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Acute Effects of Parallel Back Squat Performed in Different Set Configurations on Neuromuscular Performance

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1	Acute effects of different resistance training configurations on neuromuscular performance								
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15 Abstract

We compared the acute effects of parallel back squat performed from different resistance training 16 configurations on neuromuscular performance. Twenty-eight young adults underwent the four 17 18 experimental conditions: inter-repetition rest, traditional, traditional to failure, and rest-pause in the 19 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 20 21 (90 and 120%) in three moments (before, post, and post-30 min). The peak torque of the knee extensors 22 and flexors at 90 and 120% decreased immediately after training for traditional, traditional to failure, 23 and rest-pause (-8.1% to -17.7%, P < .001). A greater reduction in the extensor peak torque was found at 120% (P < .05) in the rest-pause (-17.7%) when compared to traditional (-10.8%). The peak torque 24 returned to baseline values only at post-30 min for the traditional configuration for the knee flexion 25 26 action at 120%. 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 27 be a more appropriate strategy for maintaining the lower limb neuromuscular performance after a 28 29 resistance training session.

30

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

34 Introduction

Resistance training is characterized by a systematic organization and manipulation of 35 prescription variables (external load, number of repetitions, muscle action velocity, and rest intervals 36 37 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 38 premise of optimizing short- and long-term muscular adaptations [4, 5]. For example, recovery 39 40 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 41 42 substantial reduction of velocity and power output throughout a set [4]. On the other hand, there is 43 another possible cluster-set configuration that has been widely used is the rest-pause (RP) [6, 7]; in 44 this case, the rest is given only after the practitioner reaches voluntary muscle failure (i.e., inability to 45 complete a repetition with a full range of motion) [6, 8].

46 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 47 48 muscle action velocity and power output when compared to traditional (TRD) configuration during 49 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. 50 However, the only study that compared the RP with other set configurations, and that was included in 51 52 the meta-analysis, found similar reductions in force output between two different training 53 configurations (RP and IRR) after 20 repetitions of squats with equalized volume-load [6]. Also, five 54 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 55 56 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 57 58 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 59 training dose may induce significant neuromuscular adaptations and performance improvements in 60 young and older adults [9, 10]. Therefore, the analysis of the effects of different resistance training 61 62 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 63 neuromuscular performance. Furthermore, depending on exercise choice, different muscles will 64 65 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 66 67 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 68 (i.e., hamstrings) and the effect of different set configurations. 69

Therefore, given the scenario described above, the present study aimed to compare the acute 70 71 effects (immediately after and post-30 min) of the parallel back squat performed from different 72 resistance training configurations on neuromuscular performance. Besides, we tested whether there 73 are differences in the force output of the extensors versus knee flexors after each experimental 74 protocol. Our initial hypotheses are i) the IRR and TRD induce reductions of small magnitude when 75 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 76 77 immediately after a training session is higher in the extensors than in the knee flexors after the parallel 78 back squat exercise.

79 Materials and Methods

80 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 84 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 85 to the laboratory. The first visit was intended to familiarize participants with the procedures and to 86 87 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 88 two angular velocities (see procedures below). The reliability of these measures was obtained during 89 90 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 91 92 knee extensors and flexors at 90% and 120% in an isokinetic dynamometer was evaluated before, immediately after the end of each experimental condition, and 30 min later. The rating of perceived 93 exertion (RPE) was measured 30 min after the end of each session. Participants were instructed to 94 95 avoid the practice of intense physical exercise and alcohol intake 48 h before, avoid caffeine intake six 96 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 97 98 the same evaluators in the afternoon hours (3 PM to 6 PM).

99 Participants

The subjects were recruited through social media and personal invitations using the non-probabilistic 100 101 sampling method yielding 31 volunteers. Three subjects were excluded from the analysis for not 102 having attended the tests and experimental conditions, leaving 28 healthy participants (15 men and 13 103 women, age: 23.6 ± 3.7 years; body mass: 75.9 ± 15.3 kg; stature: 173.6 ± 9.8 cm; body mass index: $24.9 \pm 2.9 \text{ kg/m}^2$; training age: 6.8 ± 3.5 years). The participants were engaged in RT for at least two 104 uninterrupted years, with a weekly frequency of four to six sessions. Subjects were familiarized with 105 106 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 107 108 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].

114 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.

121 Neuromuscular performance

122 The isokinetic force of knee extension (ISOKext) and flexion (ISOKflex) were assessed at angular 123 velocities of 90% and 120% at pre-training, immediately post-training, and after 30 min using a 124 Biodex System 4 dynamometer (Biodex Medical Systems Inc., Shirley, NY, USA). The measurements 125 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 126 127 measure was analyzed from the peak torque (Nm) of the concentric action of the dominant leg (the 128 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 129 130 dynamometer lever arm attachment was aligned with the lateral epicondyle of the femur, and it was 131 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 132 133 straps were placed to keep shoulders, torso, and pelvis stabilized. The total range of motion during the 134 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 135 136 the arms crossed during the tests and to perform the movement [knee extension (ext) and flexion (flex)] 137 as fast and strong as possible. Three submaximal repetitions at 90% were used as familiarization and warm-up. The testing procedure was initiated one minute after the warm-up. Actual testing at each 138 velocity consisted of one set of three repetitions. The participants were notified by a verbal countdown 139 140 and accompanied by verbal encouragement and visual feedback to ensure maximum effort. Also, 141 participants were coached to exert maximal effort using incentive phrases such as "force up," "force 142 down," "go faster and stronger," accompanied by clapping. The rest intervals were 2-min between 143 different angular velocities. The maximum value of peak torque in each muscle action and velocities 144 (ISOK90ext, ISOK90flex, ISOK120ext, and ISOK120flex) was obtained and used in analyses. The 145 tests were performed in the same sequence and by the same evaluator in the afternoon (3 PM to 6 PM). 146 These procedures were repeated on two non-consecutive days, at least 48 hours apart.

147 **Resistance training sessions**

148 The exercise performed was the parallel back squat using free weights. All participants performed the 149 15RM test in two sessions separated by 48 h to determine the RT loads for experimental protocols. 150 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 60 151 152 repetitions for the same relative intensity (15RM) in all conditions. The experimental protocols were 153 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), 154 155 with 180 s of rest interval; (iii) TRD-F, four sets of 15 repetitions with 200 s of rest interval between 156 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 157 158 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**.

164

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

165 Rating of perceived exertion

166 The OMNI-RES scale [14] was used to obtain the RPE from the experimental sessions. All volunteers 167 were submitted to two sessions (visits 2 and 3) for the RPE anchoring procedures. The leading 168 investigator explained to each participant what each descriptor in the OMNI-RES scale represents 169 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?". 170 171 Participants were asked to indicate a score corresponding to perceived exertion experienced during 172 each of the four experimental sessions (IRR, TRD, TRD-F, and RP) in visits 4, 5, 6, and 7. The same 173 investigator carried out this procedure during all sessions. Each participant's response was obtained 174 without any other observer to reduce the chances of having effects of external factors on the RPE 175 response.

176 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 (np2)]. 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 ($\Delta\% = [(post - pre) / pre] \ge 100$). We compared the $\Delta\%$ (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.

191 **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.

198 The total ~781s, 900s, 780s, and 761s, IRR, TRD, TRD-F, and RP, respectively. The TQR, 199 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 200 repetitions performed in each experimental session ($F_{(1.0, 24.0)} = 1.080, P > .05, \eta p^2 = 0.04$), and volume-201 load $(F_{(1,0,27,0)} = 0.717, P > .05, \eta p^2 = 0.02)$. A significant main effect $(F_{(3,78)} = 75.903, P < .001, \eta p^2)$ 202 203 = 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) 204 configurations. The TRD configuration had lower RPE scores when compared to the TRD-F (95%CI: 205 206 -3.1, -1.4, *P* < .001) and RP (95%CI: -3.7, -1.9, *P* < .001).

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

208	The peak torque data for the two muscular actions (knee extension and flexion) at the two
209	angular velocities (90% and 120%) from the four resistance training configurations are described in
210	Table 2. There was a significant interaction ($F_{(3.7, 82.9)} = 11.647$, $P < .001$, $\eta p^2 = 0.34$) for the
211	ISOK90ext. In the IRR condition, there were no significant changes among the three moments (ES \leq
212	-0.51, $P > .05$). The ISOK90ext was significantly lower at post in the TRD (ES = -1.42, $P < .001$),
213	TRD-F (ES = -1.27, $P < .001$), and RP (ES = -1.62, $P < .001$). At post-30 min, the peak torque of
214	ISOK90ext remained suppressed in the TRD (ES = -1.37, $P < .001$), TRD-F (ES = -1.26, $P < .001$),
215	and RP (ES = -1.21 , $P < .001$) when compared to the pre; without significant differences between post
216	and post-30 min (Table 2). About the differences between configurations, the ISOK90ext was
217	significantly lower in TRD ($P = .004$), TRD-F ($P = .001$), and RP ($P < .001$) configurations when
218	compared to IRR (Fig. 2). This scenario remained relatively stable post-30 min, the ISOK90ext
219	remained lower in the TRD ($P = .002$), TRD-F ($P < .001$) and RP ($P = .001$) when compared to the
220	IRR.
221	*** PLEASE INSERT TABLE 2 NEAR HERE ***

222

*** PLEASE INSERT FIG. 2 NEAR HERE ***

For ISOK90flex, there was a main effect of time ($F_{(1.2, 26.9)} = 36.955$, P < .001, $np^2 = 0.62$) and condition ($F_{(2.0, 45.1)} = 22.400$, P < .001, $np^2 = 0.50$). In the IRR condition, there were no significant changes between any of the three moments (ES \leq -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, $\eta p^2 =$ 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), 233 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), 234 and RP (ES = -1.66, P < .001) when compared to the pre; without significant differences between post 235 236 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 237 ISOK120ext (P = .008; P < .001, respectively) values when compared to IRR. In the post-30min, the 238 conditions TRD (P < .001), TRD-F (P = .001) and RP (P < .001) showed lower ISOK120ext than IRR. 239 For ISOK120 flex, there was also a main effect of interaction ($F_{(2,3,52,5)} = 6.323$, P = .002, ηp^2 240 241 = 0.22). There were no significant changes between the three moments in the IRR (ES \leq -0.33, P > .05). The ISOK120flex decreased at post in the TRD (ES = -0.72, P = .005), TRD-F (ES = -1.18, P < .005) 242 243 .001), and RP (ES = -1.61, P < .001). At post-30 min, the peak torque of ISOK120 flex in the TRD had 244 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 245 246 differences between post and post-30 min (Table 2). Regarding to comparisons between 247 configurations, the ISOK120 flex in the post was significantly lower in TRD (P = .007), TRD-F (P = .00.012) and RP (P < .001) when compared to IRR. At the post-30min, ISOK120flex in TRD was 248 significantly higher than RP (P = .027). TRD-F and RP also showed lower ISOK120flex (P = .006; P 249 <.001, respectively) values when compared to IRR (Table 2 and Fig. 2). 250

From the secondary analysis, we observed that the relative changes ($\Delta\%$) 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%. The decrease in ISOK120ext was significantly greater [$\Delta\%$ = -15.9 (95%CI: -21.1, -10.7)] than the decrease in ISOK120flex [$\Delta\%$ = -3.8 (95%CI: -9.0, 1.4)] at post-30 min (P = .001).

257 Discussion

258 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 259 experimental protocols; (ii) the IRR configuration allowed the maintenance of performance even with 260 261 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 262 experimental protocols at the two angular velocities; (iv) after 30-min of the TRD protocol, the 263 264 decrease in the isokinetic force of the quadriceps was higher than the reduction in the isokinetic strength of the hamstrings at 120%; and (v) the TRD-F and RP caused higher RPE, followed by TRD 265 266 and IRR configurations, respectively.

267 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. 268 269 In fact, in a meta-analysis, the authors demonstrated that the IRR and intra-set rest (commonly 270 characterized as types of cluster sets) configurations acutely reduced velocity and power throughout 271 the sets [4]. These configurations seem to be effective because the accumulation of metabolites is 272 avoided, and fatigue dissipation is favored [7]. In addition, it makes it possible to achieve a high 273 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 274 universal. For example, the force output was similar between the IRR and intra-set rest and TRD 275 276 configuration [4], suggesting that responses may depend, at least in part, on the performance variable 277 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 metaanalysis 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).

289 Regarding the TRD-F and TRD configurations, both reduced the force output immediately after 290 the end of the session for the two muscular actions and angular velocities tested. However, while these 291 measures remained attenuated after 30-min in the TRD-F protocol, the flexors' peak torque at 120% 292 returned to the baseline values in the TRD. Together, these findings can be interpreted as follows: (a) 293 performing multiple sets to or near to voluntary muscle failure induce reductions in neuromuscular 294 performance in trained subjects [16-18]; (b) to perform the exercise close to failure in most sets (a fact 295 that occurred in the TRD), even with high volume-load, can be harmful the force production, since the 296 peak torque of the flexors returned to baseline values 30-min after the TRD condition. However, 297 further investigations are needed to characterize the time-course, this possible difference, and how 298 many repetitions in reserve are necessary to the strength return to baseline values quickly.

299 Our results revealed that both quadriceps and hamstrings experienced a similar performance 300 reduction. Therefore, our hypothesis was not confirmed. Because the quadriceps are the agonist group 301 in the parallel back squat exercise and supported by previous studies [19-21], we believed that this 302 muscle group would significantly reduce the peak torque. However, except for the ISOK120flex, 303 which flexors showed less reduction compared to the extensors in the TRD, all other responses were 304 similar between quadriceps and hamstrings. This finding might be explained by the fact that the 305 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 306 307 overall strength production and not only of the agonist muscles [22]. Another factor that may have 308 contributed to such responses may be the role of antagonistic exercised by the hamstrings that act in309 co-contraction during the squat [19].

To the best of our knowledge, our study was the first to investigate the effects of different 310 311 resistance training configurations on the knee extensors and flexors' neuromuscular performance and 312 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 313 314 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 315 316 using an isokinetic dynamometer, which is commonly pointed out as the gold standard instrument for 317 this purpose. In contrast, some limitations should not be ignored. The present study was conducted 318 with a single multi-joint exercise (parallel back squat), and our sample was composed of trained 319 subjects. Therefore, the information in this investigation must be interpreted with caution and applied 320 in a similar context. Another significant limitation is the fact that we did not follow up neuromuscular 321 performance hours after each condition. Such information could show us how long it would take to 322 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 323 324 this characteristic to describe the effects of different configurations on neuromuscular performance and include force tests at higher speeds (e.g., 180°/s and 300°/s). 325

326 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 333 performance of their athletes before applying a new training session. Additionally, although the squat 334 is an exercise that primarily involves the actions of hip and knee extension in the concentric phase, 335 which in theory, would require more considerable effort in the quadriceps when compared to the 336 hamstrings, the reduction in performance occurs in a similar way between these two muscle groups.

337

338 Conflict of interest

339 The authors report no conflicts of interest.

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393 TABLE LEGENDS

- 394 Table 1. State of recovery, performance, and perceived effort in the four experimental conditions (n
 395 = 28).
- 396 *Note.* The data are presented in mean and 95% CI; TQR = total quality recovery; AU = arbitrary units; RPE = rating of
- 397 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,
- 400 immediately post, and post-30min each experimental condition (n = 28).
- 401 *Note.* The data are presented in mean and 95% CI; IRR = inter-repetition rest configuration; TRD = traditional
- 402 configuration not to failure; TRD-F = traditional configuration to failure; RP = rest-pause; * different when compared to
- 403 pre; † different when compared to IRR; ‡ different when compared to TRD.
- 404

405 FIGURES LEGENDS

- 406 Fig. 1. Resistance exercise sessions.
- 407 *Note.* rep = repetitions; IRR = inter-repetition rest configuration; TRD = traditional configuration not to failure; TRD-F =
 408 traditional configuration to failure; RP = rest-pause.
- 409
- 410 Fig. 2. Relative changes for the isokinetic force of knee extensors and flexors at both velocities are in
- 411 the four experimental conditions (n = 28).
- 412 *Note.* The data are presented in mean and 95% CI; IRR = inter-repetition rest configuration; TRD = traditional configuration
- 413 not to failure; TRD-F = traditional configuration to failure; RP = rest-pause; * different when compared to pre; † difference
- 414 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
 10s

 TRD
 5 sets

Rep 1	Rep 2	Rep 3	Rep 4		Rep 11	Rep 12
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TRD-F

4 sets								
Rep 1	Rep 2	Rep 3	Rep 4		Rep 13	Rep 14	Rep 15	





л	С	1
4	2	т

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) N° 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) 3340 (2695-3984) 3340 (2695-3984) 3279 (2636-3922) 3340 (2695-3984) Volume-load (kg) 8.2 (7.8-8.7)*† RPE (AU) 5.3 (4.9-5.7) 6.0 (5.5-6.5)* 8.8 (8.5-9.1)*†

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.

Monsuros		Conditions					
Ivicasui	65	IRR	TRD	TRD-F	RP		
ISOK90ext (Nm)	ISOK90ext (Nm) Pre		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)*†‡		

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.