scientific reports

Check for updates

OPEN

Acute effects of isometric conditioning activity with different distribution contraction on countermovement jump performance in resistance trained participants

Jakub Jarosz[1]✉, Milosz Drozd[1], Dawid Gawel[1], Michal Wilk[1], Jonatan Helbin[1] & Michal Krzysztofik[1,2]

The aim of this study was to compare the effects of 3 sets of isometric conditioning activity (ICA), each with an equal total duration (9 s per set) but with different distributions contractions, on force production during ICA and subsequent countermovement jump (CMJ) performance. Fifteen resistance-trained males participated in this study (age: 22.1 ± 2.4 years; body mass: 85.1 ± 9.7 kg; height: 181.3 ± 6.5 cm; relative one-repetition maximum (1RM) in back squat: 1.59 ± 0.32 kg/kg of body mass). Participants completed 3 conditions, each consisting of ICA in the half-back squat with a pushing isometric muscle action (PIMA) position at a 120-degree knee angle against an immovable barbell, differing in repetition distribution: 3 sets of 9 repetitions lasting 1 s each (SUST-1), 3 sets of 3 repetitions lasting 3 s each (SUST-3), 3 sets of single repetitions lasting 9 s (SUST-9), and a control condition (CTRL) without ICA. A 1-minute rest was allowed between sets. Approximately 3 min pre-ICA and at 15 s, 3-, 6-, 9-, and 12-minutes post-ICA, the CMJ performance was assessed. Moreover, peak force (PF) production, and force generated at 100 (Force100) and 200 ms (Force200) during each ICA were evaluated. A two-way repeated measures ANOVA indicated a main effect of time on CMJ height (F = 2.674; p = 0.029; ηp²=0.171) but did not show significant differences between conditions (F = 0.934; p = 0.434; ηp²=0.067) or interactions (F = 0.826; p = 0.648; ηp²=0.060). Post-hoc comparisons indicated a significant decrease in CMJ height at the 9th minute compared to the 3rd minute (35.7 ± 5.6 cm vs. 36.8 ± 5.5 cm post-CA; d = 0.161; p = 0.048). In addition, no significant interactions or main effects were found for CMJ contraction time, PF and Force100 during ICA. However, a main effect of condition was demonstrated on Force200 (F = 19.181; p < 0.001; ηp²= 0.013). Post-hoc comparisons revealed higher Force200 values in SUST-1 (mean difference [MD] = 549 ± 137 N; d = 1.049; p < 0.001) and SUST-3 (MD = 348 ± 112 N; d = 0.665; p = 0.002) compared to the SUST-9 condition. None of the ICAs used in the present study had any effect on the CMJ performance. However, the significantly higher Force200 values noted in the SUST-1, and SUST-3 conditions compared to the SUST-9 condition suggest that the specific distributions of isometric contraction influence the force generated during their execution.

Keywords Post-activation performance enhancement, Isometric squat, Isometric contraction distribution, Force production

Post-activation performance enhancement (PAPE) is a phenomenon characterized by the acute increase in neuromuscular capacity following specific conditioning activities[1,2]. These activities typically involves high-intensity isotonic or isometric exercises performed before high-velocity activities with similar movement patterns, such as high-loaded squats before vertical jumps[2,3]. PAPE also causes elevated muscle temperature, decreased

[1]Institute of Sport Sciences, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland. [2]Department of Sports Games, Faculty of Physical Education and Sport, Charles University, Prague, Czech Republic. ✉email: j.jarosz@awf.katowice.pl

pH, increased blood and water circulation within myocytes, enhanced muscle activation, and intensified muscle-tendon stiffness, facilitating temporary improvements in peak force and rate of force development[4].

Isometric muscle contractions are widely utilized in both research and training due to their effectiveness in eliciting the PAPE effect[5], chronic adaptation changes[6,7] and their role in testing neuromuscular performance[2]. Common modifications in isometric training include manipulating training variables such as method (holding isometric muscle action (HIMA) or pushing isometric muscle action (PIMA))[8], position[9], joint angle[10], as well as the intensity and duration of the isometric contraction[11]. Less-studied variants include various rapid or sustained contraction distributions within a single set (e.g., ~ 1 s, 3 s, and ≥ 5 s)[2,12], as well as the total contraction duration. Some studies suggest that a short total duration of isometric conditioning activity (ICA) with PIMA lasting only 3–9 s within a single set may be sufficient to enhance countermovement jump (CMJ) performance[13,14]. This is significant because, as reported by Tillin & Folland[15], the structure of ICA distributions within a set plays a crucial role in generating high levels of isometric force production. This may serve as a distinct stimulus induced by the ICA and, consequently, influence the occurrence of the PAPE effect. This is supported by the findings of Spieszny et al.[16], which demonstrated that a longer total duration of ICA, consisting of 3 sets in a distribution of 3 contractions lasting 3 s each (with a set duration of 9 s), resulted in a total ICA duration of 27 s, leading to a significant enhancement in CMJ performance. In contrast, Krzysztofik et al.[2] did not confirm positive benefits from a single ICA set consisting of 3 contractions of 3 s each, with a total duration of 9 s, as no significant increases in CMJ height were observed. However, none of these studies analyzed the impact of different distributions of isometric contractions within a single set, given a specific total duration of isometric contraction, on CMJ performance or isometric force production during ICA.

As suggested by Balshaw et al.[11] and Tillin & Folland[15], significant differences in training effects result from different isometric contraction durations, which can variably affect force production across different time intervals, such as 50–200 ms[11,15,17]. These differences may also influence subsequent athletic performance. According to Balshaw et al.[11] and Lum et al.[17], these effects are due to the fact that the duration of an isometric contraction determines the level of motor unit recruitment. Explosive isometric contraction emphasizing rapid torque development during short contractions primarily engage fast-twitch muscle fibers (type II), increasing neural transmission speed and resulting in greater isometric force production within short time frames (≤ 100 ms)[11]. In contrast, typical isometric training primarily emphasizes sustained isometric contractions at high loads, leading to a gradual increase in muscle tension. This improves neuromuscular control and activates both slow-twitch (type I) and fast-twitch fibers, promoting a more comprehensive enhancement of force production, which becomes particularly evident after 200 ms[15]. Recommendations regarding shorter and longer isometric contractions arise from differences in the rate of force development, which are crucial in various sports disciplines. Short contractions are particularly advantageous in sports that demand maximum power in a short timeframe, such as sprinting[11,15,18,19]. Conversely, prolonged isometric contractions, in which force is developed more slowly but can be sustained over an extended period, are beneficial in disciplines that require sustained force production[20]. However, to the best knowledge of the authors, various distributions of isometric contractions within a single set, given a specific total duration of isometric contraction, and their subsequent impact on athletic performance have not been considered. Furthermore, previous studies by Tillin & Folland[15] and Lum et al.[17] focused on the analysis of isometric force production using sustained contractions of 1 and 3 s; however, they did not include sustained isometric contractions lasting 9 s, nor did they compare different timing distributions of isometric contractions with the same total duration (e.g., ~ 9 s) within a single set to a total contraction duration of 27 s concerning isometric force production and CMJ outcomes. Importantly, such ICA may function differently depending on the distribution and total duration of the contraction, potentially influencing various neuromuscular mechanisms distinct from those observed in previous studies. Variations in contraction duration or distribution may differentially affect central and peripheral fatigue, modulating motor unit synchronization, firing rates, and activation strategies[21]. Consequently, neuromuscular control mechanisms may differ from those observed in studies employing distinct contraction protocols. Taking into account the above considerations, existing knowledge, and noting certain deficiencies therein, the aim of the present study was to determine which distributions: SUST-1 (1 s per 9 repetitions), SUST-3 (3 s per 3 repetitions), or SUST-9 (9 s per 1 repetition) with the same total isometric duration per set (~ 9 s), implemented in 3 sets (with a total contraction duration of 27 s) with 1-minute rest, would influence force production during ICA and CMJ performance at the following time points: 15 s, 3, 6, 9, and 12 min post each ICA. Additionally, the study aimed to compare isometric peak force, as well as force production at 100 and 200 ms during the ICA. We hypothesized that a significant increase in CMJ performance and isometric force production would be observed between the SUST-1 and SUST-3 isometric contractions compared to the SUST-9 contraction, with the SUST-1 contraction generating greater isometric force at 100 ms and the SUST-3 contraction at 200 ms, compared to the SUST-9 condition.

Materials and methods

Experimental approach to the problem

The study was conducted using a randomized crossover design, in which each participant completed four experimental sessions to compare the acute effects of maximal isometric squats (serving as ICA) on subsequent CMJ performance. Participants were randomly assigned to 3 different conditions, each involving a distinct distribution contraction of PIMA within a single set (each lasting 9 s), performed in 3 sets (with a total contraction duration of 27 s) and with a 1-minute rest between sets, as well as a control condition with no ICA.

CMJ measurements were taken approximately 3 min pre-ICA and time point at 15 s, 3-, 6-, 9-, and 12 min post completing the ICA[14]. In the CTRL condition, measurements were performed at the same time points, but no ICA was applied (Fig. 1).

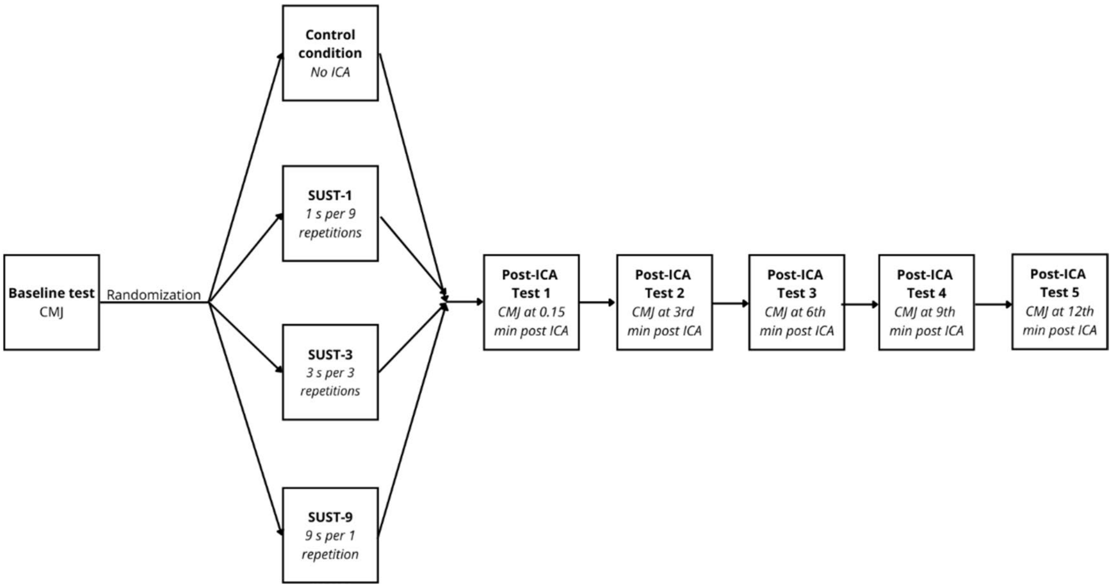

Fig. 1. Study design flowchart. CMJ—countermovement jump; ICA—isometric conditioning activity; SUST-1 – sustained pushing isometric muscle action condition 1 s per 9 repetitions; SUST-3 – sustained pushing isometric muscle action condition 3 s per 3 repetitions; SUST-9 – sustained pushing isometric muscle action condition 9 s per 1 repetition.

Age [years]	22.1 ± 2.4
Body mass [kg]	85.1 ± 9.7
Body fat [%]	9.9 ± 4.2
Body height [cm]	181.3 ± 6.5
Resistance training experience [years]	4.5 ± 3.7
Relative 1RM BS [kg/kg of body mass]	1.59 ± 0.32

Table 1. Descriptive characteristics of the study participants. 1RM – one-repetition maximum; BS – back squat.

Participants

Fifteen resistance-trained male participants took part in this study (Table 1)[22]. The inclusion criteria were: (a) participation in resistance training at least 3 times a week, for at least 3 years; (b) no muscle injuries (leading to absence from training for more than 4 weeks) for at least 6 months before the start of the study. Participants were instructed to abstain from engaging in any resistance exercises within the 48 h leading up to the commencement of the experimental session. Additionally, they were advised to maintain their regular dietary habits and avoid consuming any supplements or stimulants, except for habitual supplementation such as creatine, during the week preceding the experiment. At the initiation of the experimental session, body composition was assessed through multi-channel bioelectrical impedance analysis, conducted in a laboratory setting utilizing the InBody 370 device (InBody, Seoul, South Korea). Participants were informed of the potential risks and benefits of their involvement in the project and were clearly advised of their right to withdraw at any time, without the need to provide a reason for their decision before providing their written informed consent for participation. The study employed a randomized crossover design, wherein each participant remained unaware of the assigned experimental condition. Randomization was conducted using the (randomization.org) generator, assigning a unique number and distributions for each participant's session execution. Following the random allocation to the training intervention, participants remained unaware of the subsequent course of the experiment. Written consent for participation in the study was obtained from all participants, albeit without disclosing specific details regarding the study's objectives and anticipated outcomes. The entirety of the research protocol transpired at the Academy of Physical Education in Katowice, Poland. The experimental endeavor received formal endorsement from the Bioethics Committee for Scientific Research (3/2021) at the Academy of Physical Education in Katowice, Poland, adhering to the ethical tenets outlined in the Declaration of Helsinki, 1983.

Familiarization session

All experimental sessions were conducted between 9:00 and 11:00 AM. At least two days prior to the first experimental session, participants underwent a familiarization session, which included maximal isometric squats with different contraction distributions and CMJ. The session began with a standard warm-up consisting of a 5-minute cycling. The sequential exercises included: air squats (10 repetitions), forward lunges (10 repetitions), leg swings (10 repetitions), jumping jacks (10 repetitions), and CMJ (5 repetitions) to complete the comprehensive warm-up routine. Subsequently, each participant performed, in random order, 1 set of isometric squats with different distributions contractions and 3 CMJ trials after each set. Each participant was assigned an individual rack height for performing the maximal isometric squat, which was determined by the height of the barbell holders on the rack. Participants had the barbell on their shoulders, which was immobilized by the barbell holders to ensure isometric muscle action, and the squat depth was individually set to a 120-degree knee angle[17] determined by an experienced coach using a goniometer (EasyAngle, Meloq AB, Stockholm, Sweden). An experienced strength and conditioning coach standardized body positions to ensure a vertical torso in all conditions. During the CMJ, the depth of the countermovement was not restricted.

Experimental sessions

After the warm-up (identical to the familiarization session), participants performed a baseline assessment of CMJ performance. The 3 trials of each jump were conducted with approximately 5-s intervals between them. The use of arm swings was not allowed. After approximately 3 min of rest, participants performed maximal isometric squats as ICA (depending on the condition) or no ICA (CTRL) in random order. The individual adjustment of rack heights during maximal isometric squats was consistent with the familiarization session. Depending on the condition, with different distributions of isometric contraction, 3 sets were performed, each with 1 maximal attempt (lasting 9 s) and 1-minute rest intervals between sets. The time required to perform each condition was monitored using a stopwatch. In the CTRL condition, to maintain physical activity, participants had to walk on a treadmill at a speed of 5 km/h for the duration required to complete the entire ICA (approximately 3 min and 30 s.). Following the protocol, CMJ measurements were taken at the same time points, but without applying ICA (Fig. 1). Every session was separated by at least 48 h. Between experimental sessions, participants were asked to not perform any high intensity physical activity.

Measurement of force during isometric squats

The individual adjustment of height during maximal isometric squats was consistent with the familiarization session. The vertical component of the ground reaction force was measured with a force platform positioned on the floor inside the power rack under the participants' feet (Force Decks, Vald Performance, Australia). Upon the researcher's command, participants were instructed to "*push the barbell vertically upwards as strongly and as quickly as possible*" pressing their back against the barbell and pushing their feet against the floor. Participants had to maintain tension for a specified time depending on the conditions undertaken. The highest force production during the maximal isometric barbell squat test was reported as absolute peak force (PF)[23]. Additionally, force at 100 ms (Force100) and 200 ms (Force200) from the start of the push was determined for each trial separately[8,24,25].

Measurement of countermovement jump performance

Countermovement jump performance was evaluated using a force platform (Force Decks, Vald Performance, Australia), which has been previously validated as a reliable tool for measuring vertical jump kinematics[26]. Each participant performed three CMJ without arm swing about 3 min before ICA and at 15 s, 3-, 6-, 9-, and 12 min after[14]. During the measurement, participants started from a standing position with hands on their hips and maintained a straight back posture to reduce angular displacement of the hips. Participants were instructed to stand as still as possible for > 1 s before initiating the countermovement. They then descended into a squat to a predetermined depth before exerting maximum effort in a vertical jump. Participants were instructed to land in the same position as during take-off, centrally on the force platform. The following CMJ performance variables were evaluated: jump height (JH) peak power, RSI modified, countermovement depth, and contraction time (CT). JH was calculated based on the center of mass velocity at take-off using the equation relating to impulse and momentum.

Statistical analyses

All statistical analyses were performed using JASP (Version 0.18.3; JASP Team, University of Amsterdam, Netherlands) and were shown as means with standard deviations (± SD). Statistical significance was set at $p < 0.05$. The normality of data distribution was checked using Shapiro–Wilk tests. The two-way ANOVAs (4 conditions [CTRL; SUST-1; SUST-3; SUST-9] × 6 time-points [pre-ICA; 15 th s, 3rd, 6 th, 9 th, and 12 th minute post-ICA]) were used to investigate the influence of ICA on CMJ height and CT. Additional two-way ANOVAs (3 × [SUST-1; SUST-3; SUST-9] × 3 time-points [set 1, set 2, set 3 of ICA]) were used to examine the PF, Force100 and Force200 during each ICA. When a significant main effect or interaction was found, the post-hoc tests with Bonferroni correction were used to analyze the pairwise comparisons. The effect sizes were determined by Cohen's d, which was characterized as "trivial" (|d| < 0.20), "small" (0.20 ≤ |d| < 0.50), "moderate" (0.50 ≤ |d| < 0.80), or "large" (|d| ≥ 0.80)[27].

Results

Jumping performance

A repeated measures two-way ANOVA did not show statistically significant interaction for CMJ height (F = 0.826; $p = 0.648$; η_p^2=0.060), however determined a main effect of time (F = 2.674; $p = 0.029$; η_p^2=0.171) without significant differences between conditions (F = 0.934; $p = 0.434$; η_p^2=0.067).

	Baseline [cm]	15 s [cm]	3 min [cm]	6 min [cm]	9 min [cm]	12 min [cm]
SUST-1	36.9 ± 4.1	36 ± 5.4	37.9 ± 5.9	36.7 ± 5.5	36.5 ± 5.6*	36.3 ± 5.2
SUST-3	36.8 ± 6.8	36.1 ± 5.8	36.8 ± 6.3	36.7 ± 5	35.9 ± 6.8*	35.9 ± 6.1
SUST-9	37.4 ± 5.7	36.7 ± 5.8	37 ± 5.9	36.8 ± 5.9	36.5 ± 5.5*	36.5 ± 5.9
CTRL	36.7 ± 4.3	36.9 ± 4.7	36.4 ± 4.5	35.3 ± 5.1	35.6 ± 5.5*	35.6 ± 4.8

Table 2. Change of jump height between time points and conditions. SUST-1 – sustained of pushing isometric muscle action condition 1 s per 9 repetitions; SUST-3 – sustained of pushing isometric muscle action condition 3 s per 3 repetitions; SUST-9 – sustained of pushing isometric muscle action condition 9 s per 1 repetition. BL – baseline, 15 s – 15 th s post-ICA, 3 m – 3rd minute post-ICA, 6 m – 6 th minute post-ICA, 9 m – 9 th minute post-ICA, 12 m – 12 th minute post-ICA; * — significant difference in comparison 3rd and 9 th minutes within the condition, $p < 0.05$.

	Peak force [*N*]	Force at 100 ms [*N*]	Force at 200 ms [*N*]
SUST-1	3770 ± 838	1744 ± 295	2566 ± 565
SUST-3	3658 ± 761	1808 ± 434	2449 ± 534
SUST-9	3800 ± 684	1638 ± 458	2039 ± 462*

Table 3. Force production during isometric squat. SUST-1 – sustained of pushing isometric muscle action condition 1 s per 9 repetitions; SUST-3 – sustained of pushing isometric muscle action condition 3 s per 3 repetitions; SUST-9 – sustained of pushing isometric muscle action condition 9 s per 1 repetition; * — significant difference in Force200 within the SUST-1 and SUST-9, $p < 0.05$.

The post-hoc comparisons showed statistically significant decrease of CMJ height in the 9 th minute compared to 3rd minute post-ICA (Mean difference [MD]= −0.9 ± 0.2 cm; Cohen's d = 0.161; p_{bonf}=0.048) (Table 2).

Furthermore, repeated measures two-way ANOVA did not show any statistically significant interactions (F = 1.125; p = 0.336; ηp^2 = 0.08), main effect of time (F = 0.330; p = 0.893; ηp^2 = 0.025) nor condition (F = 1.485; p = 0.243; ηp^2 = 0.103) for CMJ CT.

Force production during isometric squat

The repeated measures two-way ANOVA did not indicate any statistically significant interaction for PF and Force100 during ICA (F = 1.173; p = 0.334; ηp^2 = 0.083 and F = 0.126; p = 0.972; ηp^2 = 0.010 respectively) also did not showed either main effect of time (F = 1.649; p = 0.212; ηp^2 = 0.113 and F = 2.624; p = 0.092; ηp^2 = 0.168) and condition (F = 0.976; p = 0.390; ηp^2 = 0.070 and F = 1.916; p = 0.167; ηp^2 = 0.128) during ICA.

Further, the analyses did not showed any statistically significant interaction (F = 0.177; p = 0.949; ηp^2 = 0.013) nor main effect of time (F = 2.873; p = 0.075; ηp^2 = 0.181) in Force200, however the main effect of condition (F = 19.181; p < 0.001; ηp^2 = 0.013) was revealed.

The post-hoc comparisons showed significantly greater Force200 in SUST-1 (MD = 549 ± 137 N; Cohen's d = 1.049; p_{bonf}<0.001) and SUST-3 (MD = 348 ± 112 N; Cohen's d = 0.665; p_{bonf}=0.002) compared with SUST-9 (Table 3).

Discussion

The aim of this study was to investigate the impact of 3 different distributions of isometric contraction activities by pushing ICA on CMJ height, isometric peak force, Force100 and Force200. The 3 ICA protocols were compared: SUST-1, SUST-3 and SUST-9, each performed in 3 sets with a total contraction time of 27 s. The results showed no significant differences in CMJ performance across the protocols. However, in the analysis of isometric force production, Force200 was found to be higher under the SUST-1 and SUST-3 conditions compared to SUST-9, suggesting that shorter, more intermittent isometric contractions more effectively enhance force production at 200 ms. These findings indicate that the applied ICA distributions do not significantly influence the PAPE effect, but they highlight that selecting an appropriate ICA-PIMA protocol may be crucial for optimizing strength training, particularly regarding the force production.

The results obtained did not confirm the hypothesis of improved CMJ performance following ICA; instead, they demonstrated a decrease in performance at the 9 th minute post-ICA compared to the 3rd minute post-ICA. This finding is inconsistent with the results reported by Spieszny et al.[16], who observed a significant increase in CMJ height when employing PAPE using the same total duration of isometric contraction (27 s) as in the present study. Despite the favorable responses noted in the study by Spieszny et al.[16], this analysis focused on a different population. The resistance training experience of the participants in this study and that of Spieszny et al.[16] was comparable (4.5 ± 3.7 vs. 4 ± 2 years); however, the authors did not report 1RM back squat values. Therefore, the observed differences in results may be attributed to the participants' training background. In Spieszny et al. study[16], the participants were semi-professional handball and soccer players, whereas in this study, they were resistance-trained. As Boullosa et al.[28] suggest, the optimal duration of a conditioning activity may depend on an athlete's training background, such as their trained discipline. For instance, speed-power athletes may benefit more from brief, high-intensity conditioning activities, whereas endurance athletes may benefit more from submaximal, prolonged conditioning activities[28]. Unfortunately, Spieszny et al.[16], did not account for the effects of different distributions of isometric contractions, such as SUST-1 or SUST-9.

The results of previous studies indicate that differences in recovery durations between sets may play a crucial role in shaping the PAPE response[14,16]. In the study by Spieszny et al.[16], 3-minute recovery intervals were utilized between sets, which may explain the discrepancies in results compared to the present study, where the recovery time was reduced to 1-minute. The shortened recovery time between sets may have caused the fatigue induced by the ICA protocol to outweigh the potential benefits of PAPE, resulting in no significant differences in CMJ height[29–31]. The findings of Blazevich & Babault[4] support this hypothesis, suggesting that a 1-minute recovery interval between sets may be insufficient for complete recovery, especially given the high muscular load resulting from the 27-s isometric contraction. On the other hand, study by Tsoukos et al.[14] indicates the potential for improvement in CMJ height with a 1-minute recovery interval, suggesting that the effectiveness of this parameter might depends on other methodological variables, such as the number of ICA sets, their temporal distribution, and the training background of participants. A key difference in the study by Tsoukos et al.[14] was the use of a protocol comprising 3 sets with 1 contraction per 3 s and a greater knee joint angle (140°) in national-level male track and field power athletes. This approach may have facilitated more effective muscle activation and reduced fatigue while maintaining 1-minute recovery intervals[32]. This inconsistency highlights the need for further research to optimize recovery intervals and adjust the ICA timing according to participants' training levels. In turn, this could lead to more consistent results regarding jump performance and facilitate a better understanding of the mechanisms underlying PAPE, ultimately contributing to the development of more effective interventions.

To the best of authors knowledge, the current literature lacks studies examining the effect of different ICA durations within a single set at a specified total contraction duration on isometric force production and its distribution at specific time points, such as Force100 and Force200. This gap substantially limits the potential for direct comparisons with prior research. Consequently, the results obtained can be interpreted in the context of previous studies on the impact of various ICA durations on isometric strength improvement during long-term isometric training[11,15,17]. The results of this study demonstrated a higher in Force200 in the SUST-1 and SUST-3 groups compared to the SUST-9 group, although no such increase was observed in Force100. This suggests that varying ICA distribution within a single set may significantly affect isometric force production levels. Prior research analyzing the effects of long-term isometric training on isometric force production with durations of 50, 100, and 150 ms[11,15,17] reported significant increases at all time points under conditions with 1 s isometric contraction and at 150 ms under conditions with 3 s isometric contraction compared to the control group[11]. These findings are partially consistent with this study, as an increase in Force200 was observed in the SUST-1 and SUST-3 groups compared to SUST-9, but not in Force100. It is worth noting that micro-breaks between contractions in the SUST-1 and SUST-3 groups, as suggested by Buckthorpe et al.[33], may limit peripheral fatigue accumulation, thereby facilitating better force production, particularly in Force200. Additionally, it can be hypothesized that shorter distributions of isometric contractions in the SUST-1 and SUST-3 groups, compared to the longer distributions applied in the SUST-9 group, may have fostered better concentration and engagement among participants. This effect could hypothetically influence the efficiency of isometric force production, which may, in turn, be reflected in the Force200 measurement results obtained in this study.

One limitation of this study is the comparison of only a single volume, specifically 3 sets of ICA with a total contraction time of 27 s. Additionally, fatigue onset was monitored via changes in performance in this study; however, non-volitional methods such as tensiomyography or electromyography could have provided additional insights. These limitations highlight the need for further comparative analysis of different ICA volumes, incorporating fatigue monitoring, to determine the optimal ICA volume for maximizing acute PAPE responses. Such research would help establish an optimal protocol and clarify potential outcomes despite the numerous methodological differences present in the literature.

Conclusions

The presented study demonstrated that different distributions of ICA durations (with an equal set [9 s] and total contraction time duration [27 s]) for trained participants, with a 1-minute rest between sets, did not affect CMJ performance. Furthermore, higher Force200 values were observed in the SUST-1 and SUST-3 groups compared to the SUST-9 group, indicating that shorter, more intermittent ICA distributions could have practical implications for higher rapid force production during isometric contractions.

Data availability

The datasets analyzed during the current study are available from the corresponding author uponreasonable request.

Received: 7 November 2024; Accepted: 12 May 2025
Published online: 15 May 2025

References

1. Kalinowski, R. et al. Acute effects of combined isometric and plyometric conditioning activities on sports performance and tendon stiffness in female volleyball participants. *Front. Physiol.* **13**, 1025839 (2022).
2. Krzysztofik, M. et al. Acute effects of isometric conditioning activity on the viscoelastic properties of muscles and sprint and jumping performance in handball participants. *J. Strength. Cond Res.* **37**, 1486–1494 (2023).
3. Bogdanis, G. C., Tsoukos, A., Veligekas, P., Tsolakis, C. & Terzis, G. Effects of muscle action type with equal impulse of conditioning activity on postactivation potentiation. *J. Strength. Cond Res.* **28**, 2521–2528 (2014).

4. Blazevich, A. J. & Babault, N. Post-activation potentiation versus post-activation performance enhancement in humans: historical perspective, underlying mechanisms, and current issues. *Front. Physiol.* **10**, 1359 (2019).
5. Boullosa, D. Post-activation performance enhancement strategies in sport: a brief review for practitioners. *Hum. Mov.* **22**, 101–109 (2021).
6. Damas, F. et al. Early resistance training-induced increases in muscle cross-sectional area are concomitant with edema-induced muscle swelling. *Eur. J. Appl. Physiol.* **116**, 49–56 (2016).
7. Magnusson, S. P. & Kjaer, M. The impact of loading, unloading, ageing and injury on the human tendon. *J. Physiol.* **597**, 1283–1298 (2019).
8. Oranchuk, D. J., Storey, A. G., Nelson, A. R. & Cronin, J. B. Isometric training and long-term adaptations: effects of muscle length, intensity, and intent: A systematic review. *Scand. J. Med. Sci. Sports*. **29**, 484–503 (2019).
9. Schaefer, L. V. & Bittmann, F. N. Are there two forms of isometric muscle action? Results of the experimental study support a distinction between a holding and a pushing isometric muscle function. *BMC Sports Sci. Med. Rehabil.* **9**, 1–13 (2017).
10. Noorkõiv, M., Nosaka, K. & Blazevich, A. J. Effects of isometric quadriceps strength training at different muscle lengths on dynamic torque production. *J. Sports Sci.* **33**, 1952–1961 (2015).
11. Balshaw, T., Massey, G. J., Maden-Wilkinson, T. M., Tillin, N. A. & Folland, J. P. Training-specific functional, neural, and hypertrophic adaptations to explosive- vs. sustained-contraction strength training. *J. Appl. Physiol.* **120**, 1364–1373 (2016).
12. Garbisu-Hualde, A., Gutierrez, L., Fernández-Peña, E. & Santos-Concejero, J. Intermittent voluntary isometric contractions effects on performance enhancement and sticking region kinematics in the bench press. *J. Hum. Kinet*. **87**, 105 (2023).
13. French, D. N., Kraemer, W. J. & Cooke, C. B. Changes in dynamic exercise performance following a sequence of preconditioning isometric muscle actions. *J. Strength. Cond Res.* **17**, 678–685 (2003).
14. Tsoukos, A., Bogdanis, G. C., Terzis, G. & Veligekas, P. Acute improvement of vertical jump performance after isometric squats depends on knee angle and vertical jumping ability. *J. Strength. Cond Res.* **30**, 2250–2257 (2016).
15. Tillin, N. A. & Folland, J. P. Maximal and explosive strength training elicit distinct neuromuscular adaptations, specific to the training stimulus. *Eur. J. Appl. Physiol.* **114**, 365–374 (2014).
16. Spieszny, M. et al. Post-isometric back squat performance enhancement of squat and countermovement jump. *Int. J. Environ. Res. Public. Health*. **19**, 12720 (2022).
17. Lum, D. et al. Effects of two isometric strength training methods on jump and sprint performances: a randomized controlled trial. *J. Sci. Sport Exerc.* **3**, 115–124 (2021).
18. Gruber, M. et al. Differential effects of ballistic versus sensorimotor training on rate of force development and neural activation in humans. *J. Strength. Cond Res.* **21**, 274–282 (2007).
19. Tillin, N. A., Pain, M. T. G. & Folland, J. P. Short-term training for explosive strength causes neural and mechanical adaptations. *Exp. Physiol.* **97**, 630–641 (2012).
20. Kamimura, T. & Ikuta, Y. Evaluation of grip strength with a sustained maximal isometric contraction for 6 and 10 seconds. *J. Rehabil Med.* **33**, 225–229 (2001).
21. Dalton, B. et al. Central and peripheral neuromuscular fatigue following ramp and rapid maximal voluntary isometric contractions. *Front. Physiol.* **15**, 1434473 (2024).
22. McKay, A. K. et al. Defining training and performance caliber: a participant classification framework. *Int. J. Sports Physiol. Perform.* **17**, 317–331 (2021).
23. Haff, G. G., Ruben, R. P., Lider, J., Twine, C. & Cormie, P. A comparison of methods for determining the rate of force development during isometric midthigh clean pulls. *J. Strength. Cond Res.* **29**, 386–395 (2015).
24. Comfort, P. et al. Normalization of early isometric force production as a percentage of peak force during multijoint isometric assessment. *Int. J. Sports Physiol. Perform.* **15**, 478–482 (2019).
25. Lum, D., Comfort, P., Barbosa, T. M. & Balasekaran, G. Comparing the effects of plyometric and isometric strength training on dynamic and isometric force-time characteristics. *Biol. Sport*. **39**, 189 (2022).
26. Heishman, A. D. et al. Countermovement jump reliability performed with and without an arm swing in NCAA division 1 intercollegiate basketball participants. *J. Strength. Cond Res.* **34**, 546–558 (2020).
27. Cohen, J. Statistical Power Analysis for the Behavioral Sciences (Electronic). *Burlington, MA: Elsevier Science* (2013).
28. Boullosa, D. et al. A new taxonomy for postactivation potentiation in sport. *Int. J. Sports Physiol. Perform.* **15**, 1197–1200 (2020).
29. Docherty, D. & Hodgson, M. J. The application of postactivation potentiation to elite sport. *Int. J. Sports Physiol. Perform.* **2**, 439–444 (2007).
30. Xenofondos, A., Bassa, E., Vrabas, I. S., Kotzamanidis, C. & Patikas, D. A. Muscle twitch torque during two different in volume isometric exercise protocols: fatigue effects on postactivation potentiation. *J. Strength. Cond Res.* **32**, 578–586 (2018).
31. Skurvydas, A. et al. What are the best isometric exercises of muscle potentiation? *Eur. J. Appl. Physiol.* **119**, 1029–1039 (2019).
32. Lum, D., Ong, K. Y. & Haischer, M. H. Postactivation performance enhancement with maximal isometric contraction on Power-Clean performance across multiple sets. *Int. J. Sports Physiol. Perform.* **19**, 265–270 (2023).
33. Buckthorpe, M., Erskine, R. M., Fletcher, G. & Folland, J. P. Task-specific neural adaptations to isoinertial resistance training. *Scand. J. Med. Sci. Sports*. **25**, 640–649 (2015).

Author contributions

Conceptualization, JJ; methodology, MK and JJ; software, JH and DG; validation, JH and MD; formal analysis, JJ and JH; investigation, JJ and DG; data curation, JJ and MD; writing – original draftpreparation, JJ; writing – review and editing, JJ, MW, MK; supervision, MK and MW; projectadministration, JJ and JH. All authors have read and agreed to the published version of the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to J.J.

Reprints and permissions information is available at www.nature.com/reprints.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.