warm up: 0.35<br>Vs stretching: 0.27<br>Vs submaximal: 0.25 | ↑ VJ height vs no warm up (~3.2%), vs stretching warm up (~2.5% ) and vs submaximal warm up (~2.3%) |

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|---|---|---|---|---|---|---|---|
| Chen et al. (13) | 10 male volleyball players | Training Status: Collegiate<br><br>Strength Level: NA | 1 x 5 drop jumps, or 2 x 5 drop jumps at individualized drop height (20cm, 40cm or 60cm) | CMJ | 2, 6 and 12 min | NA | ↑ CMJ height at post 2 min by ~3 to 5% vs pre-test in both protocols |
| de Villarreal et al. (18) | 12 First Division male volleyball players | Training Status: Competitive & resistance trained<br><br>Strength Level: NA | WP1: 3 x 5 optimal loaded CMJs<br><br>WP 4: 3 x 5 DJs from optimal height<br><br>WP 5: Specific volleyball standard warm up | CMJ, DJ and loaded CMJ | 5 mins, 6 h | NA | WP1:<br>↑ CMJ height (4.1%), ↑ DJ height (4.18%), ↑ max power output (2.43%) @ post 5 mi<br>Improvement maintained in loaded CMJ (9.03%) @ post 6hr<br><br>WP4:<br>No significant difference in all post warm up measurement<br><br>WP5:<br>↑ CMJ height (6.96%), ↑ DJ height (4.49%), ↑ max power output (10.90%) @ post 5 min<br>Improvement not maintained for all |

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| | | | | | | | post warm up measurement @ post 6hr |
| Esformes et al. (20) | 13 male athletes | Training Status: Competitive & resistance trained<br><br>Strength Level: NA | 3 x 6 alternate speed bounds, right leg speed hops, left leg speed hops and vertical bounds | CMJ | 5 min | NA | No Significant. improvements in displacement compared to CON |
| Faigenbaum et al. (22) | 60 children | Training Status: Active<br><br>Strength Level: NA | SS = 5 mins of static stretches on lower body<br><br>DY= 10 mins of dynamic exercises<br><br>DYJ= 10 mins of dynamic exercises + 3 DJs from 15cm boxes | VJ, LJ | 2 min | VJ<br>DY: 0.27<br>DYJ: 0.31<br><br>LJ<br>DYJ: 0.17 | DY: ↑ VJ height (5.5%)<br><br>DYJ: ↑ VJ height (6.1%) and LJ distance (1.9%) |

**Abbreviations: BW = Body Weight, CON = Control, CMJ = Countermovement Jump, DJ = Drop Jump, DY = Dynamic exercises, DYJ = Dynamic exercises + drop jump, JH = Jump Height, LJ = Long Jump, NA = not available, VJ = Vertical jump, WP = Warm up Protocol.*

**Table 7.** Summary of selected studies using plyometric to elicit PAP in other sports performances.

| Study | Subjects | Training Status & Strength level | Intervention | Performance Measure | Rest | Effect Size | Results |
|---|---|---|---|---|---|---|---|
| Gelen et al. (26) | 26 young tennis players | Training Status: Elite<br><br>Strength Level: NA | TRPLYO: 6 ballistic exercises<br><br>TRDE: 6 dynamic exercise<br><br>TRSS: 7 static stretches | Tennis serve performance | 2- 4 min | Vs CON<br>TRDE: 0.27<br>TRPLYO: 0.71<br><br>Vs TRSS<br>TRDE: 0.35<br>TRPLYO: 0.78<br><br>Vs TRDE<br>TRPLYO: 0.42 | Sig ↑ in serve velocity in TRDE (~1.31%) and TRPLYO (~3.42%) vs CON.<br>Sig ↑ in serve velocity in TRDE (~1.76%) and TRPLYO (~3.88%) vs TRSS<br>Sig ↑ in serve velocity in TRPLYO (~2.09%) vs TRDE |
| Karampatsos et al. (36) | 32 track and field throws | Training Status: Competitive<br><br>Strength Level: NA | 1 x 3 consecutive CMJs | Shot put throw, hammer throw, discus throw & javelin throw | 1 min | Best performance with CMJs vs without CMJs<br>Shot put: 0.09<br>Hammer throw: 0.04<br>Discus throw: 0.16 | ↑ in mean throwing performance (2.66%)<br><br>↑ in maximum throwing performance (2.76%) |

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| | | | | | | | Best performance with CMJs vs without CMJs:<br>↑ in shot put performance by 1.7%<br>↑ in hammer throw performance by 1.1%<br>↑ in discus throw performance by 3.3% |
| Lum (41) | 11 male judo athletes | Training Status: Elite<br><br>Strength Level: NA | 3 x 5 standing broad jump | SJFT & HPT | 5 min (HPT), 7 min (SJFT) | 0.7 | Significant ↑ in number of throws in SJFT series A (~8%) |
| Miarka et al. (47) | 8 male judo athletes | Training Status: State-level<br><br>Strength Level: NA | 10 series of 3 consecutive jumps from elevated surface and jumping onto benches of height (20, 40 & 60cm) | SJFT | 3 min | 1.4 | Significant ↑ in no. of throws during series A vs CON (~12%) |

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| Terzis et al. (61) | 16 subjects | Training Status: Moderately trained NA | 5 consecutive drop jump from 40cm | Squat underhand front shot throw | 20s | As a group: 0.32 Men only: 0.69 | Significant ↑ in shot throw performance as a group (~4.6%) Significant ↑ in shot throw performance in men only (~7.4%) |

**Abbreviations:* *CON = Control, CMJ = Countermovement Jump, HPT = High Pull Test, NA = not available, SJFT = Special Judo Fitness Test, TRPLYO = Traditional warm up + plyometric activity, TRDE = Traditional warm up + dynamic exercise, TRSS = Traditional warm up + static stretching.*

## Conclusion

The current review has provided information on the effects of various modes of exercise in inducing PAP for various sports related performances. Each method resulted in varying degrees of PAP and has its own pros and cons. Several factors that have been shown to affect the magnitude of PAP include lifting load, rest period and strength level. Current findings have also shown that replacing a 20-35% of the load with VR when performing free weight exercise could result in a greater PAP effect, with shorter recovery time. In addition, methods such as VR, isometric and plyometric exercises can be performed to induce PAP in situations where free weights are not available. Furthermore, exercises performed to induce PAP should be mechanically specific to the main activities. Coaches and athletes should take the available information into consideration when choosing the most suitable modes of exercise to induce PAP for training and competition purposes.

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