ORIGINAL SCIENTIFIC PAPER

Acute effect of time and set configuration of squat exercise on jump performance of male soccer players: a randomized crossover study

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Abstract

This study aimed to examine the acute effects of squat exercise performed with different set configurations on jump performance of U19 male soccer players. Seventeen male soccer players from a U19 elite soccer league team participated in the study. In a randomized crossover manner (with 72-hour rest between testing sessions), participants performed four different squat (80% one repetition maximum) set configurations. The set configurations included a traditional set configuration [(TSC); 6 repetitions × 3 sets with 180 seconds rest between sets] and three rest redistribution methods: RR_1 (3 repetitions × 6 sets, 20 seconds rest between repetitions, 150 seconds rest between sets), RR_2 (2 repetitions × 9 sets, 20 seconds rest between repetitions, 120 seconds rest between sets), and RR_3 (1 repetition × 18 sets, 20 seconds rest between repetitions). The rest duration was equalized across all set configurations. Countermovement jump was performed at pre-test, and 15 seconds, 4 minutes, 8 minutes, and 12 minutes post squat exercise. A two-way ANOVA [4×5 (set configuration × time)] was used for statistical analysis. The findings indicated that all RR methods proved effective in acutely enhancing performance when employed with 4–8 minute intervals. In addition, the RR methods appear to be more effective than TSC. In conclusion, practitioners may prioritize using the RR method over TSC to acutely improve the jump performance, with 4 minutes being optimal recovery between the squat and jump.

Keywords: *plyometric exercise, resistance training, warm-up exercise, human physical conditioning*

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Introduction

High-intensity actions such as sprinting, jumping, and/or changing direction are strong predictors of competitive success in modern soccer (Castagna & Castellini, 2013; Wragg et al., 2000). Therefore, training methods that enhance these high-intensity actions are crucial. Indeed, different training methods can induce acute and chronic adaptation to improve these actions (de Hoyo et al., 2016; Janz & Malone, 2008). Post activation performance enhancement (PAPE) is a strategy to induce acute performance improvement (Blazevich & Babault,

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2019; Hodgson et al., 2005; Ulloa-Sánchez et al., 2024), by using conditioning exercises during warm-up (Hodgson et al., 2005; Ulloa-Sánchez et al., 2024).

PAPE is suggested to occur when an activity requiring sub-maximal to maximal contraction (e.g., squat) acutely improves a biomechanically similar low-load activity (e.g., countermovement jump) (Blazevich & Babault, 2019; Hodgson et al., 2005; Prieske et al., 2020). However, performing sub-maximal to near-maximal effort may also lead to fatigue, which may overlay the potentiation effects (Tillin & Bishop, 2009). Therefore, the net effect on performance is determined by the balance between potentiation and fatigue. Indeed, studies have highlighted the importance of manipulation of different variables on balancing potentiation and fatigue, thereby inducing PAPE (Chiu et al., 2003; Gourgoulis et al., 2003; Kilduff et al., 2008). For example, some key variables affecting this balance are the participant's muscle strength (Gourgoulis et al., 2003), muscle fiber type distribution, and training level (Chiu et al., 2003); while the intensity (Gołaś et al., 2017), recovery time (Kilduff et al., 2008), number of sets (Wilson et al., 2013), and set configuration (Boullosa et al., 2013; Dello Iacono et al., 2020) may also affects this balance.

Amongst the aforementioned key variables, recovery period between the high-load and low load activity helps understand the balance between fatigue and potentiation (Dobbs et al., 2019), with studies reporting different recovery intervals (usually varying between 4 and 16 minutes) favorable for PAPE (Blazevich & Babault, 2019). Of note, the recovery period to induce PAPE may be moderated by both the characteristics of the participant and conditioning exercises, respectively. For example, a previous study showed that experienced athletes required less recovery time to induce the PAPE effects (Jo et al., 2010). In this context, cluster set organization uses shorter recovery intervals instead of longer recovery periods, and may help optimize the PAPE effects (Tufano et al., 2017). For example, a previous study has reported cluster set configuration to be effective in improving acute performance with a shorter recovery period, when compared to a traditional set configuration (TSC) (Boullosa et al., 2013). In addition, Hardee et al. (2012) also reported that including rest intervals between sets (i.e., cluster set configuration) resulted in a lower rating of perceived exertion compared to performing the same load using a TSC.

Moreover, the cluster set configurations can be applied using four different rest allocation methods (i.e., basic cluster set, equal work-rest ratio, rest pause, and rest redistribution [RR]) (Tufano et al., 2017). Amongst the four methods, the basic cluster set, equal work-rest ratio, and rest pause methods require a longer completion time compared to the RR method, for an equalized volume (González-Hernández et al., 2020; Tufano et al., 2017). The lower completion time in the RR method is obtained by dividing the rest duration between sets to smaller and frequent rest intervals (Tufano et al., 2017). While, in other cluster set methods, the rest duration between sets is similar to traditional resistance set configuration and only additional rest duration is added within sets (i.e., repetitions) (Tufano et al., 2017). Therefore, the RR method may be a viable option to implement as it provides similar benefits as other three methods, whilst requiring lesser completion time (González-Hernández et al., 2020).

However, no previous research has studied the effects of different RR strategies with overall equalized rest period (i.e., requiring similar overall completion time, albeit using different repetition and rest strategies) to induce acute performance enhancement. Therefore, the aim of this study was to examine the acute effects of squat exercises performed with traditional and different RR methods on jump performance. Based on available literature (Boullosa et al., 2013; Dello Iacono et al., 2020; Tufano et al., 2017), the authors hypothesized that the RR method would improve jump performance, compared to the TSC.

Materials and methods

Experimental approach to the problem

The study was conducted over a period of three weeks. The participants performed back squat and countermovement jump (CMJ) as a part of their regular training routine, and hence no familiarization session was conducted. Anthropometric measurements (height and body mass) were recorded at the start of the study. Thereafter, the participants were randomly divided into four groups, with each group performing different set configuration procedures on separate days separated by 72 hours in a randomized crossover manner. On each testing day, the participants performed CMJ before (baseline) and 15 seconds, 4 minutes, 8 minutes, and 12 minutes after the completion of the experimental protocols (Figure 1). A standardized 10-minute warm-up protocol was implemented before the experimental protocols. The warm-up programme comprised a 5-minute general warm-up on a bicycle ergometer with 50 revolutions per minute, followed by a soccer-specific dynamic stretching program as described in Ayala et al. (2017).

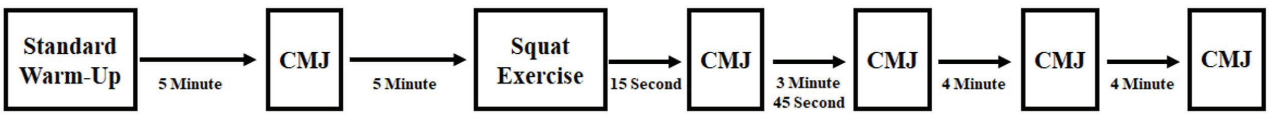

Figure 1. Schematic representation of the study's testing day plan. Note: CMJ – countermovement jump.

Participants

Seventeen male outfield soccer players were recruited from a team competing in the U19 elite soccer leagues (age: 18.6±0.2 years; height: 180.7±5.3 cm; body mass: 70.9±5.0kg; training age: 8.5±2.6 years; 1RM squat: 73.8±6.8 kg). The data collection was conducted during the first competition period of the season, and the participants were actively engaged in training sessions (70–90 minutes duration, 5 days/week) and participated in official competitions on the weekends. Additionally, the participants were free from injuries in the previous six months. The potential risks and challenges associated with the study were explained to each participant and thereafter informed consent forms were signed. Furthermore, ethical approval was obtained from the Local University Faculty of Medicine's Non-Interventional Clinical Research Ethics Committee Commission

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(decision dated 16/08/2022, numbered 12 (E-60116787-020-245291). This study was conducted in accordance with the Declaration of Helsinki.

Traditional set configuration (TSC) protocol

Three sets of squats were performed with a load of 80% 1RM, with each set comprising six repetitions. The rest interval between sets was 180 seconds (Figure 2).

Rest redistribution (RR) protocol

In rest redistribution (RR) protocols, the total number of repetitions and total recovery time were equalized, while the repetitions and recovery times were allocated proportionately. In RR_1, six repetitions were divided into two subsets (3+3) with 20 seconds of rest between each set, and the remaining recovery time was distributed as 150 seconds. In RR_2, the six repetitions were divided into three subsets (2+2+2), with 20 seconds of recovery allocated between each set, and the remaining recovery time was distributed as 120 seconds. In RR3, 18 repetitions were performed, and a 20-second rest period was allocated between each repetition, and a 30-second rest period was provided after the 6th and 12th repetitions. A detailed description of repetitions, sets, and recovery allocation is presented in Figure 2.

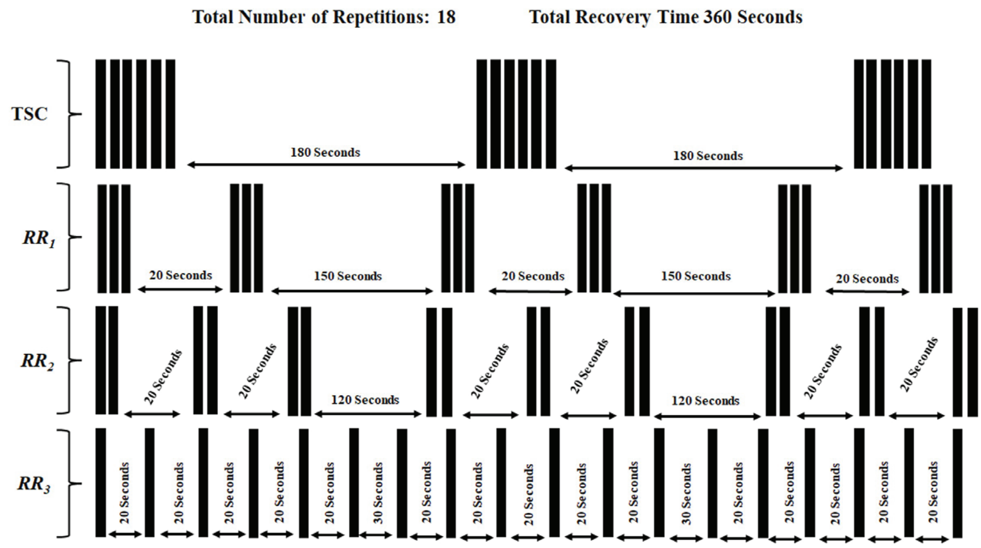

Figure 2. Schematic representation of different set configurations used in the study. TSC: Traditional set configuration; RR_1: First rest redistribution; RR_2: Second rest redistribution; RR_3: Third rest redistribution.

One repetition maximum

Prior to the commencement of the 1RM testing, each participants were required to perform a standardized warm-up protocol. To obtain the 1RM values, participants started with attempting five repetitions with 20%, followed by three repetitions at 50%, two repetitions at 75%, and finally one repetition at 85% of their last known 1RM. After that, the participants attempted the 1RM by using incremental loads, with a 3-minute rest period between the incremental loads. Participants were given a second attempt for their last unsuccessful lifts, with the load in the last successful lift expressed as the participant's 1RM. An observer was present on both sides of the weight bar during squat repetitions as a precautionary measure.

Countermovement Jump (CMJ)

The CMJ test was performed by the participants after the instructions from the researcher and was conducted on a portable jump mat (SmartSpeed; Fusion Sport, Brisbane, Australia). During the testing, the athletes were instructed to keep their hands on their waist and their torsos upright. The participants were asked to jump as high as possible immediately after squatting downwards rapidly, with self-selected squat depth. Verbal cues such as 'jump explosively' were provided to the participant. Two trials were conducted, and the highest jump height was recorded for analysis.

Statistical Analysis

All performance test scores are presented as means and standard deviations. Before performing the statistical analyses, the data set was assessed for normal distribution using the Shapiro-Wilk test. A two-way repeated measures analysis of variance (4 protocols × 5 time points) was applied to analyze the effects of protocols at different time points on countermovement jump performance. For significant differences, post hoc analyses using the Bonferroni correction method were used to identify the specific location of the difference between protocols or time points. The analyses were conducted using the SPSS v21.0 (IBM SPSS, Chicago, IL, USA) package programme. Partial eta squared values (ηp2; small < 0.0588, medium > 0.0588, large > 0.1379) were used as effect sizes for the ANOVA output (Cohen, 1988). In addition, Hedge's g effect size (g; trivial< 0.2; 0.2<small<0.6; 0.6<moderate<1.2; 1.2<large<2) was also calculated for between-protocol or time-point significant differences (Hopkins et al., 2009). Furthermore, intraclass correlation coefficients (ICC) were calculated to assess the reliability of the measurements. For all the analyses, the significance level was set at $p < 0.05$.

Results

Table 1 and Table 2 present the mean and standard deviation and statistical analysis results, respectively. Figure 3 presents a graphical representation of individual jump data across different protocol. The ICC for test-retest of CMJ was 0.96-0.97. The two-way repeated measures analysis of variance reported a significant main effect of time ($F=14.32$; $p=<0.01$; $\eta_p^2=0.47$; large effect size) and interaction effect

(F=3.003; p=0.021; η_p^2=0.158; large effect size) on the CMJ performance. Further, Bonferroni corrected post hoc analysis revealed no significant difference in the CMJ values at 15th seconds (36.2±4.4 cm), 4th minute (38.6±4.6 cm), 8th minute (38.9±4.6cm), and 12th minute (38.0±4.1 cm) compared to the baseline values (36.5±3.9) for TSC. However, for RR1, a significant difference was observed between the CMJ height at baseline (36.4±4.0 cm) and at 4th (40.5±5.0 cm) and 8th minute (39.4±4.7 cm) (4th minute: p=0.014, Hedge's g=0.89 and 8th minute:p=0.027, Hedge's g=0.67). No significant difference was found in the CMJ values at 15th seconds (38.55±4.25 cm) and 12th minutes (38.65±4.02 cm) compared to the baseline for RR_1. In addition, for RR_2, a significant difference was found between the CMJ height at baseline (36.5±3.8 cm) and at 4th (40.0±4.8 cm) and 8th minute (39.5±4.9 cm) (4th minute: p=0.008, Hedge's g=0.68 and 8th minute: p=0.022, Hedge's g=0.66). However, no significant difference was found in the CMJ values at 15th seconds (38.9±4.7 cm) and 12th minutes (38.6±4.7 cm) compared to the baseline (36.5±3.8) after RR_2. Lastly, for RR_3, a significant difference was found between the CMJ height at baseline (36.5±3.9 cm) and at 4th (39.4±4.2 cm) (p=0.024, Hedge's g=0.70). However, no significant difference was found in the CMJ values at 15th seconds (38.3±4.1 cm), 8th minute (39.4±4.2 cm), and 12th minutes (38.3±4.2 cm) compared to the pretest (36.5±3.9) for RR_3.

When the protocols were compared, a significant difference was observed between TSC and RR_2 for the CMJ height at 15th second, favouring the RR_2 (p=0.020, Hedge's g=0.60). There was no significant difference between the protocols at other time points.

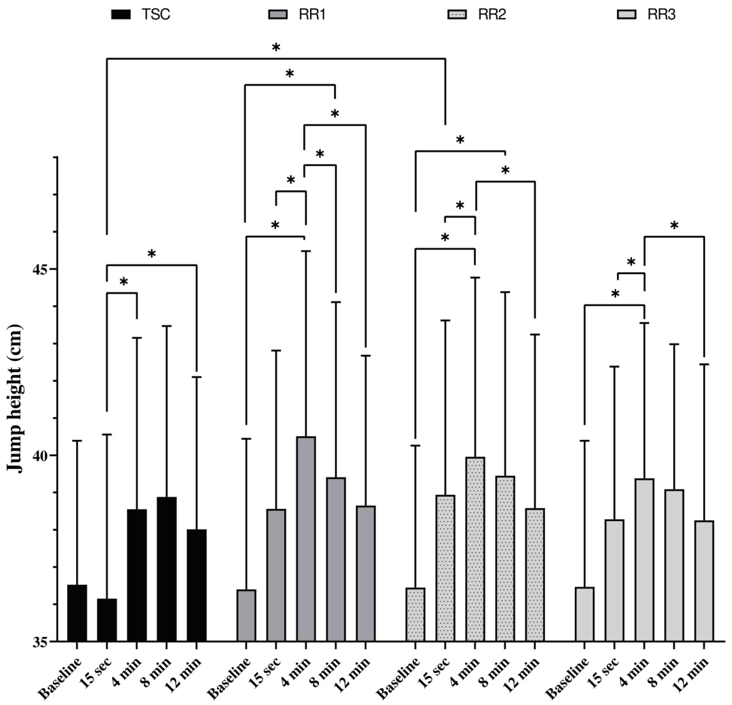

Figure 3. Graphical representation of countermovement jump performance before and after the protocols at specific time points. TSC: Traditional set configuration; RR_1: First set sonfiguration; RR_2: Second set configuration; RR_3: Third set configuration

Table 1. Mean and standard deviation of CMJ heights at different recovery times after squat exercise performed with different set configurations.

Protocols	Baseline		15th second		4th minute		8th minute		12th minute	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
TSC	36.53	3.86	36.15	4.40	38.55¶	4.60	38.88¶	4.59	38.01¶	4.09
RR_1	36.39	4.04	38.55	4.25	40.51†¶¥§	4.97	39.4†	4.7	38.65	4.02
RR_2	36.45	3.81	38.94#	4.68	39.95†¶§	4.81	39.45†	4.93	38.58	4.66
RR_3	36.46	3.92	38.28	4.1	39.38†¶§	4.17	39.09	3.89	38.25	4.19

TSC: Traditional set configuration; RR_1: First set configuration; RR_2: Second set configuration; RR_3: Third set configuration; SC: Set Configuration; SD: Standard deviation; †: Significantly different from baseline; ¶: Significantly different from 15th second; ¥: Significantly different from 8th minute; §: Significantly different from 12th minute; #: Significantly different from traditional set configuration; ICC: intraclass correlation coefficient

Discussion

The aim of this study was to examine the acute effects of squat exercise performed with TSC and three different RR methods on CMJ performance at different recovery times. Compared to the baseline, significant within-condition improvements were observed after all RR methods at the 4th minute, and after RR_1 and RR_2 at the 8th minute. Of note, a significant decline in CMJ performance was observed after the 4th minute in all the RR protocols. However, no within-condition improvement was observed after TSC when compared to baseline. Moreover, when protocols were compared, a significant difference was observed only between TSC and RR_2 at the

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15th second, favoring RR_2. No between-protocol differences were observed at other time points.

One of the key findings of this study was that all RR protocols significantly improved the CMJ performance compared to baseline, whereas no such effect was observed following the TSC protocol. However, when compared to 15th seconds, the TSC as well as the RR protocols improved the CMJ performance at the 4th minute. Another trend observed across all the RR protocols was the attainment of peak performance at 4-8 minutes duration and a temporal decline at 12th minutes. These findings highlight the complex intricacies associated with fatigue-potentiation between the conditioning activities and performance. The significant improvement in the CMJ performance at 4-8 minutes duration may be due to the acute physiological changes associated with PAPE, such as phosphorylation of myosin light chain, an increase in muscle temperature, calcium ion sensitivity (due to increase in muscle temperature, decrease in muscle pH, increase in blood flow and water content in the muscles), increased neural drive, or increased muscle-tendon stiffness (Blazevich & Babault, 2019). While the significant decline in performance at the 12th minute compared to the 4th minute in all RR protocols is indicative that PAPE effects do decline after a certain period of time.

Furthermore, although non-significant, the CMJ performance declined at 15th seconds for TSC, while an increase in performance (non-significant) was observed for all the RR protocols (Figure 3). This is indicative that TSC induced greater fatigue than potentiation in the initial 15 seconds, while the RR resulted in a trend showing positive improvement in performance. Previous studies that incorporated TSC as conditioning exercise have consistently reported a decline in performance immediately but had improved performance after a longer (e.g., ≥4 minute) recovery period (Crewther et al., 2011; Dello Iacono et al., 2020; Kilduff et al., 2008). Kilduff et al. (2008) also reported a significant decrease in CMJ height immediately (~15 seconds) after performing conditioning exercise using 87% of 1RM squat using TSC configuration, but showed improved performance after 8 minutes of recovery. Another study by Crewther et al. (2011) also reported a significant decrease at ~15 seconds but a subsequent increase in the CMJ performance after 4-, 8-, and 12-minute periods of performing 3RM squats using TSC. These differences in how participants' immediate response differed between TSC and RR protocol, favoring RR, may be due to the short rest period embedded within the RR protocols that resulted in less fatigue accumulation at the end of the completion of the sets. In a similar study conducted by Dello Iacono et al. (2020), the authors reported that the participants were able to maintain 95% of their relative mean propulsive power during cluster set configuration, whereas in TSC, the participants were able to maintain only 85%. Indeed, early proponents of cluster set configurations have suggested a similar rationale of lesser fatigue compared to TSC, leading to higher quality of technique execution (Haff et al., 2008).

Moreover, when TSC and RR protocols were compared, a significant difference was observed at 15th seconds, favoring the RR_2 protocol. This is again in line with the findings of Dello Iacono et al. (2020) that reported a significant difference between cluster set configuration and TSC post 30 seconds recovery, favoring the cluster set configuration, even if there were no improvements compared to baseline. This finding indicates a higher fatigue with the TSC protocol compared to the RR protocol. Moreover, Boullosa et al. (2013) also reported that peak CMJ performance occurred significantly earlier (3.6±2.9 minutes vs. 6.1±3.3 minutes) after the cluster set compared to the traditional 5RM set, indicating the effectiveness of cluster set configuration in mitigating fatigue. Indeed, González-Hernández et al. (2020) reported greater mechanical, metabolic, and perceptual fatigue, whereas cluster set configurations highlighted the importance of rest distribution in optimizing performances.

While this novel study contributes to the existing literature by comparing TSC and three different RR protocols on acute performance enhancement of CMJ performance at four different rest periods, it is important to consider the limitations of the study. One major limitation of this study was that it did not examine fatigue during the performance of squats at different set configurations. Using commercially available velocity-based training devices to determine the decrease in velocity of squat at each set configuration could provide vital information about the fatigue response of participants to perform the exercise. In addition, the use of the rating of perceived exertion scale or the collection of biomarkers (e.g., creatine kinase) to determine physiological fatigue would have provided insight into the internal response due to different set configurations. Therefore, the precise physiological advantage of RR compared to TSC remains speculative. Furthermore, the study was limited to male soccer players, and therefore, the findings should not be extrapolated to females or athletes from other sports.

Conclusion

In conclusion, the findings suggest that performing squats using RR protocols may be effective in improving the acute performance of CMJ. Moreover, the improvement in performance can also be observed post 4-minute recovery period with all the protocols. However, the RR protocols, specifically the RR2 protocol, were effective in reducing fatigue at shorter recovery times (i.e., 15 seconds) compared to the TSC protocol, while also improving the performance at the 4th minute. Practitioners may use different RR protocols as a part of the standard warm-up routine instead of TSC, which may help in reducing the fatigue effect observed immediately and also improve the performance of the athletes after a standard resting period of ≥4 minutes.

Conflicts of Interest

The authors declare no conflict of interest.

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