Post-Activation Performance Enhancement Through Variable Loading Maintains Power Output Over Five Sets in Highly Trained Athletes

American football is a collision-based sport characterized by short bursts of power alternated with rest (Iosia & Bishop, 2008). While players of specific position groups such as linemen or ball carriers have different tactical demands, power development is a universal and critical training component (Fry & Kraemer, 1991; Hoffman, 2008). Strength and conditioning specialists utilize a multitude of innovative training strategies to enhance strength and power (McMaster et al., 2009). Accordingly, high-intensity conditioning contractions have become a popular means to induce acute improvements in muscle contractile properties that theoretically translate to power enhancement (Prieske et al., 2020). This mechanism is known as post-activation performance enhancement (PAPE). PAPE is more specifically described as the acute improvements in muscular contractile performance [e.g., vertical jump (VJ) power] from pre-loading the muscle with high resistance loads with an exercise of similar biomechanics (e.g., back squat) (Blazevich & Babault, 2019; Tillin & Bishop, 2009). PAPE is the performance approach to post-activation potentiation versus the mechanistic approach. In brief, the mechanistic approach is in situ and verified through electrostimulation of muscle whereas the performance approach is ex situ and verified through voluntary muscle contractions (Prieske et al., 2020). Processes of PAPE may be like PAP and include increased phosphorylation of the myosin light chain, heightened sensitivity of actin and myosin to calcium availability, and increased excitability of α-motorneurons (Blazevich & Babault, 2019). Further, fast-twitch type II muscle fibers may be more sensitive to potentiation (Moore & Stull, 1984). PAPE training protocols pairing flywheel squats with VJ have shown to significantly improve peak force, concentric peak power and velocity, rate of force development, and jump height (Maroto-Izquierdo, 2020; McErlain-Naylor & Beato, 2021).

Heavy squats utilizing chains may be used by practitioners during PAPE sessions. The chains are attached to both ends of a barbell, and as the bar moves upward, resistance progressively increases because the chains are lifted off the ground, and as the bar is lowered the resistance decreases. Resistance is increased in ranges of motion where the muscles can produce the greatest relative force, and unloaded in ranges where force production is compromised. See figure 1a. This variable loading (VL) allows for near-maximal contractions to be performed at high velocities thus inducing large neural adaptations. Thus, having a target bar velocity is an important metric for denoting load intensity (Mann, 2020). Godwin et al (2018) compared bench press throw performance with and without chains and found trivial but not significant improvements in peak and mean power output, but bar acceleration was significantly faster in the VL with chains condition. VL may also be induced using elastic bands around the ends of the bar. Mina et al. (2019)

compared the effects of a single back squat set with and without elastic bands on post-VJ performance in physically active men. Results showed VL was superior in improving jump height, peak power, rate of force development, peak concentric knee angular velocity, and vastus lateralis muscle activity. However, in field strength and conditioning sessions typically involve more than one set of exercises. Miret et al (2022) studied a small group (N=8) of veteran National Football League (NFL) players who trained over three sets of VL with banded squats with VJ performance measured at baseline and after each set. Mean power outputs were stable from baseline across the sets with lighter total body mass players experiencing appreciable improvements across sets. VL may have potential to elicit PAPE response. Previous PAPE research presents the following limitations: (a) primarily conducted in artificial laboratory settings (versus during actual training sessions), (b) acute effects assessed over three sets (versus four or five that occur during actual training sessions), and (c) minimal inclusion of elite athletes. Therefore, the purpose of this study was to examine the acute effects of 5 sets of VL on the PAPE response during a live training session in highly trained athletes.

Methods

Participants

Twelve adult male American football players (height, 188 ± 0.01 cm; total body mass, 114.4 ± 25.3 kg) training in a specialized camp to prepare for the 2023 NFL draft at a local performance center volunteered for this study. Players represented a variety of field positions and competed for different teams. All participants had recently completed their collegiate competitive football season, were active players training 5-6x per week, and were 12 of the 319 players invited to the distinguished 2023 NFL combine. All participants were experienced in performing resistance training and the VJ. Each participant read and signed a written-informed consent form, and this study was approved by the university's Institutional Review Board (#2022-570).

Instrumentation

Data were collected during a coach-organized training session as part of the NFL combine preparation camp in a performance center on a single day. Baseline and subsequent VJ were performed on dual uniaxial force plates (FD Lites, Vald Performance, Queensland, Australia) sampling at 1000 Hz and ForceDecks software (ver. 1.8.6, Vald Performance, Queensland, Australia) was used to calculate power variables that are described in Table 1.

Table 1. Description of vertical jump power variables collected via force plates.

Variable	Description
Jump height (cm)	Maximal displacement of the participant's center of mass; take-off velocity)^2 / 2(9.81m/s^2)
Absolute peak power (W)	Highest power output during the jump
Normalized peak power (W/kg)	Highest output during the jump relative to a participant's body mass
Reactive strength (m/s)	Ability to change quickly from eccentric to concentric contraction; jump height / contraction time

ForceDecks uses a 20-N offset from the measured bodyweight, which was quantified before all jump trials to define the start of the movement. The end of the eccentric phase and start of the concentric phase was defined as minimum absolute displacement (zero velocity), and take-off was defined as the time point at which the total vertical force fell below the threshold of 20 N below bodyweight. VJ landing was not analyzed in this study.

VL back squats were performed using a 20 kg barbell and weighted plates (Xult Fitness, Wisconsin, USA), and 10kg chains. A PUSH band unit (WHOOP Unite, Boston, MA, USA) was used to monitor bar velocity.

Figure 1. (a) Participant performing heavy VL back squat. (b) Participant receiving instructions. (c) Participant at peak height of a VJ.

Protocol

All participants completed a dynamic warm-up that included a low load back squat set directed by their strength and conditioning coach. They performed a contrast PAPE protocol consisting of 2 baseline VJ followed by five sets 2-5 repetitions of VL back squats using chains alternated with 2 VJ. Squat load intensity was velocity based. The target velocity of each repetition was 0.90 m/s, estimating the loads to be between 50-60 percent of one repetition maximum (Mann, 2020) in the strength-speed zone where moderately heavy loads are moved at moderate velocities (Mann et al., 2015). Repetitions were stopped if the athlete's velocity dropped below 0.90 m/s. To determine enhancement effects, the VJs were performed on the force platforms 2-4 min. after each squat set.

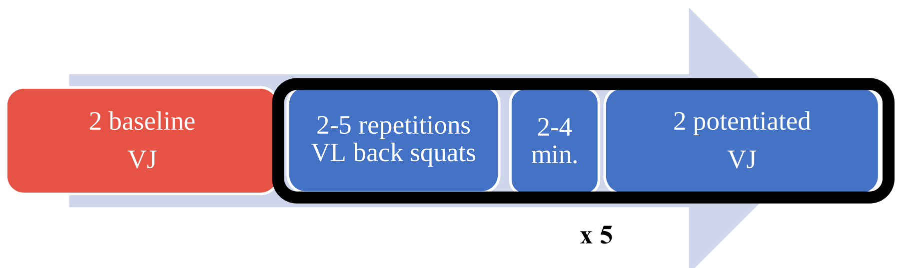

Figure 2. Schema of testing protocol.

Data analysis

Data for the dependent variables were downloaded from the ForceDecks software into an Excel spreadsheet. This spreadsheet was uploaded into SPSS statistical software (ver. 28; IBM, Chicago, IL, USA). Skewness and kurtosis were evaluated for each variable by set in SPSS and found to be ±2.0, and no value was greater than two times its standard error indicating normal distribution (George & Mallery, 2010). Separate repeated measure of analysis of variance (RM ANOVA) were used to compare differences in jump height (cm), absolute peak power (W), normalized peak power (W/kg), and reactive strength (m/s) from baseline across five sets. Alpha was set to 0.05.

Results

Participants showed no significant changes in jump height ($F_{(2.2,23.8)}$=0.588, p=0.576), absolute peak power ($F_{(5,55)}$=0.821, p=0.540), normalized peak power ($F_{(5,55)}$=0.490, p=0.782), or reactive strength ($F_{(5,45)}$=0.290, p=0.916) from baseline across the five sets demonstrating stability in power output. PAPE with

VL did produce practical increases in reactive strength and decreases in jump height, absolute peak power, and normalized peak power. See figure 3.

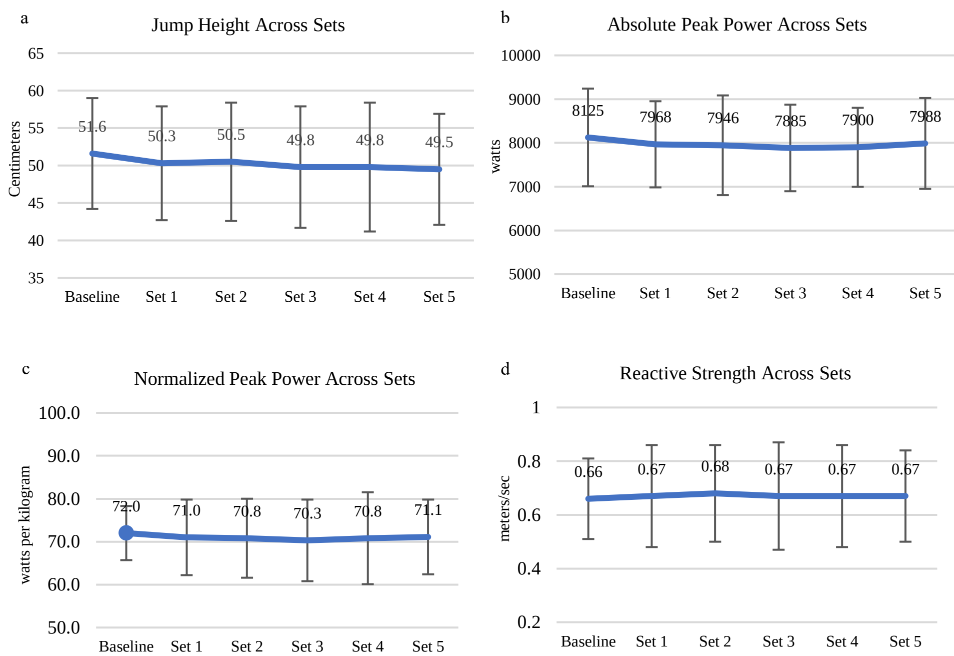

Figure 3. Means changes in (a) jump height, (b) absolute peak power, (c) normalized peak power, and (d) reactive strength from baseline across 5 sets of PAPE with VL.

Discussion

We sought to determine the effects of using VL as a method of PAPE over five sets during a live training session. The key finding was that all power variables remained stable. The maintenance of power across the sets of intense conditioning is remarkable. However, we expected to see potentiation, or significant increases in all power variables from baseline across all sets. Results may be influenced by (a) rest period, (b) lift velocity, and/or (c) muscle fiber type. The rest period between the VL squat set and the VJ was between 2 – 4 min. It was not controlled by the researchers, but rather a constraint of a coach directed live training session. Results from two meta-analyses on factors affecting post-activation potentiation and power (Dobbs et al., 2019; Wilson et al., 2013) showed that potentiation was optimal using moderate rest periods. Wilson et al (2013) concluded that rest periods of 7-10 min. were optimal over multiple sets. Dobbs et al (2019) concluded that rest intervals between 3-7 min. showed the greatest increase in potentiation (ES = 0.18, 95% CI

0.05 to 0.31, $p = 0.007$) compared with rest intervals of <3 min. (ES = −0.16, 95% CI −0.31 to 0.01, $p = 0.052$) between 8-12 min. (ES = 0.03, 95% CI −0.12 to 0.18, $p = 0.676$) and >12 min. (ES = 0.04, 95% CI −0.22 to 0.31, $p = 0.742$). Seitz et al (2014) tested jump power (absolute peak power, relative peak power, and jump height) before, 15 sec, 3, 6, 9, and 12 min. after a single set of three back squats and found that stronger individuals demonstrated significant potentiation at 3 min. with the greatest potentiation at 6 min. Weaker participants did not show significant potentiation until 6 min., and had the greatest potentiation response at 9 min. PAPE induces a state of fatigue, requiring a sufficient rest period before performing the subsequent explosive activity. While this period appears to be lower for stronger and highly trained individuals than weaker and recreationally trained individuals, participants in the current study may not have had adequate time between the VL squat set stimulus and the VJ performance. Dobbs et al (2019) suggested that rest intervals <3 min. may impair VJ power. However, a recent investigation using VL via a banded trap bar deadlift exercise to potentiate squat jumps over three rest intervals, 90, 120, and 150 sec, and found that 90 sec was optimal for enhancement jump performance (Masel & Maciejczyk, 2023). PAPE induced with accommodative resistance may allow for observance of potentiation in a smaller rest interval in comparison with original recommendations (Dobbs et al., 2019). However, bar or movement velocity were not measured in the Masel & Maciejczyk (2023) study.

The velocity of the VL may have influenced the results. This study utilized VL in the form of chains whereby as the bar was moved upward, the load increased because the chains were lifted off the ground; this was reversed as the bar was lowered. VL is different than traditional resistance training in that the changing resistance is thought to optimally overload the muscle at each point in its range of motion. A training study utilizing VL with chains over a four-week period was shown to be superior to traditional resistance training in developing lower body strength, but not power (Ataee et al., 2014). However, Ebben and Jensen (2002) found no difference in force production or muscle activity between back squats performed with and without chains. Coker et al. (2006) found no differences in movement velocity, or the rate and magnitude of the ground reaction force applied during two other lifts, the snatch and the clean with and without chains. Studies incorporating VL with chains as a method of inducing PAPE are limited. One study by Mina et al. (2016) reported that warming up with chain loaded back squats at 85% of one repetition maximum (1RM) enhanced subsequent free-weight 1RM back squat performance. No known studies have investigated the incorporation of VL with chains on potentiating jumps over successive sets. Thus, comparisons are limited. VL appears to cause greater fatigue compared to traditional methods due to higher neural involvement (Coker et al., 2006). This may be recruitment of additional stabilization muscles necessary to steady the bar when the chains are fully lifted from the floor (Ataee et al., 2014). Achieving peak performance is dependent upon the balance between fatigue and potentiation, and velocity loss during a set is considered a sign of neuromuscular fatigue (Sanchez-Medina & Gonzalez-Badillo, 2011). Using lift velocity as a target aids the practitioner in monitoring the level of effort. However, high-intensity exercise can potentiate the muscle groups involved but can also reduce maximum force generating capacity immediately after the contractions which may reduce the effect of mechanisms that elicit potentiation. Perhaps the target velocity of 0.90 m/s using VL with chains interferes with potentiation for the group. Individuals in the current study, such as the lighter participants (e.g., ball carriers) appeared to benefit from the protocol. Five of the six participants that were <100 kg demonstrated increases in jump height and normalized peak power from baseline to set 1; 4/6 demonstrated increases in absolute peak power. One participant >100 kg produced an enhancement, and it was in jump height only. Masel & Maciejczyk (2022) in their study using of 12 elite male volleyballers acknowledged that VL PAPE response may be individualized.

Variation in participant Type II muscle fiber relative to fat composition may have influenced the PAPE response. Participants were all about the same height, 1.88 ± 0.01 cm, but varied greatly in mass with a range of 86.9 to 151.0 kg. Larger football players of positions such as linemen also possess greater body fat percentages than their smaller ball carrier counterparts (Matthews & Wagner, 2009). Relative to size, larger players have a smaller Type II muscle fiber to body fat ratio. Type II muscles fibers have greater twitch force potentiation than Type I fibers (Hamada et al., 2003). This greater twitch potentiation is due to myosin light phosphorylation prior to a threshold amount of calcium (Ca+2) being released from a muscle contraction that activated the protein kinase Ca2+/calmodulin-dependent skeletal muscle myosin light chain kinase (Zhi et al., 2005). This leads to increasing Ca2+/ troponin-dependent force generation (Stull et al., 2011). Given the relative differences between player sizes that includes a smaller Type 2 muscle fiber to body fat ratio of the group's larger players, this may account for the lack of significant power increases.

This study has practical recommendations for practitioners. PAPE response through VL with chains with a velocity in the strength-speed zone may be individualized. Players lighter in total body mass may realize greater benefits. The protocol also calls for more precise control over the rest interval to understand if those responders benefited due to shorter (Masel & Maciejczyk, 2023) or longer (Dobbs et al., 2019) time intervals.

Conclusion

Acute PAPE through VL with chains in the strength-speed zone appears to preserve power output across multiple sets but does not increase power in highly trained athletes.

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