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Acute effects of different resistance training configurations on neuromuscular performance

Authors: Witalo Kassiano[1]*, Manoel da Cunha Costa[2], Fabiano de Souza Fonseca[3], Dalton de Lima-Júnior[4], Bruna Daniella de Vasconcelos Costa[1], and Leonardo de Sousa Fortes[4]

Affiliations:

[1]GEPEMENE—Metabolism, Nutrition and Exercise Laboratory, Physical Education and Sport Center, Londrina State University, Londrina, Brazil.

[2]Superior School of Physical Education of University of Pernambuco, Brazil.

[3]Department of Physical Education of Federal Rural University of Pernambuco, Brazil.

[4]Department of Physical Education of Federal Univerity of Paraíba, João Pessoa, Brazil.

***Correspondence author:** Witalo Kassiano. E-mail: acc.witalo@gmail.com | **ORCID number:** 0000-0002-0868-8634. Metabolism, Nutrition, and Exercise Laboratory. Physical Education and Sport Center, Londrina State University, Rodovia Celso Garcia, km 380, 86057-970, Londrina, Brazil.

Abstract

We compared the acute effects of parallel back squat performed from different resistance training configurations on neuromuscular performance. Twenty-eight young adults underwent the four experimental conditions: inter-repetition rest, traditional, traditional to failure, and rest-pause in the parallel back squat in a randomized, counterbalanced, and cross-over design. The neuromuscular performance was assessed through peak torque of knee extensors and flexors at two angular velocities (90 and 120º/s) in three moments (before, post, and post-30 min). The peak torque of the knee extensors and flexors at 90 and 120º/s decreased immediately after training for traditional, traditional to failure, and rest-pause (-8.1% to -17.7%, $P < .001$). A greater reduction in the extensor peak torque was found at 120º/s ($P < .05$) in the rest-pause (-17.7%) when compared to traditional (-10.8%). The peak torque returned to baseline values only at post-30 min for the traditional configuration for the knee flexion action at 120º/s. The peak torque remained similar for the muscular actions and angular velocities for the inter-repetition rest ($P > .05$). Our results suggest the inter-repetition rest configuration seems to be a more appropriate strategy for maintaining the lower limb neuromuscular performance after a resistance training session.

Keywords: peak torque, neuromuscular fatigue, isokinetic strength, strength training, resistance training systems, force.

Introduction

Resistance training is characterized by a systematic organization and manipulation of prescription variables (external load, number of repetitions, muscle action velocity, and rest intervals between sets), adjusted according to each training session objective [1-3]. In this context, some set configurations have been adopted to mitigate the reduction in neuromuscular performance, with the premise of optimizing short- and long-term muscular adaptations [4, 5]. For example, recovery intervals between a block of repetitions or between each repetition—which characterizes two types of cluster-set configurations—seem to be an effective strategy to increase the volume-load without a substantial reduction of velocity and power output throughout a set [4]. On the other hand, there is another possible cluster-set configuration that has been widely used is the rest-pause (RP) [6, 7]; in this case, the rest is given only after the practitioner reaches voluntary muscle failure (i.e., inability to complete a repetition with a full range of motion) [6, 8].

In this regard, a recent systematic review with meta-analysis [4] demonstrated that intra-set rest and inter-repetition rest (IRR) configurations (both not to muscle failure) allow the maintenance of muscle action velocity and power output when compared to traditional (TRD) configuration during and post-exercise. On the other hand, the insertion of rest intervals after voluntary muscle failure seems ineffective in preserving performance in the RP [4], likely because of the accumulated fatigue. However, the only study that compared the RP with other set configurations, and that was included in the meta-analysis, found similar reductions in force output between two different training configurations (RP and IRR) after 20 repetitions of squats with equalized volume-load [6]. Also, five minutes following the end of the session, the force output had returned to the pre-training values, suggesting that the RP maintains force output when protocols with a low number of repetitions or volume are performed. In addition, since practitioners often perform a high volume (i.e., a higher number of repetitions), and this strategy potentially induce higher acute reductions in neuromuscular performance, it is necessary to investigate set configurations that attenuate this impairment.

About RT volume, different systematic reviews with meta-analysis have suggested that higher training dose may induce significant neuromuscular adaptations and performance improvements in young and older adults [9, 10]. Therefore, the analysis of the effects of different resistance training configurations (e.g., IRR, RP, TRD) with a higher number of repetitions may support the prescription of such set structures to perform a higher amount of work with less or without impairment of neuromuscular performance. Furthermore, depending on exercise choice, different muscles will experience different magnitudes of acutely reduced force output and muscle damage [8, 11]. For example, when performing the squat, trained subjects experienced severe muscle damage in the quadriceps [11]. However, we do not have an accurate description of the effects of this exercise on the neuromuscular function of the other muscles that participate in the hip and knee extension movement (i.e., hamstrings) and the effect of different set configurations.

Therefore, given the scenario described above, the present study aimed to compare the acute effects (immediately after and post-30 min) of the parallel back squat performed from different resistance training configurations on neuromuscular performance. Besides, we tested whether there are differences in the force output of the extensors versus knee flexors after each experimental protocol. Our initial hypotheses are i) the IRR and TRD induce reductions of small magnitude when compared to TRD-F and RP configurations; ii) the performance is restored under all circumstances after 30 min of the training session; and iii) the fatigue induced by TRD-F and RP configurations immediately after a training session is higher in the extensors than in the knee flexors after the parallel back squat exercise.

Materials and Methods

Study design

A randomized, counterbalanced, and cross-over study with four experimental conditions was carried over four weeks, with a seven-day washout between each one. The sample was composed of trained young adults with experience in the parallel squat exercise from the following resistance training configurations: inter-repetition rest (IRR), traditional set without concentric muscle failure (TRD), traditional to muscle failure (TRD-F), and rest-pause (RP). The participants made seven visits to the laboratory. The first visit was intended to familiarize participants with the procedures and to sign the informed consent form. The second and third visits were designed to perform the test and retest of 15 repetitions maximum (15RM) and measure the knee extensors' peak torque and flexors at two angular velocities (see procedures below). The reliability of these measures was obtained during these two occasions. Visits four, five, six, and seven were intended to carry out the experimental conditions. Perceived recovery was measured before each experimental session. The peak torque of knee extensors and flexors at 90º/s and 120º/s in an isokinetic dynamometer was evaluated before, immediately after the end of each experimental condition, and 30 min later. The rating of perceived exertion (RPE) was measured 30 min after the end of each session. Participants were instructed to avoid the practice of intense physical exercise and alcohol intake 48 h before, avoid caffeine intake six hours before each visit in the laboratory, and were asked to maintain the same eating habits before each of the visits. The tests and experimental protocols were performed in the same sequence and by the same evaluators in the afternoon hours (3 PM to 6 PM).

Participants

The subjects were recruited through social media and personal invitations using the non-probabilistic sampling method yielding 31 volunteers. Three subjects were excluded from the analysis for not having attended the tests and experimental conditions, leaving 28 healthy participants (15 men and 13 women, age: 23.6 ± 3.7 years; body mass: 75.9 ± 15.3 kg; stature: 173.6 ± 9.8 cm; body mass index: 24.9 ± 2.9 kg/m^2; training age: 6.8 ± 3.5 years). The participants were engaged in RT for at least two uninterrupted years, with a weekly frequency of four to six sessions. Subjects were familiarized with measurements and sets of repetitions to failure in the parallel squat exercise before the initiation of the study. Eligible participants had no muscular or joint injury history and did not intake any ergogenic substance for strength and muscle mass in the last six months. Also, the participants were oriented to maintain their routines and eating habits. The participants signed an informed consent term after receiving a detailed description of the study procedures. According to the Declaration of Helsinki, this investigation was conducted and was approved by the local University Ethics Committee (protocol number 2.581.474). The investigation meets the guidelines set forth by the International Journal of Sports Medicine [12].

Perceived recovery

The total quality recovery (TQR) scale [13] was applied before each experimental condition to assess the level of perceived recovery. TQR is a scale that ranges from zero (very poorly recovered/extremely tired) to 10 (very well recovered/highly energetic). The higher the level of perceived recovery is associated with higher values. Participants were familiarized with this scale on visits 1, 2, and 3. The data collected at visits 4, 5, 6, and 7 (days of the experimental conditions) were used for the analyses. Upon arriving at the laboratory, the participants were asked how well they recovered.

Neuromuscular performance

The isokinetic force of knee extension (ISOKext) and flexion (ISOKflex) were assessed at angular velocities of 90°/s and 120°/s at pre-training, immediately post-training, and after 30 min using a Biodex System 4 dynamometer (Biodex Medical Systems Inc., Shirley, NY, USA). The measurements immediately after each experimental condition had a delay of ~60 s due to displacement time from the squat exercise to the isokinetic dynamometer and to adjust their position on the equipment. This measure was analyzed from the peak torque (Nm) of the concentric action of the dominant leg (the preferred used for kicking a ball). According to the anatomical position, participants were placed in a seated position, adjusted based on the manufacturers' recommendations in ~85° of hip flexion. The dynamometer lever arm attachment was aligned with the lateral epicondyle of the femur, and it was secured with straps around the medial malleoli, according to the manufacturer's recommendations. Another strap was placed over the thigh of the participant's dominant leg in the device. Three more straps were placed to keep shoulders, torso, and pelvis stabilized. The total range of motion during the isokinetic test was 90°. Cushing was set as moderate. Gravity correction was performed based on the manufacturer's recommendations. Participants were instructed to put their hands on the shoulders with the arms crossed during the tests and to perform the movement [knee extension (ext) and flexion (flex)] as fast and strong as possible. Three submaximal repetitions at 90º/s were used as familiarization and warm-up. The testing procedure was initiated one minute after the warm-up. Actual testing at each velocity consisted of one set of three repetitions. The participants were notified by a verbal countdown and accompanied by verbal encouragement and visual feedback to ensure maximum effort. Also, participants were coached to exert maximal effort using incentive phrases such as "force up," "force down," "go faster and stronger," accompanied by clapping. The rest intervals were 2-min between different angular velocities. The maximum value of peak torque in each muscle action and velocities (ISOK90ext, ISOK90flex, ISOK120ext, and ISOK120flex) was obtained and used in analyses. The tests were performed in the same sequence and by the same evaluator in the afternoon (3 PM to 6 PM). These procedures were repeated on two non-consecutive days, at least 48 hours apart.

Resistance training sessions

The exercise performed was the parallel back squat using free weights. All participants performed the 15RM test in two sessions separated by 48 h to determine the RT loads for experimental protocols. The procedures for this test are described in more detail in Kassiano et al. [3]. The resistance training sessions were planned to equalize the volume-load. Therefore, the participants had to complete 60 repetitions for the same relative intensity (15RM) in all conditions. The experimental protocols were different regarding the resistance training configurations, namely: (i) IRR, 60 repetitions interspersed with ~10 s of rest in between them; (ii) TRD, five sets with 12 repetitions (~3 repetitions in reserve), with 180 s of rest interval; (iii) TRD-F, four sets of 15 repetitions with 200 s of rest interval between sets; and (iv) RP, blocks of repetitions performed until concentric muscle failure (i.e., inability to complete a repetition with a full range of motion and proper technique [6, 8]) and 30 s of rest interval between them, until the completion of 60 repetitions. The participants were instructed to perform the repetition tempo at a ratio of 1:2 (concentric and eccentric muscular actions, respectively). The four experimental conditions were carried out in a randomized and counterbalanced order with a seven-day washout between each one. The number of repetitions in each set was recorded. The volume-load of the experimental sessions was calculated from of product between the number of repetitions and load lifted. The configuration of each experimental condition is illustrated in **Fig. 1**.

***** PLEASE INSERT FIG. 1 NEAR HERE *****

Rating of perceived exertion

The OMNI-RES scale [14] was used to obtain the RPE from the experimental sessions. All volunteers were submitted to two sessions (visits 2 and 3) for the RPE anchoring procedures. The leading investigator explained to each participant what each descriptor in the OMNI-RES scale represents according to the procedures proposed by Robertson et al. [14]. The RPE was obtained 30 min after the end of each experimental condition through the following question: “How (hard) was your training?”. Participants were asked to indicate a score corresponding to perceived exertion experienced during each of the four experimental sessions (IRR, TRD, TRD-F, and RP) in visits 4, 5, 6, and 7. The same investigator carried out this procedure during all sessions. Each participant's response was obtained without any other observer to reduce the chances of having effects of external factors on the RPE response.

Statistical analyses

The Shapiro-Wilk test was used to evaluate the data distribution. The data are presented through mean and confidence intervals (95% CIs). Repeated-measures analysis of variance (ANOVA) was used to compare the level of perceived recovery, RPE, and volume-load between the experimental conditions. A two-way repeated-measures ANOVA was used to analyze the conditions (IRR, TRD, TRD-F, and RP) x time (pre, post, and post-30min) interaction for isokinetic strength measures (ISOK90ext, ISOK90flex, ISOK120ext, and ISOK120flex). When sphericity was violated, the Greenhouse-Geisser correction factor was applied. When the F was significant, a Bonferroni post hoc test was used to identify possible statistical differences. We adopted the effect size (ES) of the model [partial eta squared (ηp2)]. In addition, we calculated the ES (Cohen's *dz*) proposed by Dankel and Loenneke [15] for comparisons pre to post and pre to post-30 min. In addition, we carry out a secondary analysis based on the relative changes (Δ% = [(post – pre) / pre] x 100). We compared the Δ% (pre vs. post and pre vs. post-30 min) of the extensors vs. knee flexors within each condition through a two-way ANOVA with muscle action (extension and flexion) and angular velocities as fixed factors. Significance was accepted at $P < 0.05$.

Results

For the 15RM test, the $ICC_{3,1}$, coefficient of variation (CV), and standard error of measurement (SEM) were: $ICC_{3,1}$ = 0.97 (0.94, 0.98), CV = 3.5%, and SEM = 0.58 kg. Test-retest reliability of force measures, for namely ISOK90ext, ISOK90flex, ISOK120ext, and ISOK120flex yielded an $ICC_{3,1}$ (95% CI) of 0.98 (0.97, 0.99), 0.93 (0.86, 0.96), 0.97 (0.95, 0.99), and 0.97 (0.94, 0.98), respectively; CV of 3.9%, 4.5%, 3.6%, and 3.1%, respectively; and SEM of 0.65, 2.64, 1.89, and 0.83 Nm, respectively.

The total ~781s, 900s, 780s, and 761s, IRR, TRD, TRD-F, and RP, respectively. The TQR, number of repetitions, volume-load, and RPE data are shown in **Table 1**. There were no significant differences between the four conditions for the TQR ($F_{(3, 69)} = 0.472$, $P > .05$, $\eta p^2 = 0.01$), number of repetitions performed in each experimental session ($F_{(1.0, 24.0)} = 1.080$, $P > .05$, $\eta p^2 = 0.04$), and volume-load ($F_{(1.0, 27.0)} = 0.717$, $P > .05$, $\eta p^2 = 0.02$). A significant main effect ($F_{(3, 78)} = 75.903$, $P < .001$, $\eta p^2 = 0.74$) was revealed only for RPE. The IRR configuration presented lower RPE than the TRD (95%CI: -1.3, -0.0, $P = .046$), TRD-F (95%CI: -3.7, -2.1, $P < .001$) and RP (95%CI: -4.2, -2.8, $P < .001$) configurations. The TRD configuration had lower RPE scores when compared to the TRD-F (95%CI: -3.1, -1.4, $P < .001$) and RP (95%CI: -3.7, -1.9, $P < .001$).

***** PLEASE INSERT TABLE 1 NEAR HERE *****

The peak torque data for the two muscular actions (knee extension and flexion) at the two angular velocities (90º/s and 120º/s) from the four resistance training configurations are described in **Table 2**. There was a significant interaction ($F_{(3.7,\ 82.9)}$ = 11.647, P < .001, ηp^2 = 0.34) for the ISOK90ext. In the IRR condition, there were no significant changes among the three moments (ES ≤ -0.51, P > .05). The ISOK90ext was significantly lower at post in the TRD (ES = -1.42, P < .001), TRD-F (ES = -1.27, P < .001), and RP (ES = -1.62, P < .001). At post-30 min, the peak torque of ISOK90ext remained suppressed in the TRD (ES = -1.37, P < .001), TRD-F (ES = -1.26, P < .001), and RP (ES = -1.21, P < .001) when compared to the pre; without significant differences between post and post-30 min (Table 2). About the differences between configurations, the ISOK90ext was significantly lower in TRD (P = .004), TRD-F (P = .001), and RP (P < .001) configurations when compared to IRR (**Fig. 2**). This scenario remained relatively stable post-30 min, the ISOK90ext remained lower in the TRD (P = .002), TRD-F (P < .001) and RP (P = .001) when compared to the IRR.

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For ISOK90flex, there was a main effect of time ($F_{(1.2,\ 26.9)}$ = 36.955, P < .001, ηp^2 = 0.62) and condition ($F_{(2.0,\ 45.1)}$ = 22.400, P < .001, ηp^2 = 0.50). In the IRR condition, there were no significant changes between any of the three moments (ES ≤ -0.39, P > .05). The ISOK90flex was significantly lower at post in the TRD (ES = -1.37, P < .001), TRD-F (ES = -1.18, P < .001), and RP (ES = -1.13, P < .001). At post-30 min, the ISOK90ext remained suppressed in the TRD (ES = -1.14, P < .001), TRD-F (ES = -1.23, P < .001), and RP (ES = -0.99, P < .001) when compared to the pre; without significant differences between post and post-30 min (**Table 2**).

Regarding ISOK120ext, there was a significant interaction ($F_{(3.2,\ 71.4)}$ = 15.891, P < .001, ηp^2 = 0.41). In the IRR condition, there were no significant changes between any of the three moments (ES ≤ -0.52, P > .05). The ISOK120ext was significantly lower at post in the TRD (ES = -1.27, P < .001), TRD-F (ES = -1.40, $P < .001$), and RP (ES = -1.47, $P < .001$). At post-30 min, the peak torque of ISOK120ext remained suppressed in the TRD (ES = -1.28, $P < .001$), TRD-F (ES = -1.41, $P < .001$), and RP (ES = -1.66, $P < .001$) when compared to the pre; without significant differences between post and post-30 min (**Table 2**). When comparing configurations, ISOK120ext in TRD was significantly lower than IRR ($P = .029$) and higher than RP ($P = .026$) at post. TRD-F and RP also showed lower ISOK120ext ($P = .008$; $P < .001$, respectively) values when compared to IRR. In the post-30min, the conditions TRD ($P < .001$), TRD-F ($P = .001$) and RP ($P < .001$) showed lower ISOK120ext than IRR.

For ISOK120flex, there was also a main effect of interaction ($F_{(2.3, 52.5)} = 6.323$, $P = .002$, $\eta p^2 = 0.22$). There were no significant changes between the three moments in the IRR (ES ≤ -0.33, $P > .05$). The ISOK120flex decreased at post in the TRD (ES = -0.72, $P = .005$), TRD-F (ES = -1.18, $P < .001$), and RP (ES = -1.61, $P < .001$). At post-30 min, the peak torque of ISOK120flex in the TRD had returned to pre values (ES = -0.26, $P > .05$); on the other hand, remained suppressed in the TRD-F (ES = -0.95, $P < .001$), and RP (ES = -1.80, $P < .001$) when compared to the pre; without significant differences between post and post-30 min (**Table 2**). Regarding to comparisons between configurations, the ISOK120flex in the post was significantly lower in TRD ($P = .007$), TRD-F ($P = .012$) and RP ($P < .001$) when compared to IRR. At the post-30min, ISOK120flex in TRD was significantly higher than RP ($P = .027$). TRD-F and RP also showed lower ISOK120flex ($P = .006$; $P < .001$, respectively) values when compared to IRR (**Table 2 and Fig. 2**).

From the secondary analysis, we observed that the relative changes (Δ%) were not different at both angular velocities immediately after the four conditions when comparing peak torque of knee extension versus knee flexion (all $P > 0.05$). At post-30 min, the behavior was similar for all experimental conditions, except the TRD condition for muscular actions at 120°/s. The decrease in ISOK120ext was significantly greater [Δ% = -15.9 (95%CI: -21.1, -10.7)] than the decrease in ISOK120flex [Δ% = -3.8 (95%CI: -9.0, 1.4)] at post-30 min ($P = .001$).

Discussion

The main findings of our study were: (i) the neuromuscular performance of knee extensors and flexors was attenuated in response to TRD, TRD-F and RP, and remained decreased 30-min after the end these experimental protocols; (ii) the IRR configuration allowed the maintenance of performance even with a volume-load similar to the other resistance training configurations; (iii) the relative reduction in performance was similar between extensors (quadriceps) and flexors (hamstrings) after all experimental protocols at the two angular velocities; (iv) after 30-min of the TRD protocol, the decrease in the isokinetic force of the quadriceps was higher than the reduction in the isokinetic strength of the hamstrings at 120º/s; and (v) the TRD-F and RP caused higher RPE, followed by TRD and IRR configurations, respectively.

In the present study, the IRR configuration was an effective strategy to maintain the neuromuscular performance of the knee extensors and flexors after performing the parallel back squat. In fact, in a meta-analysis, the authors demonstrated that the IRR and intra-set rest (commonly characterized as types of cluster sets) configurations acutely reduced velocity and power throughout the sets [4]. These configurations seem to be effective because the accumulation of metabolites is avoided, and fatigue dissipation is favored [7]. In addition, it makes it possible to achieve a high volume-load without deleterious effects on neuromuscular performance [4]. In turn, this higher volume can potentially be converted into greater strength gains [9, 10]. However, these benefits are not universal. For example, the force output was similar between the IRR and intra-set rest and TRD configuration [4], suggesting that responses may depend, at least in part, on the performance variable being measured (power output or force output).

On the other hand, the RP configuration (another type of cluster set) [4] induced a reduction in force production that lasted up to 30-min after the end of the resistance training protocol. Differently, the IRR configuration has been less investigated concerning acute responses of neuromuscular performance [4, 7], and only one study on the RP configuration was included in the recent meta-analysis about the topic [4]. In this investigation, Marshall et al. [6] reported that the force output was suppressed shortly after the squats. However, five minutes later, the force parameters had already returned to the baseline values [6]. A possible explanation for such a divergence between our findings and those of Marshall et al. [6] may be the number of repetitions/volume-load performed in each study. For example, in the present study, participants performed 60 repetitions, while those of Marshall et al. [6] completed 20 repetitions. Therefore, under conditions of greater volume-load, the RP seems to be more harmful to the neuromuscular performance of both muscle groups (quadriceps and hamstrings).

Regarding the TRD-F and TRD configurations, both reduced the force output immediately after the end of the session for the two muscular actions and angular velocities tested. However, while these measures remained attenuated after 30-min in the TRD-F protocol, the flexors' peak torque at 120º/s returned to the baseline values in the TRD. Together, these findings can be interpreted as follows: (a) performing multiple sets to or near to voluntary muscle failure induce reductions in neuromuscular performance in trained subjects [16-18]; (b) to perform the exercise close to failure in most sets (a fact that occurred in the TRD), even with high volume-load, can be harmful the force production, since the peak torque of the flexors returned to baseline values 30-min after the TRD condition. However, further investigations are needed to characterize the time-course, this possible difference, and how many repetitions in reserve are necessary to the strength return to baseline values quickly.

Our results revealed that both quadriceps and hamstrings experienced a similar performance reduction. Therefore, our hypothesis was not confirmed. Because the quadriceps are the agonist group in the parallel back squat exercise and supported by previous studies [19-21], we believed that this muscle group would significantly reduce the peak torque. However, except for the ISOK120flex, which flexors showed less reduction compared to the extensors in the TRD, all other responses were similar between quadriceps and hamstrings. This finding might be explained by the fact that the exercise chosen for the present study involves many muscle groups [19], depending on the applied effort (that was high in the conditions that reduced the force) [22, 23]. This phenomenon affects the overall strength production and not only of the agonist muscles [22]. Another factor that may have contributed to such responses may be the role of antagonistic exercised by the hamstrings that act in co-contraction during the squat [19].

To the best of our knowledge, our study was the first to investigate the effects of different resistance training configurations on the knee extensors and flexors' neuromuscular performance and compare these effects between quadriceps and hamstrings muscle groups. Some strengths of the present study deserve mention. The randomized, counterbalanced, cross-over design, with washout and equalized volume-load, allows accurately analyzing the impact of different resistance training configurations on neuromuscular performance. Also, the measurement of force output was performed using an isokinetic dynamometer, which is commonly pointed out as the gold standard instrument for this purpose. In contrast, some limitations should not be ignored. The present study was conducted with a single multi-joint exercise (parallel back squat), and our sample was composed of trained subjects. Therefore, the information in this investigation must be interpreted with caution and applied in a similar context. Another significant limitation is the fact that we did not follow up neuromuscular performance hours after each condition. Such information could show us how long it would take to restore performance after each resistance training configuration. Finally, we did not measure the velocity component in the present study; therefore, future investigations should consider measuring this characteristic to describe the effects of different configurations on neuromuscular performance and include force tests at higher speeds (e.g., 180º/s and 300º/s).

Conclusion

From a practical standpoint, strength and conditioning coaches and resistance training practitioners who seek to maintain neuromuscular performance after a training session are encouraged to use the IRR configuration, as this set configuration does not reduce the force production of the knee extensors and flexors, even after performing 60 repetitions on the parallel back squat. Conversely, when using TRD, TRD-F, and RP configurations, the performance of lower limbs likely be decreased for at least 30 min after the resistance training session; and this will require trainers to monitor the performance of their athletes before applying a new training session. Additionally, although the squat is an exercise that primarily involves the actions of hip and knee extension in the concentric phase, which in theory, would require more considerable effort in the quadriceps when compared to the hamstrings, the reduction in performance occurs in a similar way between these two muscle groups.

Conflict of interest

The authors report no conflicts of interest.

References

[1] Kraemer WJ, Ratamess NA. Fundamentals of resistance training: progression and exercise prescription. Med Sci Sports Exerc 2004; 36: 674-688.

[2] Charro MA, Aoki M, Coutts AJ et al. Hormonal, metabolic and perceptual responses to different resistance training systems. J Sports Med Phys Fitness 2010; 50: 229-234.

[3] Kassiano W, Costa BDV, Lima-Junior D et al. Parasympathetic nervous activity responses to different resistance training systems. Int J Sports Med 2021; 42: 82-89.

[4] Latella C, Teo WP, Drinkwater EJ et al. The acute neuromuscular responses to cluster set resistance training: a systematic review and meta-analysis. Sports Med 2019; 49: 1861-1877.

[5] Jukic I, Ramos AG, Helms ER et al. Acute effects of cluster and rest redistribution set structures on mechanical, metabolic, and perceptual fatigue during and after resistance training: a systematic review and meta-analysis. Sports Med 2020; 50: 2209-2236.

[6] Marshall PW, Robbins DA, Wrightson AW et al. Acute neuromuscular and fatigue responses to the rest-pause method. J Sci Med Sport 2012; 15: 153-158.

[7] Tufano JJ, Brown LE, Haff GG. Theoretical and practical aspects of different cluster set structures: a systematic review. J Strength Cond Res 2017; 31: 848-867.

[8] Davies T, Orr R, Halaki M et al. Effect of training leading to repetition failure on muscular strength: a systematic review and meta-analysis. Sports Med 2016; 46: 487-502.

[9] Ralston GW, Kilgore L, Wyatt FB et al. The effect of weekly set volume on strength gain: a meta-analysis. Sports Med 2017; 47: 2585-2601.

[10] Krieger JW. Single vs. multiple sets of resistance exercise for muscle hypertrophy: a meta-analysis. J Strength Cond Res 2010; 24: 1150-1159.

[11] de Camargo JBB, Braz TV, Batista DR et al. Dissociated time course of indirect markers of muscle damage recovery between single-joint and multi-joint exercises in resistance-trained men. J Strength Cond Res 2020; Publish Ahead of Print.

[12] Harriss DJ, MacSween A, Atkinson G. Ethical standards in sport and exercise science research: 2020 update. Int J Sports Med 2019; 40: 813-817.

[13] Laurent CM, Green JM, Bishop PA et al. A practical approach to monitoring recovery: development of a perceived recovery status scale. J Strength Cond Res 2011; 25: 620-628.

[14] Robertson RJ, Goss FL, Rutkowski J et al. Concurrent validation of the OMNI perceived exertion scale for resistance exercise. Med Sci Sports Exerc 2003; 35: 333-341.

[15] Dankel SJ, Loenneke JP. Effect sizes for paired data should use the change score variability rather than the pre-test variability. Journal of Strength and Conditioning Research 2018. doi:10.1519/jsc.0000000000002946.

[16] Costa BDV, Ferreira MEC, Gantois P et al. Acute effect of drop-set, traditional, and pyramidal systems in resistance training on neuromuscular performance in trained adults. J Strength Cond Res 2019; 35: 991-996.

[17] Moran-Navarro R, Perez CE, Mora-Rodriguez R et al. Time course of recovery following resistance training leading or not to failure. Eur J Appl Physiol 2017; 117: 2387-2399.

[18] Gonzalez-Badillo JJ, Rodriguez-Rosell D, Sanchez-Medina L et al. Short-term recovery following resistance exercise leading or not to failure. Int J Sports Med 2016; 37: 295-304.

[19] Clark DR, Lambert MI, Hunter AM. Muscle activation in the loaded free barbell squat: a brief review. J Strength Cond Res 2012; 26: 1169-1178.

[20] Longpre HS, Acker SM, Maly MR. Muscle activation and knee biomechanics during squatting and lunging after lower extremity fatigue in healthy young women. J Electromyogr Kinesiol 2015; 25: 40-46.

[21] Slater L, Hart JM. Muscle activation patterns during different squat techniques. J Strength Cond Res 2017; 31: 667-676.

[22] Carroll TJ, Taylor JL, Gandevia SC. Recovery of central and peripheral neuromuscular fatigue after exercise. J Appl Physiol (1985) 2017; 122: 1068-1076.

[23] Barnes MJ, Miller A, Reeve D et al. Acute neuromuscular and endocrine responses to two different compound exercises: squat vs. deadlift. J Strength Cond Res 2019; 33: 2381-2387.

TABLE LEGENDS

Table 1. State of recovery, performance, and perceived effort in the four experimental conditions (n = 28).

Note. The data are presented in mean and 95% CI; TQR = total quality recovery; AU = arbitrary units; RPE = rating of perceived exertion; IRR = inter-repetition rest configuration; TRD = traditional system not to failure; TRD-F = traditional configuration to failure; RP = rest-pause; * different from IRR; † different from TRD.

Table 2. The isokinetic force of knee extensors and flexors at two angular velocities at pre, immediately post, and post-30min each experimental condition (n = 28).

Note. The data are presented in mean and 95% CI; IRR = inter-repetition rest configuration; TRD = traditional configuration not to failure; TRD-F = traditional configuration to failure; RP = rest-pause; * different when compared to pre; † different when compared to IRR; ‡ different when compared to TRD.

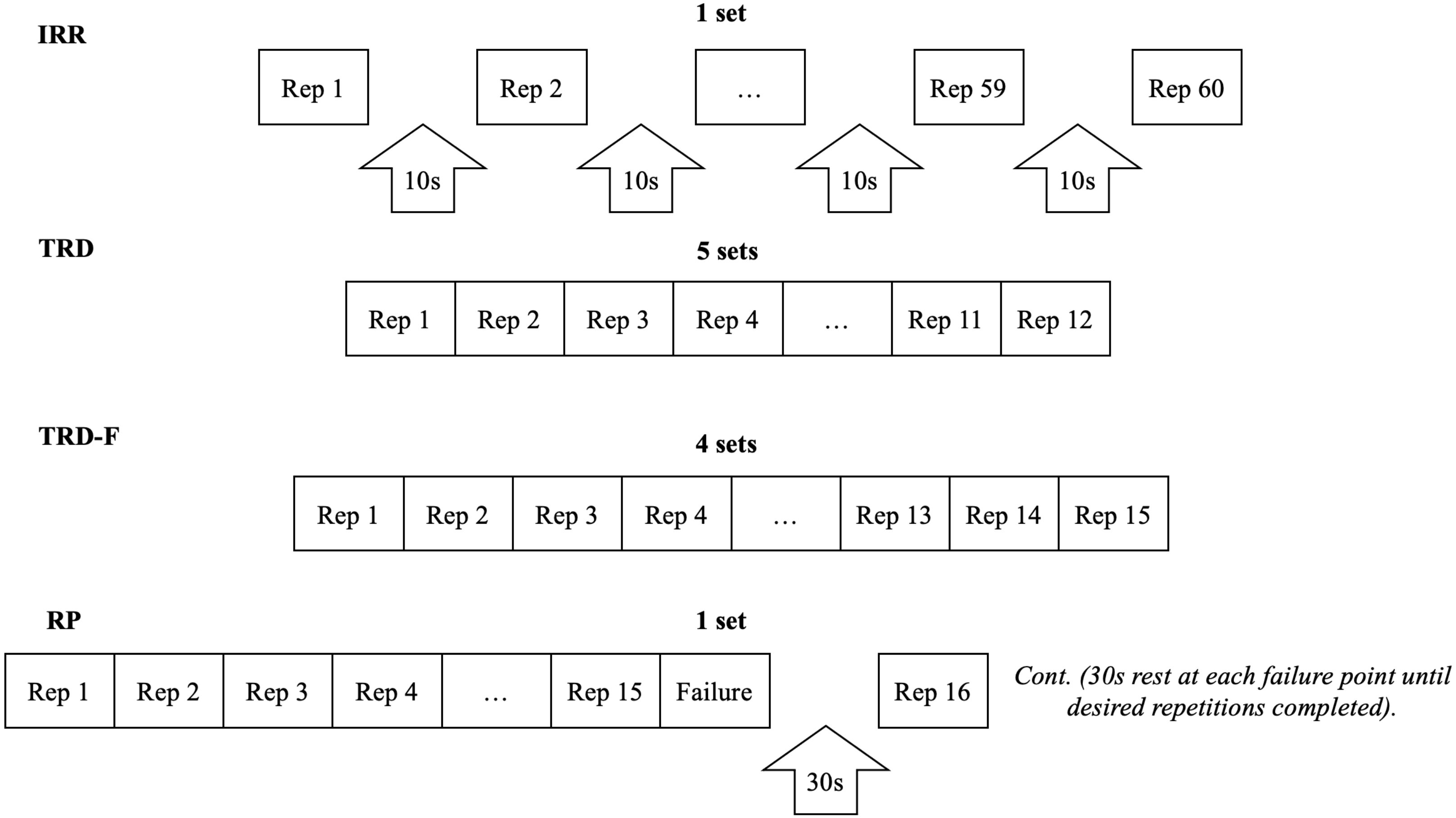
FIGURES LEGENDS

Fig. 1. Resistance exercise sessions.

Note. rep = repetitions; IRR = inter-repetition rest configuration; TRD = traditional configuration not to failure; TRD-F = traditional configuration to failure; RP = rest-pause.

Fig. 2. Relative changes for the isokinetic force of knee extensors and flexors at both velocities are in the four experimental conditions (n = 28).

Note. The data are presented in mean and 95% CI; IRR = inter-repetition rest configuration; TRD = traditional configuration not to failure; TRD-F = traditional configuration to failure; RP = rest-pause; * different when compared to pre; † difference between conditions in the post; ‡ difference between conditions at post-30min.


IRR
1 set
Rep 1
Rep 2
…
Rep 59
Rep 60
10s
10s
10s
10s
TRD
5 sets
Rep 1
Rep 2
Rep 3
Rep 4
…
Rep 11
Rep 12
TRD-F
4 sets
Rep 1
Rep 2
Rep 3
Rep 4
…
Rep 13
Rep 14
Rep 15
RP
1 set
Rep 1
Rep 2
Rep 3
Rep 4
…
Rep 15
Failure
Rep 16
30s
Cont. (30s rest at each failure point until desired repetitions completed).

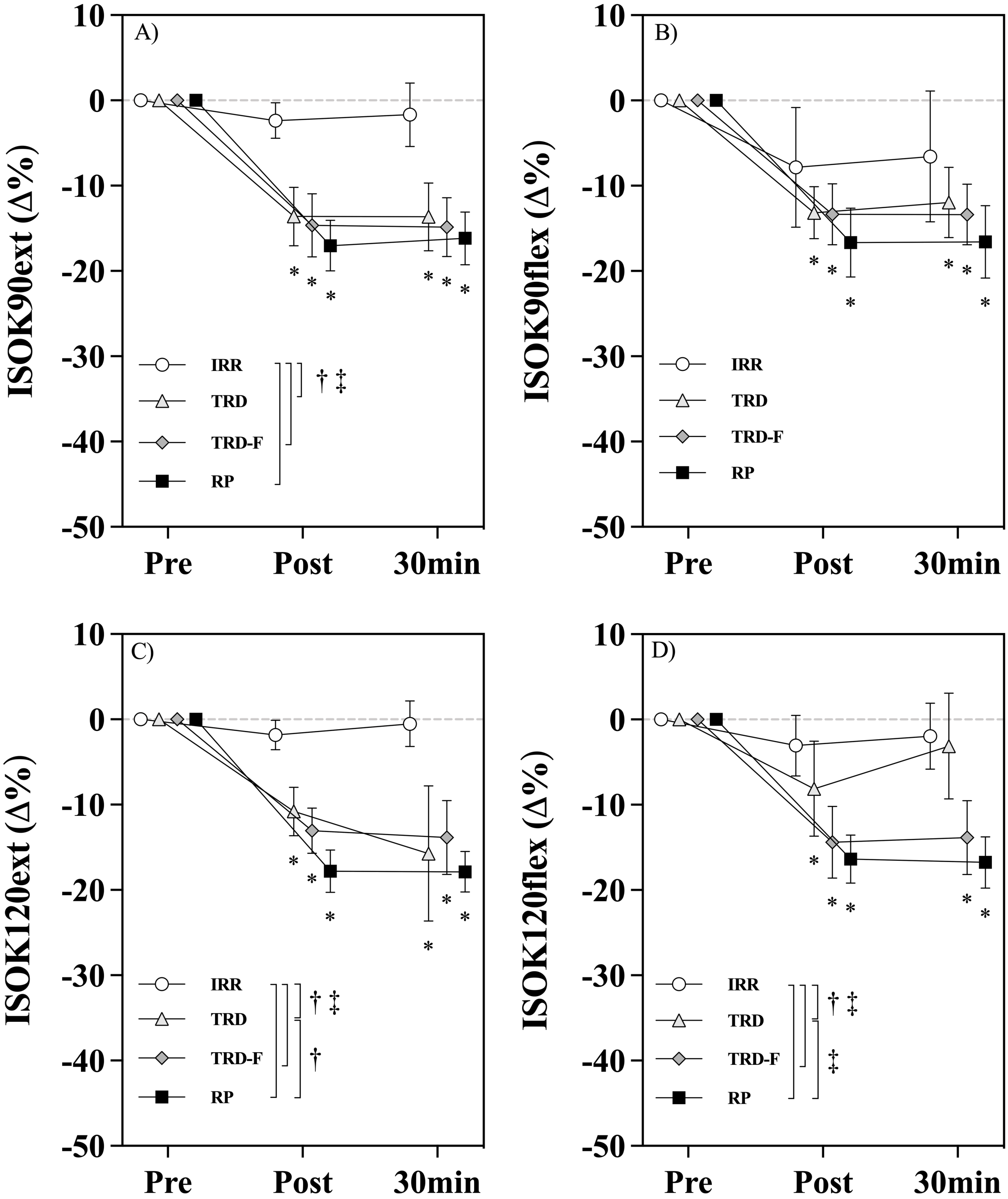

A)
ISOK90ext (Δ%)
B)
ISOK90flex (Δ%)
C)
ISOK120ext (Δ%)
D)
ISOK120flex (Δ%)
10
0
-10
-20
-30
-40
-50
Pre
Post
30min
IRR
TRD
TRD-F
RP
* * *
† ‡

Table 1. State of recovery, performance, and perceived effort in the four experimental conditions (n = 28).

	Conditions			
	IRR	**TRD**	**TRD-F**	**RP**
TQR (AU)	8.9 (8.5–9.4)	8.6 (8.1–9.0)	8.7 (8.2–9.2)	8.8 (8.3–9.3)
Nº of repetitions	60.0 (60.0–60.0)	60.0 (60.0–60.0)	58.8 (56.4–61.1)	60.0 (60.0–60.0)
Volume-load (kg)	3340 (2695–3984)	3340 (2695–3984)	3279 (2636–3922)	3340 (2695–3984)
RPE (AU)	5.3 (4.9–5.7)	6.0 (5.5–6.5)*	8.2 (7.8–8.7)*†	8.8 (8.5–9.1)*†

Note. The data are presented in mean and 95% CI; TQR = total quality recovery; AU = arbitrary units; RPE = rating of perceived exertion; IRR = inter-repetition rest configuration; TRD = traditional system not to failure; TRD-F = traditional configuration to failure; RP = rest-pause; * different from IRR; † different from TRD.

Table 2. The isokinetic force of knee extensors and flexors at two angular velocities at pre, immediately post, and post-30min each experimental condition (n = 28).

Measures		Conditions			
		IRR	TRD	TRD-F	RP
ISOK90ext (Nm)	Pre	239.5 (204.8–274.1)	241.4 (207.0–275.9)	241.4 (206.7–276.0)	238.7 (203.8–273.7)
	Post	233.2 (199.6–266.7)	207.8 (179.0–236.6)*†	205.7 (176.1–235.3)*†	199.0 (168.4–229.6)*†
	Post-30min	233.7 (200.3–274.1)	207.4 (178.4–236.3)*†	204.9 (175.5–234.2)*†	201.3 (170.3–232.3)*†
ISOK90flex (Nm)	Pre	138.8 (114.1–163.6)	123.5 (107.6–139.4)	125.0 (108.6–141.4)	122.6 (106.9–138.2)
	Post	121.2 (106.0–136.4)	105.7 (93.7–117.8)*	106.7 (93.9–119.5)*	101.8 (88.3–115.3)*
	Post-30min	122.0 (106.0–137.4)	106.7 (94.6–118.9)*	107.0 (93.7–120.3)*	101.6 (88.6–114.6)*
ISOK120ext (Nm)	Pre	221.6 (188.9–254.4)	224.6 (191.5–257.7)	224.1 (191.7–256.6)	224.8 (191.3–258.2)
	Post	216.6 (185.5–247.8)	198.6 (171.3–226.0)*†	196.3 (166.3–226.0)*†	185.0 (156.3–213.6)*†‡
	Post-30min	219.0 (187.7–250.3)	191.7 (159.5–223.8)*†	196.7 (167.1–226.3)*†	185.1 (156.3–213.9)*†
ISOK120flex (Nm)	Pre	126.1 (112.7–139.5)	122.7 (109.8–135.7)	126.6 (114.2–139.0)	124.2 (111.1–137.4)
	Post	121.1 (109.7–132.5)	111.4 (100.8–122.0)*†	108.4 (96.2–120.5)*†	102.9 (93.3–112.6)*†
	Post-30min	122.2 (111.0–133.4)	118.4 (104.7–132.2)	109.0 (96.8–121.2)*†	102.5 (92.7–112.2)*†‡

Note. The data are presented in mean and 95% CI; IRR = inter-repetition rest configuration; TRD = traditional configuration not to failure; TRD-F = traditional configuration to failure; RP = rest-pause; * different when compared to pre; † different when compared to IRR; ‡ different when compared to TRD.