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Acute effects of intra-complex rest following back squats on vertical jump performance during complex training

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ABSTRACT

Post-activation performance enhancement and complex-contrast sets are prevalent in sports science research. Typical complex-contrast sets consist of heavy back squats, an intra-contrast rest period (ICRP) and vertical jumps (countermovement jumps [CMJ], or squat jumps [SJ]). Propulsive impulse (J_{prop}) is considered the leading indicator of jump performance. However, studies evaluating jump performance during complex-contrast sets use jump height as the primary performance measure, limiting insight into ICRP's effect on jump performance. We assessed the effect of a three-repetition maximum (3RM) back squat and six ICRPs on vertical jump J_{prop} and associated force-time components. Fourteen participants completed 12 experimental conditions, assigned equally to four testing sessions. Independent variables, in a 6x2 randomised, counterbalanced design, were ICRP (0, 60, 120, 180, 240, 300 s; ICRP0, ICRP60, ICRP120, ICRP180, ICRP240, ICRP300, respectively) and vertical jump (CMJ and SJ). Conditions consisted of baseline vertical jumps, followed by three back squat repetitions at 100% 3RM, an ICRP and experimental jumps. Symmetrised percentage changes between experimental and baseline jumps were assessed using repeated measures ANOVA and pairwise effect sizes. Results showed significant effects ($p \leq 0.05$) on CMJ average rate of force development (RFD) between ICRP0 and ICRP120 and ICRP0 and ICRP300. Pairwise comparisons showed medium and large effect sizes for and increases in CMJ RFD (g = 0.83-2.69) while SJ RFD decreased (g = 0.81-2.57). Small effect sizes were found for J_{prop}, peak force and mean force. Results suggest limited change in J_{prop} (g = 0.01-0.58) but back squats may potentiate RFD via the stretch-shortening cycle.

Keywords: conditioning, contrast training, power, strength

INTRODUCTION

Complex-contrast training (CCT) is an advanced training method characterised by alternating biomechanically similar high-load exercises (conditioning activity; CA) with lower-load (high-velocity) explosive activities whilst providing an intra-contrast rest period (ICRP) in between (22, 29; 49). The CA is thought to acutely enhance explosive force application of the subsequent activity after adequate intra-contrast rest (40). Repeated exposure to CCT theoretically results in a flattening of the force-velocity curve, shifting the middle of the curve "up and right" (54). Manipulating an athlete's force-velocity curve in this manner suggests rate of force development (RFD, the speed at which force is produced, measured as the slope of a force-time curve (38)) is augmented, enhancing explosive force application. High RFD is positively correlated with sports performance (38), as the ability to generate high force in a very short period of time is essential in sport-specific tasks such as jumping (42) or sprinting (52), with most sporting actions occurring in < 0.3s (56). Augmenting RFD is therefore a primary goal of the strength and conditioning coach and as such, training methods that may enhance force application and RFD are often used. Complex-contrast training is considered an efficacious training method that maximises (1) training time, which is often limited in athletic training schedules, (2) training density, as coaches can focus on two training variables within the same session and (3) yield of adaptation with multiple or enhanced concurrent adaptations, that chronically results in improved performance (19).

A near-maximal voluntary contraction requires maximal motor unit recruitment and synchrony to complete. It primes the nervous system for the subsequent explosive movement, with enhanced rate of motor unit recruitment, recruitment synchrony and stretch-shortening cycle (SSC) efficiency, all theoretically contributing to augmented force application (4). This mechanism, known as post-activation performance enhancement (PAPE), underpins CCT theory and efficacy. While the physiological mechanisms underpinning PAPE are debatable, it is generally accepted that CAs induce neuromuscular and metabolic fatigue, which coexists alongside PAPE. Following a muscular contraction, fatigue increases sharply, dominating any PAPE-induced enhancement (13, 32, 54). However, fatigue dissipates quicker than PAPE, allowing increased performance at some point post-CA. Therefore, to maximise force application in subsequent exercises, an ICRP allows fatigue to sufficiently diminish for PAPE to effectively augment subsequent explosive performance (27, 40, 54).

Research considering the effect of CCT on acute jump performance has considered numerous movement combinations, ICRPs and performance variables, with often confounding results and practical implications. Due to its effectiveness in augmenting lower limb force application (21, 60) and biomechanical similarity to many explosive movements (13), research frequently uses the back squat as the CA in complex sets (2, 12, 13, 22, 25, 31, 32, 46, 49, 58). The back squat is often paired with a vertical countermovement jump (CMJ) (12, 13, 16, 25, 29, 31, 32, 46, 49, 58) or squat jump (SJ) (2, 9, 59). Countermovement jump and SJ performance must be interpreted differently regarding the mechanisms underpinning change. Countermovement jumps use the SSC in a rapid change of direction at the bottom of the countermovement (1), maximising propulsion through storage and use of elastic energy and the stretch reflex (56). Squat jumps minimise the SSC by increasing the duration of the isometric hold at the bottom of the countermovement (2), with enhanced motor unit recruitment and muscle fibre excitability primarily responsible for changes in performance. Therefore, understanding the effect of CCT protocols on both jumps is necessary for practitioners, as exercise selection should be chosen by considering the adaptations required to enhance explosive performance.

When considering CCT set structure, CA intensity warrants scrutiny. Research comparing different CA loads on subsequent vertical jump performance has shown greater effects of high-load compared to low-load (25, 46), even when tonnage is equated between heavy, medium and light CAs (37). Furthermore, the biomechanical similarity between the CA and performance activity should be considered, as research suggests exercises should be biomechanically similar for specific potentiation of the performance activity (13, 48, 49). However, movement pattern interference may increase the ICRP required to observe PAPE, with execution speeds of subsequent movements possibly being negatively affected due to acute preservation of the slower CA motor pattern (4). However, to date, this has not been explicitly tested in PAPE-based research. The sample demographic also warrants consideration as CCT also exhibits greater PAPE effects in jumping, sprinting and throwing in populations of stronger participants with greater training ages and who perform at higher levels, possibly due to enhanced ability to resist fatigue and recruit high threshold motor units (9, 50).

However, ICRPs and dependent variables used for analysis produce conflicting results, with no consensus on CCT structure reached. Research considering high-load back squats has shown that improvements in jump performance occur with as little as 3-5 minutes of rest (2, 12, 13, 16, 59), indicating that, within this timeframe, fatigue has dissipated sufficiently to observe PAPE. However, Kilduff et al. (32) found that eight minutes ICRP is required to enhance CMJ performance, with no change in performance after four minutes, consistent with Jensen and Ebben (2003), who found no change in CMJ performance after four minutes. Conversely, Crewther et al. (13) and Scott et al. (49) reported enhanced CMJ performance at four, eight and 12 minutes post-CA, with results showing that vertical jump performance had returned to baseline and decreased by 16 minutes, respectively. To further confound matters, Jones and Lees (31) found no change in CMJ performance after ICRPs of zero, three, ten or 20 minutes. Regardless of an optimal time to elicit PAPE, these ICRPs are too long in practice for coaches to use or implement in their training programmes, as athletes' training time is often limited. It is therefore appropriate to examine whether reduced ICRPs can still induce PAPE and make training more compact.

Studies consider a range of kinetic and kinematic variables when assessing vertical jumps. Intuitively, jump height is considered a valuable metric for assessing vertical jump performance, and this is apparent in the current literature, with several studies evaluating only jump height as the dependent variable (13, 29, 58). However, jump height alone offers limited insight into performance as change in jumping strategy (assessed by evaluating force-time characteristics between initiation of the unweighting phase and take-off) is not considered (35, 43, 45). Using force-time measures to understand acute and chronic changes in jumping strategy is critical for coaches because different strategies wil impact jumping mechanics, such as changes in countermovement speed and braking forces or longer propulsion times (t_{prop}, 30). Despite changes in jumping strategy not necessarily affecting jump height, it is important to measure jump mechanics as it is impossible to attribute changes in force production to a mechanism from jump height alone. Thus, to provide more comprehensive understanding of vertical jump performance, besides jump height, studies have included kinetic variables, including propulsive impulse (J_{prop}), PF, RFD and peak power, that offer insight into how force application changes (2, 16, 31, 32, 46, 49, 59). It is understood from the impulse-momentum theorem and use of equations of motion that, as system mass is constant, changes in J_{prop} during vertical jumping result in proportional changes in jump height (34, 41). Despite one predicting the other, J_{prop} is a more insightful metric. Changes in jumping strategy and force application can be observed by assessing how J_{prop} components like RFD and t_{prop} have also changed to produce resultant changes in J_{prop}. Furthermore, despite discussed research showing that longer, impractical ICRPs may be required to observe augmented jump height, it remains unclear how shorter, more practical ICRPs effect J_{prop} components and overall force application, rather than jump height and J_{prop} alone. Comprehension of the effect of ICRP on J_{prop} components and thus jumping strategy is therefore invaluable to coaches in discerning the effect of a training programme and informing subsequent training blocks.

With increasing accessibility to reasonably priced force platforms, evaluating $J_{prop,}$ via force-time curve integration and its components may provide greater insight into force application than jump height alone. Studies have considered J_{prop} and some components (16, 46, 58). However, to date, none have comprehensively examined the force-time variables that can influence the shape of the force-time curve during vertical jump propulsion and the magnitude of J_{prop} at take-off. Therefore, this study aimed to assess the effect of high-load back squats and various ICRPs on CMJ and SJ performance by evaluating percentage change in J_{prop} at take-off and to elucidate the jumping strategy used by considering change in associated concentric force-time variables. We hypothesised that high-load back squats, followed by 120-300 s ICRP, would augment vertical jump J_{prop} and RFD.

METHODS

Experimental Approach to the Problem

The back squat was selected as it is widely used in practice for developing lower limb force application and is biomechanically similar to vertical jumping and other sporting activities (21, 60). Participants attended the facility on six separate occasions. The first session was to confirm back squat, CMJ and SJ competency. The second session was a maximum strength test to establish participants' three-repetition maximum (3RM) back squat. The subsequent four sessions were used for data collection. They were separated by seven days and were completed at the same time of day, at least two hours postprandial. Twelve conditions were randomly assigned evenly between sessions. A 6x2, randomised counterbalanced design was used to assess the effect of different ICRPs (0, 60, 120, 180. 240 and 300 s: ICRP0, ICRP60, ICRP120, ICRP180, ICRP240, ICRP300, respectively) on two types of vertical jump (CMJ and SJ) after completing a 3RM back squat. At the start of each session, a baseline set of five repetitions of SJ and CMJ, separated by five minutes, was collected for comparison against experimental jumps completed in the experimental conditions. Each condition was performed as a CCT set: three back squats, an ICRP, and one set of five vertical jumps. A within-subject design assessed the effect of 0 s, 60 s, 120 s, 180 s, 240 s and 300 s ICRP after back squat repetitions on subsequent CMJ and SJ J_{prop} and associated force-time components: PF, mean force (MF), RFD, and propulsion time (t_{prop}). The repetition from experimental and baseline sets with the highest J_{prop} was selected for comparison. Symmetrised percentage change in variables between peak baseline and experimental repetitions was statistically analysed using repeated measures ANOVA.

Subjects

Fourteen male recreational athletes (mean ± SD; age = 24.86 ± 4.45 years, stature = 1.76 ± 0.06 m, body mass = 81.84 ± 10.25, back squat 3RM = 131.71 ± 16.32 kg, back squat to body mass ratio = 1.63 ± 0.24) were recruited from local strength and conditioning facilities and sports teams. Recreational athletes trained for general strength, three or four times a week, with no focused strength and conditioning programme aligned to sports performance. Consistent with previous research, participants were required to have at least one year of strength and power training experience, a back squat to body mass ratio >1.3 (60), be injury-free for three months before data collection and able to perform the back squat, CMJ and SJ competently under supervision of an experienced strength and conditioning coach (49). The study was ethically approved by the Institutional Review Board. After explaining the risks and benefits of the study, participants completed and signed informed consent documents and physical activity readiness questionnaire forms. Participants were asked to refrain from exercise and alcohol consumption for 48 hours before data collection.

No previous study which we could base our calculations for an a priori sample size calculation has examined this topic. Therefore, we used the qualitative descriptions of the effects sizes reported in a similar study using vertical jumps before and after a conditioning contraction (16) to apply them to the present study's design. The effect sizes reported ranged from moderate to large. In order to detect a large effect (f = 0.4) with 80% power in a one-way within subjects ANOVA (4 conditions, alpha = 0.05, sphericity assumed), we would need 10 subjects. For a moderate effect (f = 0.25) with the same criteria, we would need 24 subjects (17).

Procedures

Anthropometrics

Participants' stature and body mass were recorded before the first data collection session. Stature was measured using a calibrated stadiometer (Seca 217, Seca, UK). Body mass was measured using calibrated weighing scales (Seca 899, Seca, UK).

Three Repetition Maximum Assessment

Upon arrival at the testing facility, participants completed a standardised dynamic warm-up before the 3RM test. As participants were considered recreational athletes, procedures for the 3RM test followed the process outlined by Sheppard and Triplett (51). Participants self-reported a 3RM back squat, from which up to 90% warm-up sets were calculated. 3RM attempts were then completed until participants could not complete all three repetitions within a set. All repetitions during the 3RM test and subsequent data collection were conducted using a 20 kg Olympic barbell, competition bumper plates, collars and a squat rack (Werksan, Ankara, Turkey, provided by TechnoGym, UK). Participants typically reached 3RM within four sets. For repetitions to count, participants' hip axis had to pass below the knee axis in relation to the horizontal and return to standing, keeping the feet flat on the floor throughout. An experienced strength and conditioning coach monitored all repetitions.

Mean velocity (v_{mean}) of all repetitions during the 3RM test was measured using a Vitruve Encoder (Vitruve Fit, Spain) to ensure a true 3RM was achieved. Vitruve Encoder reliability for measuring back squat barbell v_{mean} at 90% 1RM, a similar intensity to 3RM has previously been reported by Kilgallon et al. (33): coeffient of variation (CV) = 8.8%, intra-class correlation coefficient (ICC) = 0.77. Research has shown that team sport and recreational athletes who use back squats to improve general physical preparedness and are therefore less conditioned to the high-intensity lifts required for repetition maximum testing will complete the final repetition of a repetition maximum test with $v_{mean} \leq 0.3$ $m \cdot s^{-1}$ (39). This was thus used as the minimal velocity threshold for the 3RM. Participants were allowed to continue until all three repetitions could not be completed. However, if all repetitions at a heavier load could not be completed, the set where v_{mean} of the third repetition was ≤ 0.3 $m \cdot s^{-1}$ was recorded as the 3RM. Three-repetition maximum v_{mean} was compared against experimental back squat repetitions to assess fatigue and determine whether PAPE was elicited.

Experimental Procedures

Participants were instructed to report to the testing facility at least two hours postprandial and fully hydrated. Participants were asked to refrain from caffeine consumption in the six hours preceding data collection and from alcohol consumption and vigorous exercise 48 hours before data collection.

After a familiarisation session during which participants confirmed their ability to complete the back squat, CMJ and SJ according to technical models described by Brewer and Favre (7), Acero et al. (1) and Arabatzi et al. (2) respectively, participants attended the laboratory for a 3RM assessment. Participants then completed four subsequent data collection sessions, seven days apart. Each session started with a brief to remind participants of the testing procedure, followed by confirmation that participants were injury-free and that instructions regarding nutrition and exercise had been followed. The structure of data collection sessions can be seen in Figures 1 and 2.

INSERT FIGURE 1 ABOUT HERE

INSERT FIGURE 2 ABOUT HERE

Participants completed a standardised, coach-led warm-up consisting of low-intensity static bike, dynamic mobility and activation exercises, including inch worms, lunge walks, glute bridges, deadbugs, bodyweight squats and submaximal vertical jumps. After five minutes of rest, participants completed two baseline sets: five SJ repetitions and five CMJ repetitions in a randomised order, separated by five minutes of rest. Participants were instructed to complete all jumps maximally. After 10 minutes of rest, participants completed five warm-up sets of back squats at prescribed percentages of 3RM up to 90% (Table 1). Warm-up sets were separated by two minutes.

INSERT TABLE 1 ABOUT HERE

After completing the final warm-up set, participants had a further five minutes rest before completing three randomly assigned experimental conditions. Each experimental condition consisted of one CCT set: one set of three back squat repetitions at 100% 3RM, followed by a randomly selected ICRP, followed by five repetitions of a randomly selected vertical jump. Experimental conditions can be seen in Figure 3. Between experimental conditions, participants had 10 minutes of rest to minimise fatigue (26). Participants completed three trials per session until every combination of the two independent variables had been completed. Trial order within and between data collection sessions was assigned randomly via a random number generator produced in Microsoft Excel (Microsoft, USA).

INSERT FIGURE 3 ABOUT HERE

Consistent with the 3RM test, v_{mean} for all back squat repetitions was measured for comparison to the original 3RM. Raw CMJ and SJ force-time data were collected using two force platforms (PS-2141, Pasco, Roseville, CA, USA) sampling at 1000 Hz, connected to Pasco Capstone software (Pasco Capstone 2.0, Pasco, Roseville, CA, USA). For every CMJ and SJ repetition, raw vertical ground reaction force (GRF) data from both force platforms were summated to provide total GRF (GRF_{total}).

Data Processing

Raw data was copied into separate Microsoft Excel templates for CMJ and SJ. Bodyweight was calculated as the mean of all data points in the weighing phase – the first 2000 recorded data points of each recorded jump (43). This value was used to calculate net GRF (GRF_{total} minus bodyweight) and subsequently impulse via the impulse-momentum theorem (23, 41).

Determining the Propulsive Phase of Countermovement and Squat Jumps

The propulsive phase of CMJ was deemed to start at the data point where instantaneous negative centre of mass velocity reached 0 $m{\cdot}s^{-1}$, coinciding with peak negative centre of mass displacement (36, 43). Squat jump repetitions were considered to start at the instantaneous data point where GRF_{net} first exceeded 50 N (44). The propulsive phase of both CMJ and SJ continued until the instantaneous data point where GRF_{total} reached 0 N (36). At this point, it was deemed that positive force production had ceased, and participants had fully left the ground.

Vertical Ground Reaction Forces Calculations

The repetition from each experimental and baseline set with the highest instantaneous J_{prop} at the point of take-off was used for analysis. Force-time variables were subsequently calculated from the propulsive phase. Peak force was calculated as the highest instantaneous GRF_{total} data point within the propulsive phase. Mean force was calculated as the mean of all GRF_{total} data points within the propulsive phase (60).

Propulsion time was calculated as the difference in time between the end and start of propulsion.

Rate of force development variables were calculated through force-time curve differentiation. Different RFD measurements were used for CMJ and SJ repetitions. Rate of force development was calculated for CMJ repetitions using equations described by Boullosa et al. (6) and Perez-Castilla et al. (44). Peak RFD (RFD_{peak}) was calculated as the largest instantaneous RFD point in the propulsive phase. Average RFD (RFD_{ave}) was calculated as the difference between instantaneous PF and instantaneous GRF_{total} at the start of the propulsive phase, divided by the difference in time between these two points. RFD index (RFD_i) was calculated as RFD_{peak} divided by the difference in time between RFD_{peak} and the start of the propulsive phase. For SJ, RFD_{ave} was calculated similarly to CMJ (42). Rate of force development was also calculated over the first 50 (RFD_{50}), 100 (RFD_{100}) and 150 ms (RFD_{150}) of the propulsive phase (24, 55). These variables were calculated as the difference between the instantaneous GRF_{total} at 50, 100 and 150 ms and the instantaneous GRF_{total} at the start of the propulsive phase, divided by the difference in time between these two points. Intra-class correlation coefficients (ICC), typical error (TE) and smallest worthwhile change (SWC) for all dependent variables are presented in Table 2.

Force-time variables from the best-performed jump repetition from the experimental set (based on J_{prop}) were then analysed by calculating the symmetrised percentage change between it and the best-performed jump repetition from the corresponding baseline set (14). Symmetrised percentage change was then statistically analysed to assess the effect of ICRP on each dependent variable. Individual analyses were completed by comparing change between experimental and baseline peak repetitions to SWC values (Table 2). If TE was higher than SWC, individual analyses were completed using 2*TE (28). Countermovement jumps and SJ were statistically analysed separately.

Statistical Analyses

Variables were tested for normality and confirmed using the Shapiro-Wilks test and visual inspection of Q-Q plots. Within-subject reliability for each variable was assessed with ICCs to assess intra-rater reliability and TE to assess absolute reliability. Intra-class correlation coefficients were calculated between the first and second repetitions of the baseline CMJ and SJ sets completed during the first data collection session (Table 2). 0.00–0.10, 0.10–0.30, 0.30–0.50, 0.50–0.70, 0.70–0.90, and 0.90–1.00 were classed as trivial, small, moderate, large, very large, and nearly perfect ICCs, respectively (28). Typical error was calculated as the standard deviation of the difference between baseline repetition one and two divided by $\sqrt{2}$ (53) using standard deviations and ICCs calculated between the same baseline repetitions (Table 2). Smallest worthwhile change was calculated as 0.35 multiplied by the standard deviation of baseline repetition one (53).

The difference in average back squat v_{mean} between experimental conditions was assessed using repeated measures ANOVA. Symmetrised percentage change was used to examine differences in dependent variables between conditions. To assess the statistical power of percentage change, Pearson correlations (r) were calculated between peak experimental and baseline condition repetitions for each variable, where $r > 0.65$ and $r > 0.8$ show statistical power (1-β) of 84.8% and 97.7%, respectively (57). The difference in dependent variables between peak experimental and baseline repetitions was examined between ICRP conditions using repeated measures ANOVA. Significant main effects were further examined using Holm's Sequential Bonferroni stepwise adjusted pairwise comparisons, and corrected values are reported. Overall effect size was calculated using partial eta-squared (η_p^2) (18), where 0.0099, 0.0588, and 0.1379 were considered small, medium, and large effect sizes (11). Bias-corrected pairwise effect sizes (Hedge's g) with 95% confidence intervals were also calculated to interpret change between experimental and baseline peak repetitions for each ICRP and force-time variable (10). Based on a sample of recreationally trained participants, < 0.35, 0.35–0.80, 0.81–1.50, > 1.50 were defined as trivial, small, moderate and large effect sizes respectively (47). All data are presented as mean ± SD unless otherwise stated. Significance was set at $p < 0.05$. All data were statistically analysed in IBM SPSS Statistics for Windows, version 26.0 (IBM Corp., Armonk, N.Y., USA).

RESULTS

Dependent Variable Reliability

Intraclass correlation coefficients, TE and SWC examined between the first two repetitions of the first completed baseline set of CMJ and SJ, are presented in Table 2.

INSERT TABLE 2 ABOUT HERE

Back Squat Mean Velocity

Table 3 presents v_{mean} for all three back squat repetitions completed during the 3RM assessment and each condition. Repeated measures ANOVA of the average of all three repetitions for 3RM and CMJ conditions showed a significant main effect ($p < 0.001$). Post hoc analysis showed pairwise significant differences between 3RM and ICRP0 ($p = 0.010$), 3RM and ICRP60 ($p = 0.006$), 3RM and ICRP180 ($p = 0.035$) and 3RM and ICRP240 ($p = 0.027$). Repeated measures ANOVA of the average of all three repetitions for 3RM and SJ conditions showed a significant main effect ($p < 0.001$). Post hoc analysis showed pairwise significant differences between 3RM and ICRP120 ($p = 0.026$), 3RM and ICRP180 ($p = 0.011$) and 3RM and ICRP240 ($p = 0.047$).

INSERT TABLE 3 ABOUT HERE

Countermovement Jump

Pearson correlations between experimental and baseline peak CMJ repetitions for all ICRPs showed correlations > 0.65 for PF, MF, PRFD and t_{prop}. All other variables had correlations ≥ 0.65 except for J_{prop}: ICRP0 (0.64), ARFD: ICRP120 and ICRP180 (0.63 and 0.64, respectively) and RFD_{index}: ICRP120 and ICRP300 (0.64 and 0.64, respectively).

Table 4 presents symmetrised percentage change between peak experimental and baseline CMJ repetitions. Repeated measures ANOVA results showed a significant main effect for RFD_{ave} (p = 0.042, η_p^2 = 0.146). Post hoc analysis showed significant pairwise effects between ICRP0 and ICRP120 (p = 0.036) and ICRP0 and ICRP300 (p = 0.019). No other force-time variable showed significant main effects. Pairwise effect sizes with 95% confidence intervals between peak experimental and baseline repetitions are also reported. Percentage of participants within each condition that showed changes in CMJ variables greater than SWC or 2*TE (if TE > SWC) can be seen in Table 5.

INSERT TABLE 4 ABOUT HERE

INSERT TABLE 5 ABOUT HERE

Squat Jump

Pearson correlations between experimental and baseline peak SJ repetitions for all ICRPs showed correlations > 0.65 for PF and MF. All other variables had correlations ≥ 0.65 except for J_{prop}: ICRP300 (0.42), RFD_{ave}: ICRP180 and ICRP300 (0.50 and 0.46, respectively), RFD50: ICRP0, ICRP60, ICRP120, ICRP180, ICRP240 and ICRP300 (0.51, 0.49 0.41, 0.60, 0.47 and 0.46, respectively), RFD100: ICRP120, ICRP180, ICRP240 and ICRP300 (0.47, 0.49, 0.48, and 0.56, respectively), RFD150: ICRP60 and ICRP180 (0.58 and 0.43, respectively) and t_{prop}: ICRP0 (0.51).

Table 6 shows symmetrised percentage change between peak experimental and baseline SJ repetitions. Repeated measures ANOVA results showed no significant main effects between ICRPs for any force-time variable. Pairwise effect sizes between peak experimental and baseline repetitions with 95% confidence intervals are also reported. Percentage of participants that showed changes in SJ variables that were greater than SWC or 2*TE TE (if TE > SWC) can be seen in Table 7.

INSERT TABLE 6 ABOUT HERE

INSERT TABLE 7 ABOUT HERE

DISCUSSION

This study aimed to assess the effect of high-load back squats and various ICRPs on maximal CMJ and SJ performance by evaluating percentage change in J_{prop} at take-off and to elucidate the jumping strategy used by considering change in associated concentric force-time variables. This is the first study to examine multiple ICRPs and two vertical jump variations. Despite small percentage changes in performance observed between peak experimental and baseline repetitions for most dependent variables, our results show no difference in J_{prop} (and therefore jump height) and almost all related components between conditions for either jump. The lack of significant differences between conditions suggests that ICRP had minimal effect on whether PAPE was elicited. However, medium and large pairwise effect sizes and larger percentage changes were detected for RFD variables in both jumps. Compared to baseline CMJ repetitions, experimental RFD largely increased, while experimental SJ repetitions largely decreased compared to baseline. This suggests that despite no difference between ICRP conditions, back squats may elicit PAPE on vertical jump RFD via the countermovement, regardless of ICRP duration. In agreement with previous research (15, 31), our results suggest that while it is unlikely that PAPE was elicited after a specific ICRP, heavy back squats also do not hinder subsequent ballistic activities, regardless of ICRP, and may enhance RFD via improved SSC efficiency. This is important for practitioners who may benefit from the time-saving benefits of this observation, with the possibility of non-detrimentally eliciting multiple stimuli and specifically targeting RFD within the same session.

Repeated measures ANOVA showed no significant differences between ICRPs for any dependent SJ variable, while some differences were revealed between CMJ variables. Significant main effects were found between ICRPs for RFD_{ave}, with post hoc analysis showing significant differences between ICRP0 and ICRP120 and ICRP0 and ICRP300. However, these were not between consecutive ICRPs, suggesting that PAPE is unlikely the mechanism, as it is doubtful that enhanced performance would return after diminishing. Despite the lack of change observed between ICRPs, symmetrised percentage change results show small changes in performance from baseline in most dependent variables across all ICRPs (Tables 4 and 6). Pairwise comparisons showed small effect sizes for J_{prop} for both jump variations (except SJ: ICRP60 and ICRP120), which is consistent with Hanson et al. (25), suggesting ICRPs had little effect on overall jump height, of which J_{prop} is considered the main predictor (41). However, medium and large effect sizes were revealed between peak experimental and baseline repetitions for components of J_{prop}, suggesting that while J_{prop}, the overall performance marker, remained largely unchanged, force application and the shape of the force-time curve were manipulated to generate similar performances across ICRPs.

The largest percentage changes and effect sizes between peak experimental and baseline repetitions were observed in RFD variables. Consistent with Bogdanis et al. (5), CMJ experimental RFD variables increased from baseline; moderate and large effect sizes suggest both RFD_{peak} and RFD_{ave} were augmented in all experimental conditions except ICRP0. This suggests, in addition to the repeated measures ANOVA results, that high-load back squats may elicit PAPE and improve RFD via the SSC by enhancing the use of stored elastic energy within, and stiffness of, the musculotendon unit (56). This is supported by SJ results where, when the SSC is minimised, and performance depends on rapid, synchronised motor unit recruitment, experimental RFD variables largely decreased compared to baseline. However, these results contradict Arabatzi et al. (2), who observed improved RFD in SJ. Furthermore, small percentage changes in PF and MF observed in both jumps suggest minimal change in motor unit recruitment from baseline which, despite contradicting some research (49, 59), is consistent with the general consensus that any potential performance enhancement is unlikely to be the result of increases in maximal force production (54). Therefore, to achieve similar SJ J_{prop} values, medium and large effect sizes suggest t_{prop} increased (negatively affecting RFD) to maintain jump performance, advocating the need to change jump strategy and spend longer applying force to the ground to reach similar PF and J_{prop} values. These combined results are consistent with the notion that if PAPE was elicited by high-load CAs, it likely primarily affects RFD via the SSC rather than the extremes of the force-velocity curve (54).

Analysis of back squat v_{mean} may support the idea that PAPE was not elicited. Post hoc analysis of v_{mean} showed significant pairwise differences between 3RM and experimental conditions, with none found between experimental conditions. Likewise, v_{mean} was higher for all repetitions during experimental conditions than during 3RM assessment (Table 3). Participants typically required four attempts to establish 3RM, resulting in accumulated fatigue (20). However, during experimental conditions, participants performed back squats consistently faster (indicated by the lack of significance between higher v_{mean} values during experimental conditions), potentially due to the longer rest period provided between experimental conditions. However, higher v_{mean} values may suggest that PAPE was not elicited, as participants did not receive the same accumulated neuromuscular stimulus from experimental back squats compared to 3RM (26).

The results of this study mirror those of Jones and Lees (31), who used a demographic similar to ours. Their inclusion criteria required participants to back squat >1.5 x body mass. They found no changes in CMJ performance at various time points between 0 and 20 minutes. While participants in our study had a back squat to body mass ratio of 1.63 ± 0.24, greater than Jones and Lees (31), this is still lower than similar studies (ratios ranged from 1.75-2.10) where enhanced performance was observed (12, 16, 49). Research suggests stronger athletes are more likely to benefit from PAPE (46). A well-established correlation between strength levels and type II muscle fibre development suggests the ability to better recruit high-threshold motor units. Furthermore, stronger athletes may have a greater ratio of type II to type I motor units (13). The lower ratio in our study suggests that our demographic may not have sufficient strength to benefit from PAPE. Moreover, the recreational status of the sample, although familiarised with vertical jumping, may have required more experience of regular jump training and may be less consistent in their jumping performance and strategy between repetitions (3), contributing to the high levels of variance observed in Tables 4 and 6.

Finally, one factor that has received some attention in PAPE-based studies is individual responses, which can occur due to training status, strength levels and task specificity (8) Tables 5 and 7 show the percentage of participants who produced experimental CMJ and SJ above SWC or 2*TE (in cases where TE > SWC (28)) for each dependent variable when compared to baseline. There was no discernible pattern or apparent change in these percentages with statistical differences or not. Identifying the reasons for individual responses was beyond the scope of the present study, and analysis is provided as a guide for efficacy of the training stimulus provided by CCT on a group of recreational athletes.

The sample size considered in this study (n = 14) was informed by an a priori sample size estimation and was similar to other studies with similar research aims. Numerous studies have examined the effects of ICRP on jump performance using 8-16 participants (13, 31, 46, 58, 59) with varying results. Jones and Lees (31) found no change in jump performance, acknowledging that using a sample size of eight participants with a back squat to body mass ratio >1.5 resulted in a lack of significant results despite data trending towards elicited PAPE, citing variance and possible type II error as the reason for not detecting an effect. Conversely, Crewther et al. (13) found significant improvements in jump performance in a sample of nine participants with a ratio of >1.5. Furthermore, the sample size limits individual analyses, where more participants may be required to show trends in the percentage of participants exceeding TE and SWC thresholds.

Using RFD as a jump performance metric may further magnify the variance observed in the data. McLellan et al. (42) reported that RFD metrics have low test-retest reliability (CV: 11.8%). The results of this study agree, with RFD variables showing some of the highest standard deviations around the mean (Tables 4 and 6), lowest ICCs and highest TEs (Table 2). However, when considering how J_{prop} changes with respect to force application, RFD metrics are a vital analytical component and should not be omitted. These points suggest that the sample size needs to be increased to account for sample and measurement variance and reduce the possibility of a type II error.

Based on the lack of significant findings between ICRP conditions, we conclude that no evidence supports the hypothesis that an ICRP of 120-300 s will augment jump performance after high-load back squats when performed as a CCT set. This is supported by minimal percentage change and small pairwise effect sizes between experimental and baseline repetitions for J_{prop}. However, PAPE cannot be completely ruled out due to the medium and large pairwise effect sizes found for RFD variables. Regardless of ICRP, the results suggest that high-load back squats may elicit PAPE and enhance vertical jumping RFD via the SSC rather than maximal force production. Future research should use a larger sample size to increase data homogeneity and reduce the likelihood of type II error and stronger participants to increase CA neuromuscular stimulus before explosive activities. Movement pattern interference should be specifically considered in PAPE-based studies to assess whether the longer

ICRPs required for PAPE to be observed in some research is due to preservation of CA movement pattern speeds. Furthermore, longitudinal studies should be completed to better understand the chronic effect of ICRP duration to lower limb vertical jump performance and explosive force application.

Practical Application

Complex-contrast training is widely used in training settings to maximise lower limb force application. This study has shown that high-load back squats may provide a stimulus sufficient to enhance RFD, a critical component of J_{prop}, from almost immediately post-CA up to 300 s, allowing practitioners to maximise training density and possibly adaptation, as it may not be necessary to wait for long periods post-CA to achieve greater propulsive RFD. It may be necessary for practitioners to consider PAPE response by assessing individual relationships between ICRPs and SWC for force-time metrics due to the variance observed in force-time metrics.

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TABLE LEGENDS

Table 1. Back squat warm-up sets.

Table 2. Intra-class correlation coefficient, typical error and smallest worthwhile change with 95% confidence intervals for countermovement jump and squat jump dependent variables.

Table 3. Back squat mean velocity.

Table 4. Symmetrised percentage change, expressed as mean ± SD, in propulsive force-time variables between peak experimental and peak baseline countermovement jump repetitions. Hedges *g* pairwise effect sizes with 95% confidence intervals between peak experimental and peak baseline repetitions is also included. *denotes significant difference ($p < 0.05$) for symmetrised percentage changes compared to ICRP0 condition.

Table 5. Percentage of participants showing changes in countermovement jump force-time variables greater than typical error and smallest worthwhile change.

Table 6. Symmetrised percentage change, expressed as mean ± SD, in propulsive force-time variables between peak experimental and peak baseline squat jump repetitions. Hedges *g* pairwise effect sizes with 95% confidence intervals between peak experimental and peak baseline repetitions is also included. *denotes significant difference ($p < 0.05$) for symmetrised percentage changes compared to ICRP0 condition.

Table 7. Percentage of participants showing changes in squat jump force-time variables greater than typical error and smallest worthwhile change.

FIGURE LEGENDS

Figure 1. Session overview of the data collection process.

Figure 2. Step 4: Experimental conditions.

Figure 3. Experimental conditions. Intra-contrast rest period (ICRP) and vertical jump were randomly assigned.

TABLES

Table 8. Back squat warm-up sets.

Set	Repetitions	Intensity	Rest (s)
1	10	20 kg bar	120
2	8	40% 3RM	120
3	5	60% 3RM	120
4	3	80% 3RM	120
5	3	90% 3RM	300

Table 9. Intra-class correlation coefficient, typical error and smallest worthwhile change with 95% confidence intervals for countermovement jump and squat jump dependent variables.

Jump	Variable	ICC	TE	SWC
CMJ	Propulsive Impulse (N·s)	0.97 (0.89-0.99)	10.16 (2.63-17.69)	13.76 -6.83-34.35)
	Peak Force (N)	0.93 (0.79-0.98)	123.73 (32.07-215.40)	122.98 (-61.08-307.04)
	Mean Force (N)	0.97 (0.92-0.99)	59.95 (15.54-104.36)	92.01 (-45.70-229.70)
	Peak RFD ($N \cdot s^{-1}$)	0.76 (0.44-0.92)	737.14 (-366.09-1840.38)	1270.12 (329.22-2211.03)
	Average RFD ($N \cdot s^{-1}$)	0.78 (0.30-0.93)	632.41 (-314.08-1578.89)	1070.11 (277.38-1862.84)
	RFD Index ($N \cdot s^{-2}$)	0.50 (0.22-0.68)	5585.01 (-2773.72-13943.74)	13085.85 (3391.90-22779.81)
	Propulsion Time (s)	0.87 (0.58-0.96)	0.02 (0.01-0.04)	0.02 (-0.01-0.04)
SJ	Propulsive Impulse (N·s)	0.96 (0.68-0.95)	21.65 (5.61-37.88)	15.21 (-7.55-37.96)
	Peak Force (N)	0.99 (0.97-1.00)	46.80 (12.13-81.47)	119.86 (-59.53-299.24)
	Mean Force (N)	0.98 (0.95-1.00)	39.45 (10.22-68.67)	77.15 (-38.32-192.62)
	Average RFD ($N \cdot s^{-1}$)	0.95 (0.84-0.98)	710.16 (184.07-1236.24)	805.49 (-400.04-2011.02)
	RFD 50 ms ($N \cdot s^{-1}$)	0.78 (0.32-0.93)	1140.97 (-566.65-2848.59)	1923.93 (498.69-3349.18)
	RFD 100 ms ($N \cdot s^{-1}$)	0.67 (0.33-0.86)	901.82 (-447.87-2251.51)	1958.60 (507.68-3409.53)
	RFD 150 ms ($N \cdot s^{-1}$)	0.72 (0.22-0.91)	780.55 (-387.65-1948.74)	1480.00 (383.62-2576.39)
	Propulsion Time (s)	0.96 (0.89-0.99)	0.02 (0.00-0.03)	0.02 (-0.01-0.04)

CMJ, countermovement jump; SJ, squat jump; ICC, intraclass correlation coefficient; TE, typical error; SWC, smallest worthwhile change; RFD, rate of force development.

Table 10. Back squat mean velocity.

Condition (ICRP (s) /Jump)	R1 ($m \cdot s^{-1}$)	R2 ($m \cdot s^{-1}$)	R3 ($m \cdot s^{-1}$)	Average ($m \cdot s^{-1}$)
3RM	0.38 ± 0.05	0.33 ± 0.02	0.29 ± 0.03	0.33 ± 0.02
0 s / CMJ	0.42 ± 0.04	0.39 ± 0.04	0.36 ± 0.04	0.39 ± 0.04
60 s /CMJ	0.41 ± 0.04	0.38 ± 0.04	0.34 ± 0.04	0.38 ± 0.03
120 s / CMJ	0.42 ± 0.04	0.39 ± 0.04	0.35 ± 0.04	0.39 ± 0.04
180 s /CMJ	0.41 ± 0.04	0.39 ± 0.04	0.35 ± 0.04	0.38 ± 0.04
240 s /CMJ	0.42 ± 0.03	0.38 ± 0.04	0.34 ± 0.04	0.38 ± 0.03
300 s / CMJ	0.42 ± 0.05	0.38 ± 0.04	0.36 ± 0.05	0.39 ± 0.04
0 s / SJ	0.43 ± 0.05	0.39 ± 0.06	0.35 ± 0.06	0.39 ± 0.05
60 s /SJ	0.42 ± 0.05	0.37 ± 0.05	0.34 ± 0.05	0.38 ± 0.04
120 s / SJ	0.43 ± 0.05	0.39 ± 0.04	0.34 ± 0.05	0.39 ± 0.04
180 s / SJ	0.43 ± 0.04	0.39 ± 0.05	0.36 ± 0.06	0.39 ± 0.04
240 s / SJ	0.43 ± 0.05	0.38 ± 0.05	0.34 ± 0.04	0.38 ± 0.04
300 s / SJ	0.42 ± 0.04	0.39 ± 0.04	0.36 ± 0.06	0.39 ± 0.04

ICRP, intra-contrast rest period; R1-3, repetition one, two and three; Average, mean of three repetitions; CMJ, countermovement jump; SJ, squat jump.

Table 11. Symmetrised percentage change, expressed as mean ± SD, in propulsive force-time variables between peak experimental and peak baseline countermovement jump repetitions. Hedges *g* pairwise effect sizes with 95% confidence intervals between peak experimental and peak baseline repetitions is also included. *denotes significant difference ($p < 0.05$) for symmetrised percentage changes compared to ICRP0 condition.

	Intra-contrast rest period (s)					
	0	**60**	**120**	**180**	**240**	**300**
Propulsive Impulse (N·s)	0.25 ± 2.11 *g* = 0.01 (-0.73-0.75)	0.38 ± 1.73 *g* = 0.07 (-0.67-0.82)	-0.57 ± 1.36 *g* = 0.06 (-0.80-0.68)	0.17 ± 0.84 *g* = 0.02 (-0.76-0.72)	0.83 ± 1.33 *g* = 0.53 (-0.23-1.28)	-0.14 ± 2.58 *g* = 0.38 (-0.37-1.13)
Peak Force (N)	0.62 ± 0.83 *g* = 0.28 (-0.47-1.02)	-0.52 ± 1.01 *g* = 0.08 (-0.82-0.66)	0.86 ± 0.81 *g* = 0.64 (-0.12-1.40)	0.75 ± 0.76 *g* = 0.49 (-0.26-1.25)	0.88 ± 0.96 *g* = 0.48 (-0.27-1.24)	1.12 ± 0.63 *g* = 0.54 (-0.22-1.29)
Mean Force (N)	1.71 ± 0.61 *g* = 0.93 (0.15-1.71)	0.38 ± 0.56 *g* = 0.25 (-0.50-0.99)	0.79 ± 0.80 *g* = 0.45 (0.301.20)	1.36 ± 0.61 *g* = 0.77 (0.00-1.53)	0.62 ± 0.55 *g* = 0.28 (-0.47-1.02)	2.13 ± 0.73 *g* = 0.98 (0.17-1.73)
Peak RFD ($N·s^{-1}$)	1.69 ± 5.83 *g* = 0.75 (-0.02-1.52)	6.38 ± 6.97 *g* = 0.94 (0.16-1.73)	-0.66 ± 6.38 *g* = 0.34 (-0.42-1.08)	3.12 ± 5.70 *g* = 0.57 (-0.19-1.32)	5.93 ± 5.49 *g* = 1.24 (0.43-2.05)	5.01 ± 7.22 *g* = 0.80 (0.03-1.57)
Average RFD ($N·s^{-1}$)	-11.84 ± 5.07 *g* = 2.52 (1.53-3.52)	4.00 ± 5.96 *g* = 0.94 (0.16-1.72)	5.23 ± 6.04* *g* = 0.83 (0.34-1.31)	3.18 ± 5.97 *g* = 0.52 (-0.23-1.28)	-1.52 ± 7.94 *g* = 0.29 (-0.45-1.04)	16.07 ± 7.20* *g* = 1.70 (0.83-2.56)
RFD index ($N·s^{-2}$)	8.77 ± 6.18 *g* = 2.10 (1.18-3.03)	9.17 ± 8.81 *g* = 1.81 (0.93-2.69)	3.73 ± 7.42 *g* = 1.13 (0.33-1.93)	10.91 ± 8.81 *g* = 1.60 (0.75-2.46)	1.95 ± 5.60 *g* = 0.19 (-0.55-0.93)	12.62 ± 10.88 *g* = 2.69 (1.67-3.71)
Propulsion Time (s)	3.16 ± 1.56 *g* = 0.24 (-0.50-0.98)	1.68 ± 1.29 *g* = 1.05 (0.26-1.85)	1.16 ± 1.69 *g* = 0.65 (0.13-1.41)	3.49 ± 1.90 *g* = 1.51 (0.67-2.35)	0.94 ± 1.22 *g* = 0.08 (-0.66-0.82)	1.43 ± 1.62 *g* = 0.87 (0.10-1.65)

Table 12. Percentage of participants showing changes in countermovement jump force-time variables greater than typical error and smallest worthwhile change.

	Intra-contrast rest period (s)					
	0	60	120	180	240	300
Propulsive Impulse (N·s)	14.29	0.00	7.14	0.00	0.00	14.29
Peak Force (N)	21.43	14.29	7.14	7.14	7.14	7.14
Mean Force (N)	28.57	0.00	7.14	0.00	0.00	7.14
Peak RFD ($N·s^{-1}$)	35.71	50.00	42.86	42.86	50.00	50.00
Average RFD ($N·s^{-1}$)	21.43	28.57	50.00	21.43	35.71	35.71
RFD index ($N·s^{-2}$)	7.14	50.00	50.00	28.57	21.43	57.14
Propulsion Time (s)	7.14	42.86	28.57	50.00	35.71	42.86

Table 13. Symmetrised percentage change, expressed as mean ± SD, in propulsive force-time variables between peak experimental and peak baseline squat jump repetitions. Hedges *g* pairwise effect sizes with 95% confidence intervals between peak experimental and peak baseline repetitions is also included. *denotes significant difference ($p < 0.05$) for symmetrised percentage changes compared to ICRP0 condition.

	Intra-contrast rest period (s)					
	0	**60**	**120**	**180**	**240**	**300**
Propulsive Impulse (N·s)	0.81 ± 2.39 *g* = 0.15 (-0.60-0.80)	1.57 ± 2.42 *g* = 0.70 (0.06-1.46)	2.19 ± 2.48 *g* = 0.65 (0.11-1.41)	0.34 ± 2.39 *g* = 0.01 (-0.73-0.75)	2.04 ± 1.66 *g* = 0.68 (0.08-1.44)	-0.62 ± 2.72 *g* = 0.12 (-0.86-0.63)
Peak Force (N)	1.70 ± 0.80 *g* = 0.90 (0.12-1.67)	1.95 ± 0.78 *g* = 0.90 (0.12-1.68)	-0.08 ± 0.68 *g* = 0.15 (-0.89-0.59)	0.72 ± 0.45 *g* = 0.27 (-0.47-1.02)	0.39 ± 0.57 *g* = 0.21 (-0.53-0.96)	1.78 ± 1.09 *g* = 0.72 (0.05-1.48)
Mean Force (N)	2.29 ± 0.60 *g* = 1.42 (-0.59-2.25)	1.55 ± 0.45 *g* = 0.88 (0.10-1.66)	1.04 ± 0.72 *g* = 0.54 (-0.21-1.29)	1.40 ± 0.52 *g* = 0.74 (0.02-1.51)	1.65 ± 0.62 *g* = 1.05 (0.26-1.84)	1.73 ± 0.74 *g* = 0.88 (0.11-1.66)
Average RFD ($N·s^{-1}$)	-2.69 ± 4.54 *g* = 0.72 (0.05-1.48)	-1.84 ± 2.96 *g* = 0.04 (-0.78-0.71)	-0.12 ± 2.87 *g* = 0.03 (-0.77-0.71)	-2.48 ± 4.48 *g* = 0.05 (-0.79-0.69)	-2.56 ± 2.18 *g* = 0.76 (0.01-1.52)	3.58 ± 4.39 *g* = 1.10 (0.30-1.89)
RFD 50 ms ($N·s^{-1}$)	4.94 ± 7.40 *g* = 0.47 (-0.29-1.21)	-0.87 ± 7.37 *g* = 0.52 (-0.23-1.27)	0.94 ± 9.12 *g* = 1.50 (0.66-2.34)	5.67 ± 5.07 *g* = 1.10 (0.30-1.89)	12.08 ± 11.55 *g* = 1.43 (0.60-2.26)	7.39 ± 7.37 *g* = 1.44 (0.61-2.27)
RFD 100 ms ($N·s^{-1}$)	-10.78 ± 7.03 *g* = 2.47 (1.48-3.45)	-1.95 ± 3.14 *g* = 0.69 (0.07-1.45)	-7.31 ± 8.57 *g* = 1.28 (0.47-2.10)	-17.80 ± 6.79 *g* = 2.57 (1.57-3.58)	-10.75 ± 7.72 *g* = 2.21 (1.27-3.15)	-3.24 ± 5.24 *g* = 0.67 (0.09-1.43)
RFD 150 ms ($N·s^{-1}$)	-6.24 ± 2.85 *g* = 1.64 (0.78-2.49)	-3.81 ± 2.93 *g* = 1.26 (0.45-2.07)	-7.57 ± 5.61 *g* = 1.13 (0.33-1.93)	-7.97 ± 4.72 *g* = 1.83 (0.94-2.71)	-2.87 ± 3.16 *g* = 0.96 (-0.18-1.74)	-2.96 ± 3.16 *g* = 0.81 (0.04-1.58)
Propulsion Time (s)	2.80 ± 1.64 *g* = 0.17 (-0.57-0.91)	2.69 ± 0.73 *g* = 1.14 (0.34-1.94)	1.80 ± 1.60 *g* = 0.75 (0.02-1.52)	0.83 ± 1.27 *g* = 0.46 (-.29-1.21)	2.47 ± 1.27 *g* = 1.03 (0.24-1.82)	2.23 ± 1.63 *g* = 0.85 (0.07-1.62)

Table 14. Percentage of participants showing changes in squat jump force-time variables greater than typical error and smallest worthwhile change.

	Intra-contrast rest period (s)					
	0	60	120	180	240	300
Propulsive Impulse (N·s)	28.57	28.57	28.57	42.86	14.29	35.71
Peak Force (N)	21.43	0.00	14.29	0.00	7.14	7.14
Mean Force (N)	28.57	0.00	7.14	0.00	0.00	0.00
Average RFD ($N·s^{-1}$)	42.86	7.14	21.43	0.00	7.14	28.57
RFD 50 ms ($N·s^{-1}$)	28.57	14.29	28.57	7.14	21.43	21.43
RFD 100 ms ($N·s^{-2}$)	35.71	7.14	42.86	0.00	28.57	28.57
RFD 150 ms ($N·s^{-2}$)	28.57	7.14	21.43	0.00	21.43	21.43
Propulsion Time (s)	14.29	28.57	42.86	42.86	42.86	35.71

FIGURES

Figure 1. Session overview of the data collection process

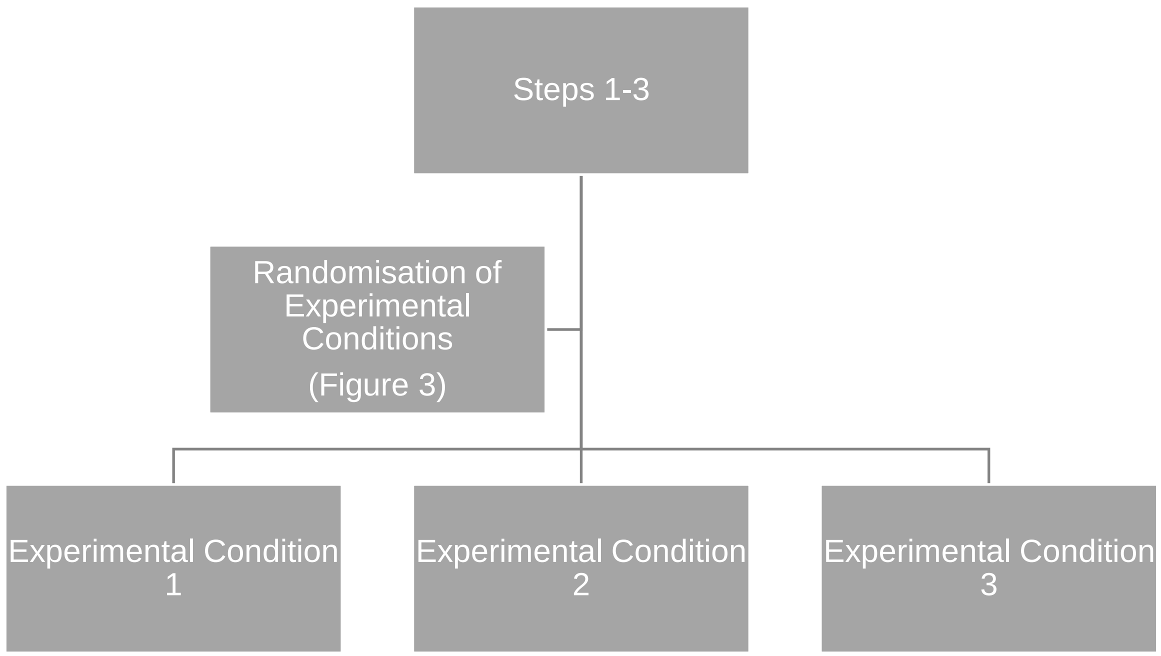

Figure 2. Step 4: Experimental conditions

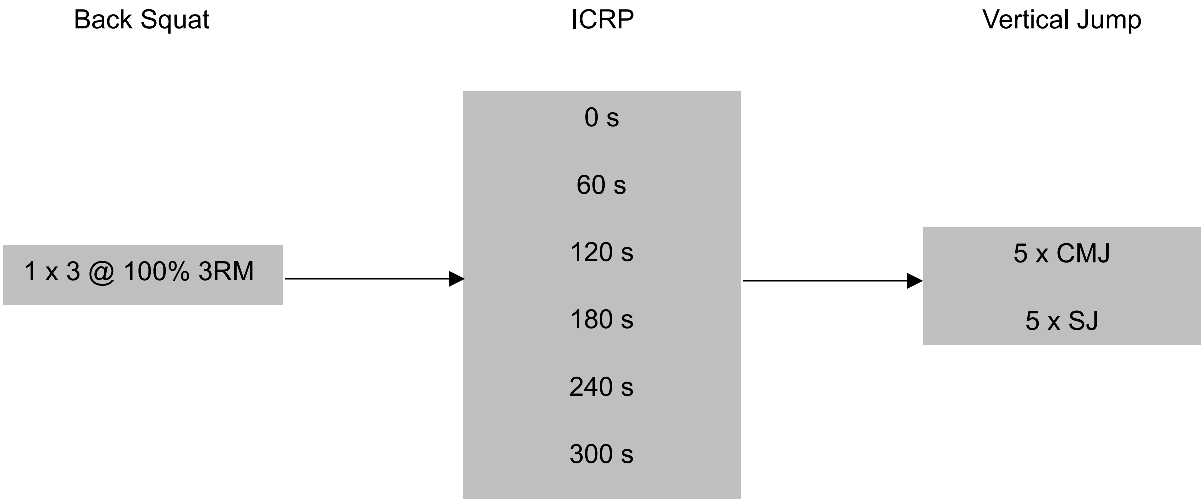

Figure 3. Experimental conditions. Intra-contrast rest period (ICRP) and vertical jump were randomly assigned.