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Effect of individualized resistance training prescription with heart rate variability on individual muscle hypertrophy and strength responses

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Abstract
The aim of the present study was to investigate if resistance training (RT), performed with individualized recovery between sessions (RT-IND), promotes greater gains in strength and muscle mass and reduces the variability on adaptations compared to RT with fixed recovery intervals (RT-FIX). Twenty young men (age 21.9 ± 3.3 years) were randomized in the RT-IND and RT-FIX groups. Five days before the beginning of the training, measurements of the root mean square of successive R-R intervals differences (RMSSD) values of each individual were performed to establish the baseline values. Before each RT session, the RMSSD values determined whether the participants from RT-IND protocol were recovered from the previous session. Participants performed the RT session only if RMSSD values had returned to the baseline, otherwise they had to wait for an additional 24 h. RT-FIX performed an RT session every 48 h. Muscle strength was measured by one-maximal repetition (1-RM) test and muscle cross-section area (CSA) of the vastus laterals by ultrasonography were assessed pre- and post-training. 1-RM values increased significantly from pre to post-training for both groups (RT-IND: 30% and RT-FIX: 42%, main time effect, $P < 0.0001$), with no significant difference between groups. Muscle CSA increased significantly from pre to post-training (RT-IND: 15.7% and RT-FIX: 15.8%, main time effect, $P < 0.0001$), with no significant difference between groups. In conclusion, RT-IND did not increase the gains in muscle strength and mass neither reduce the variability in muscle adaptations when compared to the RT-FIX.

Keywords: Muscle mass, muscle strength, frequency, autonomic nervous system, RMSSD

Highlights
• HRV is a practical tool that can monitor the individualized recovery interval between RT sessions.
• Coaches and practitioners can implement a higher RT weekly frequency when recovery interval between training sessions is determined by the return of RMSSD values to baseline.
• The recovery interval individualized by RMSSD values may allow some individuals to have the same adaptations as the fixed recovery group, but in a shorter time window.

Introduction
Large individual variation in strength and muscle mass gains (i.e. muscle hypertrophy) have been observed after a resistance training (RT) programme (Ahtiainen et al., 2016; Hubal et al., 2005). Whereas some individuals show gains greater than 100% and 40% for muscle strength and hypertrophy respectively, others do not change, or even decrease after a training period (Hubal et al., 2005). To date, factors such as baseline fitness level, genetics and nutritional status are the known determinants of the differences in individual responses to RT (Ahtiainen...
In addition, RT session variables, such as the recovery interval between sessions, have been considered as candidates to explain the large between-subject variation in RT adaptation (Ahtianen et al., 2016). For instance, high RT strain in association with inadequate recovery periods can lead to the accumulation of training-induced fatigue, resulting in a decrease in performance of the subsequent sessions, which may affect RT-induced adaptations (Xiao, Chen, & Dong, 2012). On the other hand, an optimal time of recovery would allow individuals to sustain greater loads or perform more repetitions (i.e. total training volume [sets × repetitions × load]) in the next workout, which over time seems to be associated with strength gains (Ralston, Kilgore, Wyatt, & Baker, 2017) and muscular hypertrophy (Schoenfeld, Grgic, Ogborn, & Krieger, 2017). Therefore, it is plausible to suggest that an adequate recovery between sessions could avoid accumulation of training-induced fatigue, ensure greater adaptation to RT, and possibly reduce the large between-subject variation in RT-induced adaptations.

A few authors have suggested that heart rate variability (HRV) can measure the accumulation of training-induced fatigue that may occur during periods of high training strain without adequate recovery (Bellenger et al., 2016; Borresen & Lambert, 2008; Buchheit et al., 2010). This non-invasive marker of cardiovascular-autonomic modulation has been recently viewed as one of the most promising methods to individualize training prescription (Buchheit et al., 2010; Plews, Laursen, Stanley, Kilding, & Buchheit, 2013). For instance, HRV has been deemed as an effective tool to periodize the training programme (Kiviniemi et al., 2010; Kiviniemi, Hautala, Kinnunen, & Tulppo, 2007) as it has been able to determine the training load and recovery status in several kinds of activities that require high-intensity exercise (Chen et al., 2011; Kingsley et al., 2014; Nakamura et al., 2015; Saboul, Balducci, Millet, Pialoux, & Hautier, 2016). One of the parameters of HRV considered as a training monitoring index is the root mean square of successive R-R intervals differences (RMSSD) (Plews et al. 2013). The RMSSD has been used for training monitoring because of its ability to reflect parasympathetic activity over a short time frame. In fact, it has been proposed that training prescription according to the status of parasympathetic activity may be an effective method to improve endurance training adaptation (Kiviniemi et al., 2007; Vesterinen et al., 2016). On the other hand, no study has used RMSSD measurements as a tool for adjusting the overload during RT programmes. This suggestion is based on the fact that a single RT session can change parasympathetic indices for more than 72 h (Chen et al., 2011). Therefore, decreases in RMSSD may reflect insufficient recovery from the previous RT session (Hautala et al., 2001), suggesting an unfavourable physiological condition to training.

The rationale behind HRV measurements as a tool for monitoring recovery between sessions in RT programmes can be based on the total training volume (TTV), performed in each session, over a fixed number of training sessions (e.g. 20 RT sessions). For instance, individualized recovery monitoring using the RMSSD can ensure an optimal performance in the subsequent RT session, resulting in a higher session TTV compared to an RT programme in which the recovery interval is standardized for all individuals. Thus, it is plausible to consider that RT programmes with recovery intervals controlled individually may produce higher TTV and, consequently, greater increases in muscle strength and hypertrophy. In addition, may eventually reduce the variability in the muscle adaptations, when compared to RT programmes with a constant recovery interval.

Therefore, in the aim of the present study we sought to determine if the RT programme, performed with individualized recovery between sessions (RT-IND), promotes greater gains in strength and muscle mass and reduces the variability of these adaptations compared to an RT programme with fixed recovery intervals (RT-FIX) in young men. Additionally, we sought to determine the relationships between the number of sessions that the participants were recovered (i.e. RMSSD returned to baseline) and the percentage of increase in muscle strength, hypertrophy and TTV. We hypothesized that the RT-IND would produce greater TTV over a fixed number of training sessions, thus resulting in larger muscle strength and hypertrophy gains and less variability in adaptations than the RT-FIX.

**Methods**

**Participants**

Twenty-two young men (age: 22.7 ± 3.8 years; body mass: 77.5 ± 11.6 kg; height: 176 ± 0.7 cm) volunteered for this study. Participants had to refrain from RT programme for at least 6 months prior to the beginning of the study, could not have muscle and/or joint injuries, not use of anti-inflammatory, analgesic, antihypertensive, beta-blockers, central nervous system depressant drugs or caffeine throughout the experimental protocol. The participants should attend 100% of the assessments and RT sessions. The study was conducted according to the Declaration of Helsinki and ethical approval was
granted by the ethics committee at the local University.

**Study design**

In the first week, all participants had their HRV measurement (RMSSD) assessed every day from Monday to Friday. Thus, it was possible to obtain the baseline values of each participant through the mean of five days minus one standard deviation, which was used as the recovery parameter before each training session. On Friday, the cross-sectional area (CSA) of the vastus lateralis (VL) muscle was assessed. In the second week, all participants were familiarized with the one-repetition maximum (1-RM) test and exercise protocols. Seventy-two hours after familiarization, a new 1-RM test was performed. If the 1-RM values differed more than 5% from the previous test, a subsequent test was performed after 72 h of rest. The values of CSA and 1-RM were used to rank the participants into quartiles. Following, participants from each quartile were randomly allocated in the following experimental groups: (1) resistance training with constant recovery interval (RT-FIX; \( n = 10 \)) between sessions and frequency fixed at 3 times per week (Monday, Wednesday and Friday); (2) resistance training with individualized recovery interval (RT-IND; \( n = 10 \)) (Monday to Friday). All participants underwent 20 RT sessions. Ninety-six hours after the last training session, CSA and 1-RM were reassessed.

**Heart rate variability**

The data collection was conducted in a laboratory at the same time of day. The participants were instructed to avoid stimulating beverages that could influence in the heart rate responses. In addition, they were informed to have light meals and adequate sleep (at least eight hours) as recommendations pre-evaluations. The participants rested in a quiet room for 10-min in the supine position and were instructed to not sleep, move or talk. Recordings of the R-R intervals were obtained at rest in the supine position, during a 10-min period, with a transmitter and heart rate monitor (Polar® S810i; Polar Vantage, Finland) placed on the participant’s chest. The data were subsequently downloaded to a computer programme (Kubios HRV 2.2. Finland). Sessions of 256 points free of artifacts, using the filter of the software (set at medium) were analyzed by the same evaluator. A 5-d rolling average of RMSSD (Monday to Friday) was calculated because it has been proposed to be more sensitive to track changes in the training status compared with single-day values (Plews, Laursen, Kilding, et al., 2013). We adopted the values for the RMSSD baseline for each participant, as the mean minus one standard deviation, since this arbitrary value may be a small variation with respect to observed over the five days of measurement. Before each RT session, the RMSSD values determined whether the participants from RT-IND protocol were recovered from the previous session. Participants performed the RT session only if RMSSD values had returned to the baseline, otherwise they had to wait for an additional 24 h (Monday to Friday). RT-FIX performed an RT session 48 h after the previous one (Monday, Wednesday and Friday).

**Muscle CSA**

VL CSA of the dominant leg was obtained through ultrasound (US) imaging following the procedures described in the validation study from our group (Lixandrão et al., 2014). Images were collected using the US B-mode with a 7.5 MHz probe (Samsung, MySono U6, São Paulo, Brazil). Surface gel was applied to promote acoustic coupling while avoiding dermal deforming. The VL CSA was obtained at 50% of the femur length, manually measured as the midway point between the greater trochanter and the lateral epicondyle. The skin was ink-marked transversely in 2-cm intervals toward the medial and lateral aspects of the thigh to guide probe displacement. The probe was aligned with the skin marks and sequential images were acquired by moving the probe medial-laterally on the thigh. Images were opened in Power point (Microsoft, USA) in the same sequence they were acquired, rotated and aligned in order to reconstruct whole muscle fascia. Muscle CSA was then calculated using the fascia as reference for the muscle boundaries, and CSA value was calculated using computerized planimetry. The coefficient of variation (CV) and typical error (TE) between two repeated measures performed in different days (72 h apart) for the CSA were 0.98% and 0.24 cm², respectively.

**Maximum dynamic strength test**

Maximal dynamic strength was assessed using the 1-RM test on the knee extension machine, according to the Brown and Weir (2001) protocol. Initially, participants performed a general warm-up in a cycle ergometer at 20 km h⁻¹ for 5-min, followed by two sets of specific warm-up. The first set consisted of 8 repetitions with 50% of the estimated 1-RM, and the second set, 3 repetitions with 70%
of the estimated 1-RM with a 2-min rest between the warm-up sets. After the warm-up, participants initiated the 1-RM test at full knee extension (∼180°), performing both eccentric and concentric exercise phases at a range of 90°. Participants had up to 5 attempts to reach their 1-RM in each exercise, with a rest of 3-min between attempts. The greatest load lifted was considered the 1-RM. The CV and the ET between two repeated measures performed in different days (72 h apart) were 1.2% and 1.6 kg, respectively.

Resistance training programme

All RT protocols were performed in the following fixed exercise order: leg extension, 45° leg press, leg flexion, bench press, lat pulldown, triceps pushdown, arm curl, and shoulder press. RT protocol consisted of three sets of 9–12 RM at ∼80% 1-RM to muscular failure. Sets were interrupted if participants failed to maintain proper range of motion. The load was increased whenever participants performed more than 12-RM and reduced when the numbers of repetitions was less than 8-RM, in order to maintain the number of repetitions in the desired range of motion. A 2-min rest interval was allowed between sets. Total training volume (TTV) was calculated as sets × repetitions × load (kg). The training sessions were performed from Monday to Friday. However, the RT-FIX group performed the training sessions with a 48 h interval between sessions (Monday, Wednesday and Friday), while the interval between sessions of the RT-IND group varied for each individual according to RMSSD index.

Data analysis

Two participants dropped-out from the study due to personal reasons. Thus, the statistical analyses were carried out using n = 10 for RT-FIX and n = 10 for RT-IND. After visual inspection, the Shapiro-Wilk test was used to test normality. A mixed model analysis for repeated measures, having groups (RT-FIX and RT-IND) and time (Pre [First session for TTV] and Post [Last session for TTV]) as fixed factors and participants as random factor was performed. Significant F-values, a Tukey adjustment was implemented for pairwise comparisons. Levene’s test was used to test if the variance of the RT-induced adaptations (i.e. delta change) were similar between RT-FIX and RT-IND. Participants were defined as a non-responders if muscle strength or hypertrophy did not increase more than two times the typical error (TE) previously reported (Hopkins, 2000). Pearson’s correlation coefficient was used to determine the relationships between the number of sessions that the participants were recovered (i.e. RMSSD returned to baseline) and the percentage of increased 1-RM, muscle CSA and TTV values. Effect sizes (ES) were calculated for 1-RM, CSA and TTV. ES were calculated using the changes between Pre and Post moments. ES were classified as “small” if lower than 0.2, “medium” if between 0.2 and 0.5, and “large” if higher than 0.8 (Cohen, 1988). Statistical analyses were performed in the software SAS 9.2 and significant P values were set as P < 0.05.

Results

Progression total training volume TTV

Both groups showed significantly greater TTV in the last session compared with the first session for leg extension (RT-FIX: 45.2%, Effect Size: 1.72 (large); RT-IND: 51.5%, ES: 1.50 (large); main time effect; P < 0.0001), 45° leg press (RT-FIX: 80.4%, ES: 3.79 (large); RT-IND: 102.7%, ES: 2.05 (large); main time effect; P < 0.0001), leg flexion (RT-FIX: 62.2%, ES: 2.53 (large); RT-IND: 86.5% (large), ES: 1.66 (large); main time effect; P < 0.0001), bench press (RT-FIX: 43.5%, ES: 1.74 (large); RT-IND: 53.1%, ES: 1.10 (large); main time effect; P < 0.0001), lat pulldown (RT-FIX: 45.3%, ES: 1.51 (large) and RT-IND: 29.6%, ES: 1.35 (large); main time effect; P < 0.0001), triceps pushdowndown (RT-FIX: 44.3%, ES: 2.41 (large); RT-IND: 51.0%, ES: 0.82 (large); main time effect; P < 0.0001), arm curl (RT-FIX: 61.7%, ES: 1.28 (large); RT-IND: 33.0%, ES: 0.92 (large); main time effect; P = 0.0008), shoulder press (RT-FIX: 97.5%, ES: 2.38 (large); RT-IND: 99.6%, ES: 1.84 (large); main time effect; P < 0.0001). No significant differences were detected between groups at post-training (P > 0.05) (Table I).

Individualized recovery

The RMSSD values of each individual before the RT programme are shown in Figure 1. Importantly, Figure 1 shows the RMSSD values for the days in which both groups performed the training sessions. As RT-IND performed all the training sessions with participants fully recovered from previous session, the RMSSD values were always above the baseline. Although, some participants showed RMSSD values above the reference value 24 h after the training session (i.e. suggesting a complete recovery), others did not train due to the fact that RMSSD
values were below the baseline (which occurred between 2 and 11 times). On the other hand, the participants in the RT-FIX group performed the training sessions with RMSSD values below the baseline in several occasions, which suggests that they were not recovered from the previous session. While some participants did recovery only after one session, others did not present RMSSD at baseline in 15 training sessions. On average, the RT-FIX group performed ∼9 of the 20 sessions with RMSSD values below the baseline. Interestingly, it was possible to verify that due to the individualized recovery, the RT-IND group performed the 20 sessions of RT in the period of 5.1 weeks, while the RT-FIX group needed 7 weeks to complete 20 RT sessions.

Maximum dynamic strength (1-RM) and muscle CSA

Both groups significantly increased 1-RM values from pre- to post-training (RT-FIX: 44.8%, ES: 2.03 (large); RT-IND: 30.8%, ES: 1.00 (large); main time effect; $P<0.0001$) (Figure 2 Panel A). In relation to CSA (Figure 2 Panel B), both groups significantly increased values from pre- to post-training (RT-FIX: 18.2%, ES: 0.59 (medium); RT-IND: 16.2%; ES: 0.73 (medium); main time effect; $P<0.0001$). No significant differences between protocols were detected at post-training ($P>0.05$).

Individual variation in the neuromuscular adaptation

Gains in 1-RM and CSA ranged from 26.6% to 78.9% (52.3%) and −3.4% to 42.4% (45.8%), respectively in RT-FIX and 15% to 60% (45%) and 5.3% to 29.8% (24.5%) in RT-IND. Participants were classified as non-responders if they presented enhancements of less than 0.48 cm² of CSA (2× TE [24 cm²]) and 3.2 kg to 1-RM (2× TE [1.6 kg]). Only one participant in RT-FIX showed no increase in CSA, whereas all other participants in the RT-FIX and RT-IND groups presented 1-RM and CSA gains greater than two TE. The Levene’s test found no differences between groups for variability in muscle CSA (RT-FIX: 95% CI 1.86–5.30 and RT-IND: 95% CI 1.09–3.72; $P=0.13$) and 1-RM gains (RT-FIX: 95% CI 5.86–39.81 and RT-IND: 95% CI 8.41–40.18; $P=0.57$). Furthermore, no significant correlations were found between the number of sessions that the participants were recovered (i.e. RMSSD returned to baseline) and the percentage of increase in 1-RM values (RT-FIX: $r=-0.06$, $P=0.86$; RT-IND: $r=0.18$, $P=0.61$), muscle CSA (RT-FIX: $r=0.02$, $P=0.94$; RT-IND: $r=0.04$, $P=0.90$) and TTV (RT-FIX: $r=-0.02$, $P=0.94$; RT-IND: $r=0.35$, $P=0.31$).

Discussion

The aims of the present study were to compare the effects of an RT programme with fixed recovery interval (RT-FIX) and an RT programme with individualized recovery interval (RT-IND) on muscle strength and mass and to investigate if RT-IND could decrease the variability of these adaptations. Our main finding was that individualized recovery interval, as assessed by the RMSSD, did not enhance muscle strength and hypertrophy gains, and did not reduce the variability of adaptations in young men compared with constant recovery interval.

Muscle strength gains and hypertrophy found in our study are in agreement with studies conducted in young untrained individuals, which did not control the recovery interval between RT programme individually (Aguiar et al., 2015; Ahtiainen et al., 2016; Holm et al., 2008; Hubal et al., 2005; Ronnestad et al., 2007; Wernbom, Augustsson, & Thomee, 2007). Importantly, the variability found in the

### Table I. Total training volume of resistance training with constant recovery interval (RT-FIX) and resistance training individualized recovery interval (RT-IND) in first and last training session.

<table>
<thead>
<tr>
<th>Exercises</th>
<th>RT-FIX 1st session</th>
<th>RT-FIX Last session</th>
<th>RT-IND 1st session</th>
<th>RT-IND Last session</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leg extension (kg)</td>
<td>2647.5 ± 520.4</td>
<td>4237.0 ± 794.5°</td>
<td>3097.6 ± 680.3</td>
<td>4417.5 ± 780.2°</td>
</tr>
<tr>
<td>45° Leg press (kg)</td>
<td>7445.0 ± 1296.0</td>
<td>14,896.0 ± 1888.7°</td>
<td>9458.0 ± 2507.6</td>
<td>16,675.7 ± 3482.7°</td>
</tr>
<tr>
<td>Leg curl (kg)</td>
<td>1255.3 ± 292.3</td>
<td>2234.5 ± 311.6°</td>
<td>1466.5 ± 341.7</td>
<td>2362.5 ± 601.2°</td>
</tr>
<tr>
<td>Bench press (kg)</td>
<td>949.8 ± 209.1</td>
<td>1420.2 ± 209.0°</td>
<td>1195.6 ± 338.7</td>
<td>1674.8 ± 384.9°</td>
</tr>
<tr>
<td>Lat pulldown (kg)</td>
<td>1132.5 ± 145.0</td>
<td>1467.8 ± 214.5°</td>
<td>1203.6 ± 303.1</td>
<td>1707.3 ± 303.6°</td>
</tr>
<tr>
<td>Shoulder press (kg)</td>
<td>503.0 ± 120.0</td>
<td>970.5 ± 209.5°</td>
<td>582.5 ± 1987.0</td>
<td>1095.5 ± 276.5°</td>
</tr>
<tr>
<td>Triceps push (kg)</td>
<td>943.0 ± 139.4</td>
<td>1389.0 ± 149.6°</td>
<td>1142.5 ± 385.0</td>
<td>1575.4 ± 505.4°</td>
</tr>
<tr>
<td>Arm curl (kg)</td>
<td>500.8 ± 80.7</td>
<td>656.4 ± 115.2°</td>
<td>483.2 ± 163.8</td>
<td>680.8 ± 195.7°</td>
</tr>
</tbody>
</table>

*Significant difference compared to first session (main time effect, $P<0.0001$). Values presented as mean ± SD.
Figure 1. Represents the RMSSD values measured before the sessions for the RT-IND and RT-FIX groups individually. Where the baseline RMSSD value is represented by the number zero (Pre), and the number of sessions is represented as a percentage of the pre value.

Figure 2. Maximum dynamic strength (1-RM, Figure 2A) and muscle (CSA, Figure 2B) measured at baseline (Pre) and after 20 sessions of resistance training with fixed recovery interval (RT-FIX) and resistance training with individualized recovery interval (RT-IND).

*Significantly different from Pre (main time effect, $P<0.0001$). Values presented as mean ± SD.
neuromuscular adaptations was similar between groups (RT-IND vs. RT-FIX), corroborating studies that used a larger cohort (Ahtiainen et al., 2016; Kiviniemi et al., 2010). Additionally, the number of responders was the same between groups for muscle strength and almost the same for muscle hypertrophy i.e. only one participant in the RT-FIX group showed no increase in CSA above two TE.

According to our initial hypothesis, the RT-IND group would promote greater gains in muscle strength and mass due to greater progression in TTV compared to the RT-FIX, and reduce the outcomes variability due to the individual recovery. In fact, studies have demonstrated a dose-response relationship between volume and neuromuscular adaptations (Krieger, 2010; Ralston et al., 2017; Rhea, Alvar, Burkett, & Ball, 2003; Schoenfeld, Ogborn, & Krieger, 2017). On the other hand, when TTV is equalized, neuromuscular adaptations are similar, regardless of the manipulation of other training variables such as intensity (Angleri, Ugrino-witsch, & Libardi, 2017) muscle action (Ronnestad et al.), weekly frequency (Candow & Burke, 2007; Gentil, Fischer, Martorelli, Lima, & Bottaro, 2015), which may in part help to explain our findings. Interestingly, even with RMSSD values below baseline levels in the RT-FIX group (i.e. participants were not recovered) when the subsequent session was performed, the progression of TTV was similar between groups, which also resulted in an accumulated TTV similar at the end of the 20 training sessions.

The RMSSD measurement has been used to monitor training loads and to guide prescriptions (Da Silva, Ferraro, Adamo, & Machado, 2017; Plews, Laursen, Stanley, et al., 2013; Schmitt, Regnard, & Millet, 2015; Vesterinen et al., 2016). This is the first study that investigated the use of RMSSD to monitor and guide the prescription of an RT programme. Although the RMSSD has been commonly used during endurance training, RT also alters parasympathetic system index after an RT session for up 72 h, which was supported herein and from one previous study (Chen et al., 2011). Although some individuals in RT-IND group already had the RMSSD values above baseline value 24 h after the training session, (i.e. suggesting full recovery) others maintained RMSSD values below baseline even after 48 h. Interestingly, most of the participants recovered 24 h after the training session, although sometimes they were released from training for not having the RMSSD values above baseline, which occurred between 2 and 11 times. Regarding the RT-FIX, the RMSSD values were monitored 48 h after the last RT session. However, unlike the RT-IND group, the participants performed the RT session even though they were not recovered (Figure 1), which occurred between 1 and 15 sessions. Despite the fact that the RMSSD is sensitive to the stress caused by RT session, there were no correlations between the number of times that the participants were recovered and muscle strength gains for both groups. On the other hand, the individualized control of the recovery, enabled the RT-IND group to complete 20 RT sessions in a shorter time window compared to the RT-FIX group (RT-IND: ∼5.1 weeks vs. RT-FIX: 7 weeks). This was due to the higher weekly training frequency. Therefore, our results suggest that the individualized prescription of the recovery interval between RT sessions, through RMSSD allows a higher weekly frequency of training compared to the traditionally recommended recovery interval (ACSM, 2009), without compromising neuromuscular adaptations. However, these findings should be interpreted with caution and cannot be expanded to other populations. It is possible that due to the aging process or diseases that affect the autonomic nervous system, some individuals may need even longer than the traditionally recommended recovery interval.

This study is not without limitations. (1) Due to the individualized monitoring of the recovery interval between the RT sessions, the RT-IND group performed the 20 training sessions in a shorter period of time (RT-IND: ∼5.1 weeks vs. RT-FIX: 7 weeks), but with similar muscle strength and mass gains compared with the RT-FIX group. However, these findings cannot be directly extended to other populations (e.g. elderly and trained individuals), which may require different recovery periods between sessions; (2) The intervention period may have been short precluding that differences between have been noticed. However, 20 training sessions seems to be enough to induce increases in muscle strength and mass without influence of edema caused by exercise-induced muscle damage in the initial stages of RT (Damas et al., 2016). Additionally, this number of sessions has been commonly used in studies that found differences in neuromuscular adaptations between training protocols (Campos et al., 2002; Fonseca et al., 2014; Kerssick et al., 2009; Lasevicius et al., 2018; Schuenke et al., 2012; Shepstone et al., 2005); (3) The Our results of muscle hypertrophy are specific to the quadriceps muscle, specifically for the VL muscle. We measured VL muscle hypertrophy only, because the protocol used to determine CSA by ultrasound was validated only for the VL muscle (Lixandrão et al., 2014; Reeves, Maganaris, & Narici, 2004) Thus, we chose to measure muscle strength also in an exercise with an emphasis on this muscle. However, we showed progression in TTV for all exercises performed in
both groups, suggesting similar muscle strength increases.

In terms of practical application, our study suggests that the HRV is a practical tool that can monitor the individualized recovery interval between RT sessions. Thus, coaches and practitioners can implement a higher RT weekly frequency when recovery interval between training sessions is determined by the return of RMSSD values to baseline. Finally, the recovery interval individualized by RMSSD values may allow some individuals to have the same adaptations as the fixed recovery group, but in a shorter time window.

In conclusions, the individualized recovery did not promote a greater gain in strength and muscle mass and did not reduce the variability of adaptations when compared to a fixed interval. Additionally, the correlation between the number of sessions that the participants were recovered (i.e. RMSSD returned to baseline) and relative changes in muscle strength, hypertrophy and total training volume were not significant. Thus, contrary to the findings on endurance training adaptations, RMSSD is not a good index to control training strain and to enhance training-induced adaptations when utilizing resistance exercise.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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