scientific reports

Check for updates

OPEN

Acute effects of rapid versus sustained isometric contraction durations on countermovement jump performance in national level young male soccer players

Wojciech Grzyb[1] & Jakub Jarosz[2]✉

This study investigated the effects of different distributions of isometric conditioning activity (ICA) within a single set—1 s contraction performed 9 repetitions (RAPID) versus 3 s contractions performed 3 repetitions (SUST)—on countermovement jump (CMJ) performance in national level young male soccer players. Fifteen players completed three conditions: RAPID, SUST each involving maximal isometric contractions in the half-back squat position, as well as a control condition without ICA. Approximately 3 min pre-ICA and at 3-, 6-, 9- and 12-min post-ICA, the CMJ performance was assessed. The results showed a significant decrease in CMJ height and relative peak power following the RAPID protocol, with the greatest impairments occurring at 12 min post-ICA. In contrast, no significant changes were observed in the reactive strength index modified, contraction time, and countermovement depth. These results demonstrate that short, repetitive isometric protocols do not facilitate subsequent jump performance, with the RAPID protocol causing a transient decrease in CMJ performance. Therefore, the RAPID protocol should not be recommended as an acute strategy for enhancing jump performance in national level young soccer players.

Keywords Post-activation performance enhancement, Isometric squat, Vertical jump, Sports performance

Post-activation performance enhancement (PAPE) refers to a temporary improvement in neuromuscular efficiency following specific conditioning activities[1]. Isometric conditioning activities (ICA), such as isometric squats performed in a pushing isometric muscle action (PIMA) manner[2], are among the most commonly utilized methods to induce the PAPE effect, alongside isotonic exercises. Such exercises are typically performed prior to high-intensity athletic tasks characterized by similar biomechanical patterns, for instance, a back squat preceding vertical jumps[3–5]. For instance, in soccer, it is possible that an isometric squat performed during the warm-up or prior to substitution may act as a targeted pre-activation stimulus[4], potentially enhancing maximal sprinting or jumping efforts immediately after entering the match. The PAPE effect can primarily be explained by mechanisms such as the phosphorylation of myosin regulatory light chains and the increased recruitment of higher-threshold motor units[6]. Furthermore, it might be associated with elevated muscle temperature, decreased pH levels, improved blood flow within the muscles, and enhanced muscle activation following conditioning activity[1,7]. Such acute improvements are particularly relevant for high-intensity motor tasks that require explosive strength, including sprinting, vertical jumping, and rapid changes of direction[1,3].

ICA are commonly used in scientific research and sports training[8–19], primarily due to their ease of implementation and the possibility of integration into diverse training programs that do not require specialized equipment[3,5]. Studies suggest that maximal voluntary isometric squats, based on brief contractions, can significantly enhance the height of the countermovement jump (CMJ) in athletes from various disciplines, such as volleyball, soccer, and track and field[3–5,8,9]. However, the results of research on the impact of ICA on effectiveness in improving power performance are not consistent[8–19]. For instance, Tsoukos et al.[9] demonstrated an increase in CMJ height following 3 sets of single isometric contractions lasting 3 s each (total ICA duration: 9 s), suggesting a beneficial effect of distributing activation across multiple sets. On the other hand, French et al.[10] employing the same total ICA duration (9 s) but within a single set consisting of 3 contractions lasting 3 s,

[1]Faculty of Physical Education, Gdansk University of Physical Education and Sport, Gdansk, Poland. [2]Institute of Sport Sciences, Academy of Physical Education, Katowice, Poland. ✉email: j.jarosz@awf.katowice.pl

observed no change in CMJ height. These discrepancies may indicate that differences in the temporal structure of contraction distribution affect motor unit recruitment and neuromuscular adaptations[20,21]. Because this area remains insufficiently explored, systematic studies within a single ICA set are needed to compare alternative distributions of contraction durations in the context of the PAPE effect, while concurrently precisely defining how different timing configurations influence motor unit recruitment and neuromuscular adaptations.

According to Jarosz et al.[5], recommendations regarding the duration of isometric contractions vary based on differences in the rate of force development, a factor that is essential in multiple athletic disciplines. Explosive isometric contraction emphasizing rapid torque development during short contractions is especially beneficial in sports that demand the generation of maximum power output within a brief period, such as sprinting[20–24]. Conversely, conventional strength training typically has a primary emphasis on training with sustained contractions at high loads, which is advantageous in sports that require consistent force production over time[25]. Even with identical total contraction time, varying the distribution of isometric contractions (e.g., 9 × 1 s vs. 3 × 3 s) may elicit different physiological responses due to differences in fatigue, neuromuscular activation, and potentiation. Shorter, repeated contractions may enhance neural drive and favor PAPE mechanisms, while longer contractions may induce greater local fatigue, potentially reducing the PAPE effect shortly after ICA[5]. Currently, literature lacks data on the effects of different isometric contraction durations (1 s vs. 3 s) within a single set of ICA of equal total duration on CMJ performance in high-level athletes. Specifically, no studies to date have investigated this phenomenon in national level young soccer players, who routinely rely on the ability to generate explosive power under varying fatigue conditions[4]. Addressing this gap may yield valuable practical insights for coaches and athletes, enabling the optimization of warm-up protocols implemented immediately prior to competition.

The aim of this study was to investigate the effects of different distributions of isometric contractions (1 s contractions for 9 repetitions [RAPID] versus 3 s contractions for 3 repetitions [SUST), with the same total ICA duration (9 s) within a single set, on CMJ performance measured 12 minutes post-ICA in a cohort of national level young soccer players. It was hypothesized that only the RAPID protocol would lead to a significant improvement in CMJ performance, due to its potentially greater impact on neural activation and PAPE mechanisms. The instruction "push the barbell vertically upward as hard and as fast as possible" in the RAPID protocol aimed to maximize the rate of force development (RFD), a key factor in explosive tasks such as the CMJ. An increase in RFD enhances the ability to rapidly generate force, which is critical in movements requiring high power output[20,24]. This hypothesis aligns with the theory that neural adaptations resulting from rapid and intense contractions, such as increased motor unit recruitment, can improve performance in explosive tasks[23,24]. In line with previous reports and the equivocal findings of earlier studies, no significant changes were expected following the SUST protocol or under control conditions (CTRL).

Materials and methods

Experimental approach to the problem

The study was conducted using a randomized crossover design, in which each participant completed 3 experimental sessions to compare the acute effects of ICAs on CMJ performance. Participants were randomly assigned to experimental conditions (randomization was performed via the random.org generator), each characterized by a distinct distribution of ICA duration within a single set while maintaining the same total ICA duration of 9 s in accordance with the recommendations of Xu et al.[26]. The randomization sequence was generated by an investigator not involved in data collection or analysis, and the allocation was concealed in sequentially numbered, opaque, sealed envelopes, which were opened immediately prior to each session. During the RAPID condition, the ICA protocol consisted of 1 s contractions performed for 9 repetitions, whereas in the SUST condition, it consisted of 3 s contractions performed for 3 repetitions, with a 1 s rest interval between them. Additionally, a CTRL condition without any ICA was included. CMJ measurements were taken approximately 3 min before ICA and at the 3rd, 6th, 9th, and 12th minutes after completing the ICA[9]. In the CTRL condition, measurements were taken at the same time points but without the application of ICA (Fig. 1). All sessions were separated by 4–7 days. Participants were blinded to the specific study hypothesis but could not be blinded to the order of experimental conditions due to the visible nature of the ICA protocols. However, the individual conducting the CMJ measurements and data analysis was blinded to the intervention conditions to reduce potential bias.

Participants

The sample size was determined using G*Power version 3.1.9.2 (Dusseldorf, Ger-many), with the following parameters for the statistical test: "ANOVA for repeated measures with a within-factors" (one group of participants, three experimental conditions, and five measurements), statistical power of 0.8, a significance level of 0.05, and an effect size of d = 0.5 based on previous studies evaluating the immediate impact of isometric activation exercises on jump performance[12,16]. The analysis indicated that the minimum required sample size for this study is 11 participants.

The study involved 15 national level young male soccer players classified based on training status and performance caliber according to McKay et al.[27] classification (Table 1). The inclusion criteria were as follows: (a) a minimum of 5 years of experience in soccer training; (b) (performing at least 3 strength training sessions per week over the past 5 years; (c) no muscle injuries (resulting in a training break longer than 4 weeks) for at least 6 months prior to the start of the study. Participants were instructed to abstain from any resistance training exercises within 48 h before the commencement of the experimental session. Additionally, they were advised to maintain their regular dietary habits and refrain from the consumption of any supplements or stimulants, except for habitual supplementation such as creatine in the week preceding the experiment. At the start of the experimental session, body composition was assessed using a multi-frequency bioelectrical impedance analysis

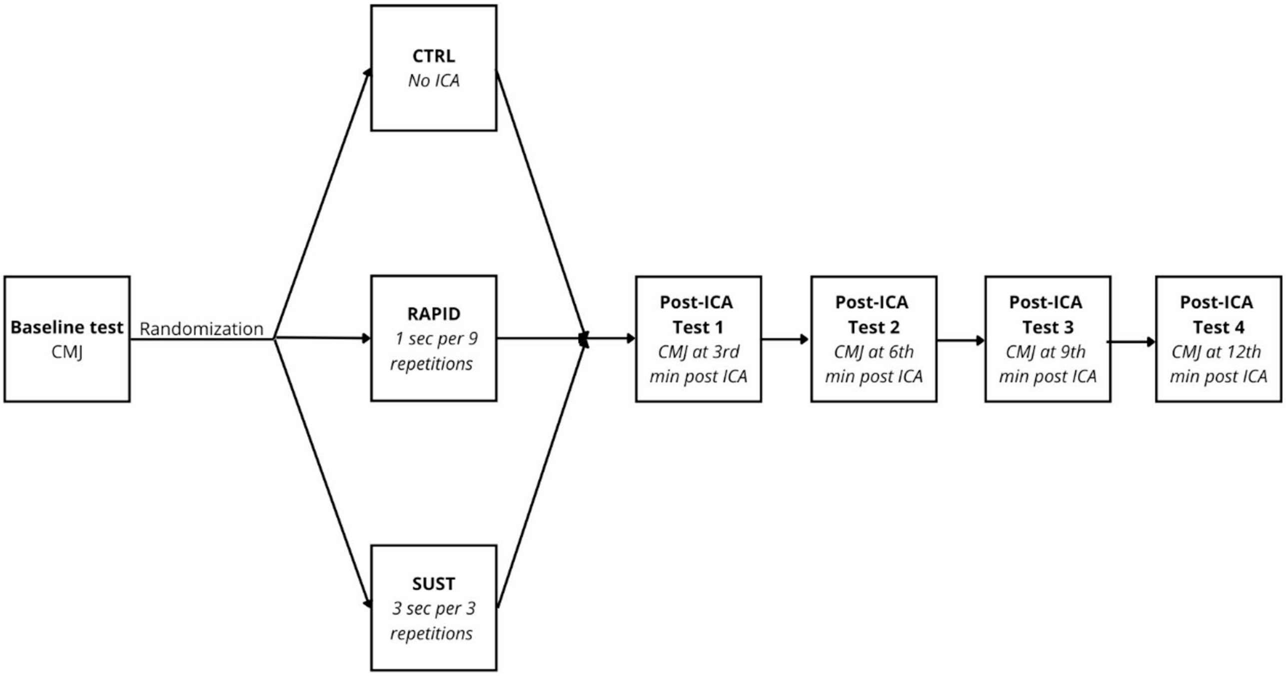

Fig. 1. Study design flowchart. CMJ—countermovement jump; ICA—isometric conditioning activity. CTRL—control condition (without ICA); RAPID – isometric muscle action condition with 1 s per 9 repetitions; SUST – isometric muscle action condition with 3 s per 3 repetitions.

Age [years]	19 ± 1
Body mass [kg]	70 ± 8
Body fat [%]	7.0 ± 2.6
Body height [cm]	180 ± 7
Soccer training experience [years]	6.0 ± 1.0

Table 1. Descriptive characteristics of the study participants.

under controlled laboratory conditions, utilizing the InBody 770 device (InBody 770 Biospace Co., Ltd, Seoul, South Korea). All participants were informed of the potential risks and benefits associated with the study and were apprised of their right to withdraw at any time without the need to provide a reason. Written informed 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 experiment received formal approval from the Bioethics Committee for Scientific Research (03/2021) at the Academy of Physical Education in Katowice in accordance with the ethical principles outlined in the Declaration of Helsinki of 1983.

Familiarization session

All experimental sessions were conducted between 15:00 and 17:00. At least 3 days before the initial experimental session, participants completed a familiarization session involving both ICA protocols (RAPID and SUST) as well as CMJ. Baseline variability of CMJ performance between sessions was not assessed in the present study. Each session began with a standard warm-up, including 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) performed to which usual warm-up of the athletes for their training[3]. Following the warm-up, participants performed, in random order, 1 set of ICA with different distribution contractions and 3 CMJ trials after each set. Each participant was assigned a customized rack height for the isometric squats based on the height of the barbell pins on the squat rack[5]. Participants held a barbell positioned on their shoulders, which was stabilized by the rack pins to maintain an isometric muscle action. Squat depth was set at a 120-degree knee angle[3], determined by an experienced coach using a goniometer (EasyAngle, Meloq AB, Stockholm, Sweden). The same coach also standardized body positioning to ensure vertical torso alignment across all conditions. Upon the researcher's verbal command, participants were instructed to "push the barbell vertically upward as hard and as fast as possible" by pressing their backs against the barbell and applying force through their feet into the ground[5]. To ensure maximal effort during each isometric contraction attempt, participants were strongly verbally encouraged throughout the trial, following common procedures used in neuromuscular testing[28]. During the CMJ, squat depth was unrestricted.

Experimental sessions
Following a standardized warm-up (identical to that used in the familiarization session), participants completed a baseline assessment of CMJ performance. Each participant performed 3 trials of the CMJ with their arms placed on their hips throughout the entire movement (without arm swing), with approximately 5 s intervals between attempts. After a rest period of approximately 3 min, participants engaged in the PIMA maximal isometric squat protocol as the ICA or, in the CTRL, without any ICA. Individual adjustments for the barbell height during ICA were consistent with the fa-miliarization session.

Participants were assigned to one of the following conditions:

- CTRL — the control condition consisted of maintaining light physical activity, where participants were re-quired to walk freely around the gym where the study took place for the time equivalent to performing the entire ICA set (10 s)[3].
- RAPID — the 1 set of ICA, consisting of 9 repetitions of 1 s maximal voluntary isometric contraction, with a total ICA duration of 9 s.
- SUST — the 1 set of ICA, consisting of 3 repetitions of 3 s maximal voluntary isometric contractions, with a total ICA duration of 9 s.

In accordance with the protocol, CMJ measurements in the CTRL condition were conducted at the same time points but without the application of ICA (Fig. 1).

Measurement of countermovement jump performance
Jump performance was evaluated using a force platform (Force Decks, Vald Performance, Australia) operating at a sampling frequency of 1000 Hz. This tool is widely recognized for its validity and reliability in assessing the kinematics of vertical jumps[29]. At each time point (3 min before ICA and at 3, 6, 9, and 12 min after), participants performed three CMJ trials without arm swing[9]. During the testing, participants began from a standing position with their hands placed on their hips, maintaining a straight posture to minimize angular displacement of the hips. They were instructed to remain as motionless as possible for at least one second before initiating the downward phase of the jump. Participants then descended into a squat to a predetermined depth before executing a maximal-effort vertical jump. They were required to land in the same position from which they started, centrally on the force platform. All measurements were conducted by the same experienced technician to ensure consistency. For further analysis, the best trial (i.e., the one with the highest jump height) out of the three attempts was used. The study's dependent variable was jumping height (JH), which was calculated based on the center of mass velocity at takeoff using the equation relating to impulse and momentum. Furthermore, relative peak power output (PP), the modified reactive strength index (RSImod), countermovement depth (CD), and contraction time (CT) were also assessed (Table 2).

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 Shapiro-Wilk was utilized for data normlatiy assumptions check. Levene's and Mauchly's tests were used to verify the homogeneity and sphericity of the sample data variances, respectively. The repeated measures two-way ANOVA (3 conditions [CTRL; RAPID; SUST] × 5 time-points [pre-ICA; 3rd, 6th, 9th, and 12th post-ICA]) was used to investigate the influence of ICA on CMJ selected variables. The order of conditions was counterbalanced across participants to minimize potential order effects. Effect sizes for main effects and interactions were determined by partial eta-squared (η2). Partial eta-squared values were classified as small (0.01 to 0.059), moderate (0.06 to 0.137), and large (> 0.137). When a significant main effect or interaction was found, the post-hoc tests with Bonferroni correction (p_bonf) were used to analyze 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)[30]. However, when normality was not confirmed, a Friedman analysis of variance for related samples was performed based on ranks. Effect sizes were estimated using Kendall's W coefficient of concordance. For post hoc pairwise comparisons in the case of non-normality, the Wilcoxon signed-rank (Wsr) test was employed. Effect size was measured using Rg, with thresholds of 0.1, 0.3, and 0.5 indicating small, medium, and large effects, respectively. The smallest worthwhile change (SWC)

	Baseline (Jump Height and Peak Power)	3 min (Jump Height and Peak Power)	6 min (Jump Height and Peak Power)	9 min (Jump Height and Peak Power)	12 min (Jump Height and Peak Power)
CTRL	36.1 ± 4.2 cm, 50.2 ± 5.7 [W/kg]	36 ± 4.7 cm, 50.2 ± 5 [W/kg]	35.4 ± 4.5 cm, 49.8 ± 4.7 [W/kg]	35.8 ± 4.9 cm, 49.7 ± 5.1 [W/kg]	36.1 ± 4.7 cm, 50.6 ± 5.6 [W/kg]
RAPID	37.3 ± 6.5 cm, 52 ± 5.7 [W/kg]	36.5 ± 5.3 cm, 51.1 ± 4.1 [W/kg]	35.3 ± 5 cm, 49.4 ± 4.3 [W/kg]#	35.8 ± 6.7 cm, 50.1 ± 5.2 [W/kg]	33.6 ± 5 cm*, 48.8 ± 4.8 [W/kg]#
SUST	36.4 ± 6.2 cm, 50.2 ± 5.6 [W/kg]	35.9 ± 5.4 cm, 50.3 ± 5.5 [W/kg]	36.6 ± 6 cm, 49.9 ± 5.3 [W/kg]	35.9 ± 6.5 cm, 49.2 ± 5 [W/kg]	35.5 ± 5.7 cm, 49.1 ± 4.7 [W/kg]

Table 2. Change in jump height and relative peak power between time points and conditions. CTRL—control condition (without ICA); RAPID – isometric muscle action condition with 1 s per 9 repetitions; SUST – isometric muscle action condition with 3 s per 3 repetitions; 3 min – 3rd-minute post-ICA, 6 min – 6th-minute post-ICA, 9 min – 9th-minute post-ICA, 12 min – 12th-minute post-ICA, * — significant difference compared to baseline value and the 3rd-minute post-ICA within the same condition $p < 0.05$; # — significant difference compared to baseline value within the same condition $p < 0.05$.

was calculated based on the between-subject standard deviation at baseline and determined using the formula: SWC = 0.6 × SDbaseline. The absolute difference between the best jump performance post-ICA and the baseline value was used to classify participants. In line with previous recommendations Turner et al.[31], individuals were categorized as: (a) responders (R), if their performance improvement exceeded the SWC threshold; and (b) non-responders (NRS), if the observed change did not surpass this threshold (Table 3).

Results

Jumping performance

A repeated measures two-way ANOVA revealed significant interaction for JH and PP (JH: $p = 0.003$; $\eta p^2 = 0.181$; PP: $p = 0.032$; $\eta p^2 = 0.136$). Post-hoc comparisons indicated a significant decrease in JH in RAPID condition at 12-minutes post-ICA compared to pre-ICA and 3rd-minute post-ICA (mean differences of -3.7 ± 3 cm and − 3 ± 2.5 cm, respectively; Cohen's d = 0.64 and 0.56; p_bonf < 0.001 for both). Additionally, PP was significantly reduced at 12- and 6-minutes post-ICA in the RAPID condition, compared to pre-ICA (MD = -3.2 ± 0.9 W/kg and − 2.6 ± 1.3 W/kg; Cohen's d = 0.61 and 0.51; p_bonf < 0.001 and p_bonf = 0.024, respectively) (Table 2). These findings are further illustrated by the visual decline in both JH and PP shown in Fig. 2.

Modified RSI

A repeated measures two-way ANOVA did not show significant interaction ($p = 0.071$; $\eta p^2 = 0.118$), main effect of time ($p = 0.430$; $\eta p^2 = 0.065$), or condition ($p = 0.901$; $\eta p^2 = 0.007$) for RSImod (Fig. 3).

Contraction time

A repeated measures two-way ANOVA did not show statistically significant in-teraction ($p = 0.543$; $\eta p^2 = 0.059$), the main effect of time ($p = 0.324$; $\eta p^2 = 0.079$), or condition ($p = 0.389$; $\eta p^2 = 0.065$) for CT (Fig. 4).

Countermovement depth

The Friedman test did not reveal significant differences over time in CD ($\chi^2 = 17.572$; $p = 0.227$; W = 0.084) (Fig. 5).

Discussion

The aim of this study was to compare the effects of different ICA distributions on CMJ performance among national level young male soccer players. The results clearly indicate that none of the tested ICA protocols elicited a PAPE effect. Notably, the RAPID protocol even led to a significant decrease in JH at the 12th minute post-activation compared to baseline and the 3rd minute, as well as a reduction in PP at both the 6th and 12th minutes. No significant changes were observed in RSImod, CT, or CD in either condition. These findings suggest that the investigated RAPID and SUST protocols are ineffective in enhancing explosive performance in the short term, and the RAPID protocol may, in fact, be detrimental to CMJ performance in national level young male soccer players.

The results obtained did not confirm the hypothesis suggesting an improvement in CMJ performance following the ICA application. Instead, under the RAPID protocol conditions, a significant decrease in JH and PP was observed at the 12th minute after ICA compared to baseline values. This finding contradicts the results of the study by Garbisu-Hualde et al.[13], in which a significant increase in peak barbell velocity was recorded after 15 repetitions of isometric contractions lasting 1 s each within a single ICA set during the flat bench press exercise. These differences may arise from varying methodological assumptions and the specific muscle groups evaluated. In the study by Garbisu-Hualde et al.[13] the effects of ICA on upper limb movement parameters were assessed, whereas the present study focused on the lower limb response to ICA performed during an isometric squat, as well as its impact on CMJ performance. This distinction suggests that the efficacy of 1-second isometric contractions in eliciting a PAPE effect may be jointly dependent on the muscle group engaged and the contraction intent. Another potential factor influencing the lack of PAPE effect could be the shorter total ICA duration (9 s) in the present study compared to the longer duration (15 s) used in the Garbisu-Hualde et al.[13]

Variable	CTRL		RAPID		SUST	
Jump height [cm]	RS	1	RS	1	RS	3
	NRS	14	NRS	14	NRS	12
Peak power [W/kg]	RS	5	RS	0	RS	1
	NRS	10	NRS	15	NRS	14
RSImod	RS	7	RS	3	RS	7
	NRS	8	NRS	12	NRS	8
Contraction time [ms]	RS	4	RS	4	RS	3
	NRS	11	NRS	11	NRS	12
Countermovement depth [cm]	RS	7	RS	2	RS	7
	NRS	8	NRS	13	NRS	8

Table 3. Distribution of responders (RS) and non-responders (NRS) across performance metrics. CTRL—control condition (without ICA); RAPID – isometric muscle action condition with 1 s per 9 repetitions; SUST–sustained of isometric muscle action condition with 3 s per 3 repetitions.

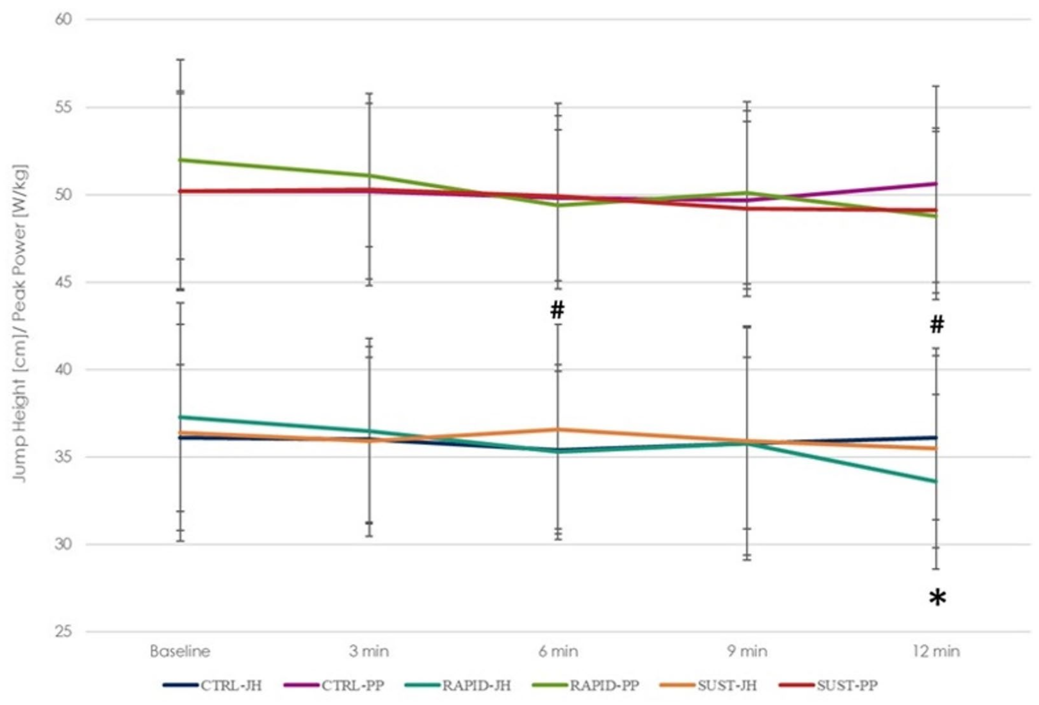

Fig. 2. Changes in jump height (cm) and relative peak power (W/kg) over time in all conditions. CTRL-JH – jump height in the control condition without ICA; CTRL-PP – peak power in the control condition without ICA; RAPID-JH – jump height in the isometric muscle action condition with 1 s per 9 repetitions; RAPID-PP – peak power in the isometric muscle action condition with 1 s per 9 repetitions; SUST-JH – jump height in the isometric muscle action condition with 3 s per 3 repetitions; SUST-PP – peak power in the isometric muscle action condition with 3 s per 3 repetitions; 3 min – 3rd-minute post-ICA, 6 min – 6th-minute post-ICA, 9 min – 9th-minute post-ICA, 12 min – 12th-minute post-ICA; * — significant difference compared to baseline value and the 3rd-minute post-ICA within the same condition $p < 0.05$; # — significant difference compared to baseline value within the same condition $p < 0.05$.

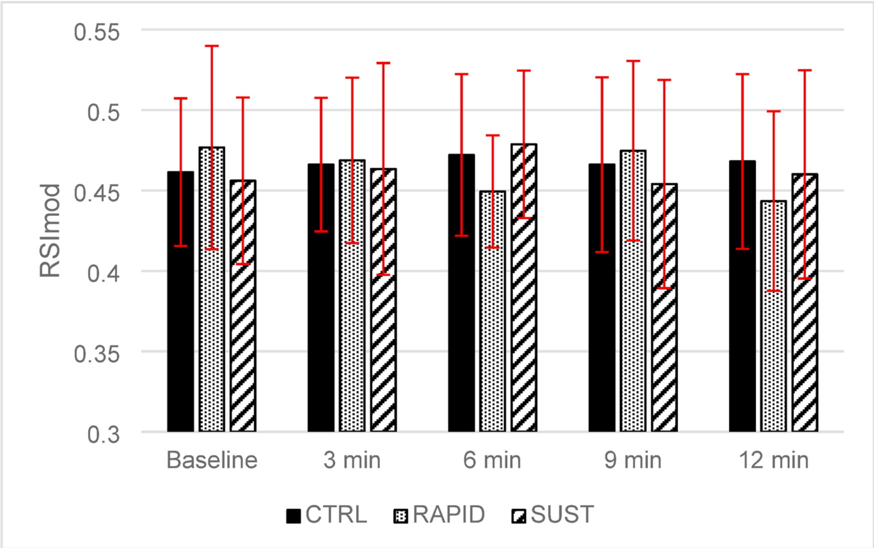

Fig. 3. Change in RSI modified across time points and conditions. CTRL—control condition (without ICA); RAPID – isometric muscle action condition with 1 s per 9 repetitions; SUST – isometric muscle action condition with 3 s per 3 repetitions; 3 min – 3rd-minute post-ICA, 6 min – 6th-minute post-ICA, 9 min – 9th-minute post-ICA, 12 min – 12th-minute post-ICA.

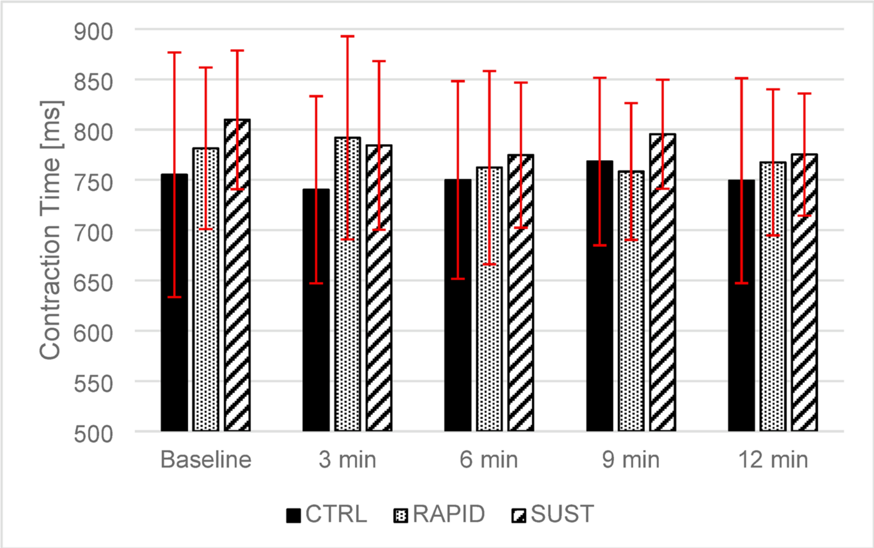

Fig. 4. Change in contraction time (ms) across time points and conditions. CTRL—control condition (without ICA); RAPID – isometric muscle action condition with 1 s per 9 repetitions; SUST– isometric muscle action condition with 3 s per 3 repetitions; 3 min – 3rd-minute post-ICA, 6 min – 6th-minute post-ICA, 9 min – 9th-minute post-ICA, 12 min – 12th-minute post-ICA.

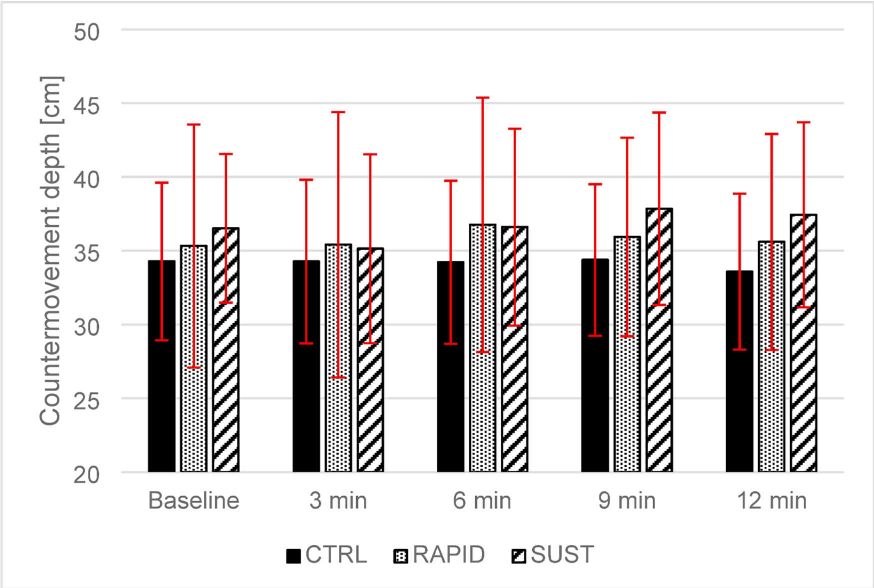

Fig. 5. Change in countermovement depth (cm) across time points and conditions. CTRL—control condition (without ICA); RAPID – isometric muscle action condition with 1 s per 9 repetitions; SUST– sustained of isometric muscle action condition with 3 s per 3 repetitions; 3 min – 3rd-minute post-ICA, 6 min – 6th-minute post-ICA, 9 min – 9th-minute post-ICA, 12 min – 12th-minute post-ICA.

study. It is also worth noting that the obtained results align with the observations of Jarosz et al.[5], who reported a decrease in JH during CMJ at the 9th minute after ICA using 1 s contractions with a total duration of 9 s per set despite an increase in isometric force production measured after 200 ms. However, in the Jarosz et al.[5] study, 3 sets of ICA were applied (totaling 27 s), which significantly differs from the protocol used in the present study with a single 9 s set. This variation in total volume could influence the potentiation–fatigue balance: while higher ICA volumes may promote potentiation through repeated stimulation, they also increase the risk of fatigue if recovery is insufficient[5]. Conversely, the lower volume used in this study may have been inadequate to trigger a measurable PAPE effect in lower-limb explosive performance. Neurologically, the increase in instantaneous discharge rate of motor units and the number of units capable of producing high frequencies during nine maximal efforts in the RAPID condition, together with partial transfer of those adaptations to maximal contractions[32,33], could have resulted in a different cumulative neuromuscular loading than a smaller number of longer efforts (e.g., three 3-second contractions). Short, repeated maximal activations may have promoted greater cumulative central fatigue due to repeated recruitment of high-threshold motor units and insufficient recovery of neural drive between efforts, potentially transiently reducing discharge rates or disrupting their synchronization, thus negating the benefits of potentiation. Conversely, the lower volume applied in the study may have been inadequate to elicit a detectable PAPE in explosive lower-limb output, and the rapid succession of efforts could have shifted the potentiation–fatigue balance toward fatigue because of accumulating neural load. Importantly, no previous studies have directly investigated the effect of single 1 s isometric contractions on CMJ performance. This gap underscores the novelty of the present investigation and highlights the need for further research into the neuromuscular consequences of brief ICA protocols. Our findings provide preliminary evidence that short-duration (1 s) isometric contractions may not be sufficient to enhance CMJ performance and may, in fact, induce transient fatigue. Future studies should systematically examine how ICA parameters—such as contraction duration, total volume, and recovery interval—modulate performance outcomes.

The observed lack of significant improvement in CMJ performance under the SUST condition aligns with the hypothesis. This finding is consistent with previous reports by Jarosz et al.[3] and French et al.[10], who also did not observe significant changes in CMJ performance after a single ICA set under the SUST condition. It is plausible that a single set of ICA, regardless of contraction distribution (RAPID vs. SUST), provides an insufficient neuromuscular stimulus to induce potentiation. As proposed by Balshaw et al.[24] and Jenkins et al.[34], short-duration ICAs may not adequately activate high-threshold motor units, limiting the potential for eliciting a PAPE effect. However, beyond suboptimal activation, the temporal distribution of contractions in the SUST protocol (i.e., prolonged yet continuously sustained efforts) may have engendered a distinct fatigue-accumulation profile relative to RAPID, potentially delaying neural-drive recovery or altering excitation–contraction coupling efficiency. The absence of performance enhancement under both protocols may also reflect insufficient total contraction time or number of sets, which have been identified as critical for eliciting potentiation effects[12,26]. This interpretation is further supported by Jarosz et al.[3], who demonstrated that 3 sets of ICA with 3 s contractions (totaling 27 s) significantly increased JH and PP compared to the control condition and a single 9 s set (SUST). Thus, these observations indicate that both the volume and temporal structure of ICA (i.e., the distribution of contractions) are critical in shaping the potentiation–fatigue interaction, with short protocols being more susceptible to fatigue predominance.

The organism's response to PAPE protocols is highly dependent on individual athlete characteristics—such as biological age, training experience, and sport-specific demands—which should be considered not merely as control variables but, more importantly, as moderators of the effectiveness of the training intervention[27,35]. Thus, PAPE protocols are not universal tools; they require precise individualization that accounts for the athlete's stage of sport development and their specific neuromuscular adaptations[35]. To reconcile the discrepancies between the present study's findings in young national-level soccer players and the existing literature, it is useful to refer to the research of Jarosz et al.[3], conducted in a cohort of adult, highly trained volleyball players, in which positive responses following ICA were observed. These athletes not only possessed advanced adaptation to training loads but also competed in a discipline characterized by high-intensity explosive efforts, particularly jumping. Such factors may contribute to a more pronounced neuromuscular response to the applied ICA protocol, potentially explaining the observed differences in outcomes. Similarly, the results reported by Tsoukos et al.[9] diverge from those of the present study—the authors documented improvements in CMJ performance after three sets of ICA with 3-second contractions each, despite the total contraction duration (9 s) being identical to our protocol. Notably, the participants in Tsoukos et al.[9] were adult, national-level male track and field athletes with a high degree of neuromuscular development and extensive training experience in a sport defined by explosive power requirements. In contrast to these studies, the present experiment involved younger national-level soccer players with relatively shorter training experience and, likely, lower neuromuscular efficiency. These distinctions may be related to developmental characteristics typical of young athletes, such as the ongoing maturation of the neuromuscular system and a specific hormonal profile, which could have contributed to an attenuated or absent PAPE response in our sample[36].

These differences indicate that it remains unclear which specific parameters—total duration of ICA, number of sets, number of repetitions, or the duration of a single contraction—play a key role in eliciting the PAPE effect. Therefore, future studies should focus on analyzing the impact of various combinations of isometric contraction durations and their frequencies—both 1- and 3-second contractions—within a single set, as well as their distribution across multiple sets. Furthermore, individual factors such as sex, age, sport discipline, and training level should be considered, as they may significantly influence neuromuscular responsiveness to ICA and modulate the effectiveness of PAPE protocols across diverse populations. Moreover, it would be beneficial to include additional physiological measurements, such as biochemical blood analysis (including lactate, creatine kinase, and cortisol levels), as well as the use of methods like tensiomyography, electromyography, mechanical muscle property assessment[37], and monitoring of isometric strength. The absence of such measurements in the current study represents a limitation. Integrating these parameters with CMJ performance outcomes could offer a more comprehensive understanding of the acute neuromuscular effects of ICA and contribute to the development of optimized protocols aimed at enhancing lower-limb explosive performance. Additionally, baseline between-session variability of CMJ performance was not assessed in the present study, which is a further limitation because without estimating within-subject variability true changes cannot be distinguished from normal measurement noise.

Conclusions

The present study showed that varying the distribution of isometric contraction duration within an ICA—specifically using 1- and 3-second contractions with equal total contraction time (9 s) —did not enhance

CMJ performance in national level young male soccer players. Notably, the 1-second contraction condition led to significant reductions in JH and PP, indicating a temporary decrease in lower-limb explosive capacity. These findings apply specifically to the tested protocols and should not be generalized to all ICA variations. This study adds to existing ICA literature by highlighting the importance of not only total isometric load but also its temporal distribution in determining performance outcomes. Coaches and practitioners working with national-level young male soccer players should exercise caution when implementing warm-up protocols involving short-duration, high-repetition isometric contractions, as our findings suggest that these may impair rather than enhance subsequent explosive performance. Future research should investigate the response to RAPID contraction protocols (e.g., comparing 3, 6, and 9 repetitions) to identify a potential threshold beyond which potentiation gives way to fatigue in this specific population. Additionally, physiological measures (e.g., neuromuscular, metabolic, or hemodynamic responses) should be incorporated to elucidate the underlying mechanisms driving these performance outcomes.

Data availability

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

Received: 25 April 2025; Accepted: 3 September 2025
Published online: 26 September 2025

References

1. 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).
2. Kasicki, K., Rydzik, Ł., Ambroży, T., Spieszny, M. & Koteja, P. The impact of post-activation performance enhancement protocols on vertical jumps: systematic review. *Appl. Sci.* **14**, 9664 (2024).
3. Jarosz, J. et al. Acute effects of isometric conditioning activity with different set volumes on countermovement jump performance in highly trained male volleyball players. *Appl. Sci.* **15**, 2393 (2025).
4. Jarosz, J. et al. How repeatable is PAPE effect: the impact of in-season isometric squat activation on countermovement jump performance enhancement in National level soccer players. *BMC Sports Sci. Med. Rehabil.* **17**, 115 (2025).
5. Jarosz, J. et al. Acute effects of isometric conditioning activity with different distribution contraction on countermovement jump performance in resistance trained participants. *Sci. Rep.* **15**, 16960 (2025).
6. Docherty, D. & Hodgson, M. J. The application of postactivation potentiation to elite sport. *Int. J. Sports Physiol. Perform.* **2**, 439–444 (2007).
7. McGowan, C. J., Pyne, D. B., Thompson, K. G. & Rattray, B. Warm-up strategies for sport and exercise: mechanisms and applications. *Sports Med.* **45**, 1523–1546 (2015).
8. 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).
9. 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).
10. 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).
11. Vargas-Molina, S., Salgado-Ramírez, U., Chulvi-Medrano, I., Carbone, L. & Maroto-Izquierdo, S. Benítez-Porres, J. Comparison of post-activation performance enhancement (PAPE) after isometric and isotonic exercise on vertical jump performance. *PLOS ONE.* **16**, e0260866 (2021).
12. Spieszny, M. et al. Post-isometric back squat performance enhancement of squat and countermovement jump. *Int. J. Environ. Res. Public. Health.* **19**, 12720 (2022).
13. 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**, 105–115 (2023).
14. Koźlenia, D. & Domaradzki, J. The effectiveness of isometric protocols using an external load or voluntary effort on jump height enhancement in trained females. *Sci. Rep.* **13**, 13535 (2023a).
15. Koźlenia, D. & Domaradzki, J. Effects of post-activation protocols based on slow tempo bodyweight squat and isometric activity on vertical jump height enhancement in trained males: A randomized controlled trial. *PeerJ* **11**, e15753 (2023b).
16. 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).
17. Helbin, J. et al. Acute effects of unilateral conditioning activity on unilateral and bilateral jumping performance and bilateral strength asymmetry. *Sci. Rep.* **15**, 10552 (2025).
18. Terbalyan, A. et al. Effects of overcoming isometric unilateral conditioning activity on subsequent single-leg drop jump in elite and amateur volleyball players: A randomized crossover trial. *BMC Sports Sci. Med. Rehabil.* **17**, 30 (2025a).
19. Terbalyan, A. et al. A systematic review and meta-analysis of effect of post-activation performance enhancement in combat sports—Part I: general performance indicators. *J. Funct. Morphol. Kinesiol.* **10**, 88 (2025b).
20. 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).
21. 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).
22. 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).
23. 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).
24. 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).
25. 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).
26. Xu, K. et al. Optimizing Post-activation performance enhancement in athletic tasks: A systematic review with Meta-analysis for prescription variables and research methods. *Sports Med.* **55**, 977–1008. https://doi.org/10.1007/s40279-024-02170-6 (2025).
27. McKay, A. K. A. et al. Defining training and performance caliber: A participant classification framework. *Int. J. Sports Physiol. Perform.* **17**, 317–331 (2022).

28. McNair, P. J., Depledge, J., Brettkelly, M. & Stanley, S. N. Verbal encouragement: effects on maximum effort voluntary muscle action. *Br. J. Sports Med.* **30**, 243–245 (1996).
29. Collings, T. J. et al. Concurrent validity and test–retest reliability of VALD forcedecks' strength, balance, and movement assessment tests. *J. Sci. Med. Sport*. **27**, 572–580 (2024).
30. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences* 2nd edn (Elsevier Science, 2013).
31. Turner, A. et al. Data analysis for strength and conditioning coaches: using excel to analyze reliability, differences, and relationships. *Strength. Cond J.* **37**, 76–83 (2015).
32. Duchateau, J. & Baudry, S. Maximal discharge rate of motor units determines the maximal rate of force development during ballistic contractions in human. *Front. Hum. Neurosci.* **8**, 234 (2014).
33. Van Cutsem, M., Duchateau, J. & Hainaut, K. Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. *J. Physiol.* **513**, 295–305 (1998).
34. Jenkins, N. D. M. et al. Greater neural adaptations following high- vs. low-load resistance training. *Front. Physiol.* **8**, 331 (2017).
35. Seitz, L. B. & Haff, G. G. Factors modulating post-activation potentiation of jump, sprint, throw, and upper-body ballistic performances: a systematic review with meta-analysis. *Sports Med.* **46**, 231–240 (2016).
36. Kraemer, W. J. & Ratamess, N. A. Hormonal responses and adaptations to resistance exercise and training. *Sports Med.* **35**, 339–361. https://doi.org/10.2165/00007256-200535040-00004 (2005).
37. Jarosz, J. et al. Effects of blood flow restriction on mechanical properties of the rectus femoris muscle at rest. *Front. Physiol.* **14**, 1244376 (2023).

Author contributions

Conceptualization, W.G., and J.J.; methodology, W.G., and J.J.; software, W.G.; validation, W.G.; formal analysis, W.G.; investigation, W.G.; writing—original draft preparation, J.J.; writing—review and editing, J.J.; supervision, J.J.; project administration, J.J.; funding acquisition, W.G. 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.