Effect of different eccentric tempos on hypertrophy and strength of the lower limbs

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ABSTRACT: The purpose of this study was to evaluate the effects of altering the duration of the eccentric phase in isotonic contractions on muscle hypertrophy and strength of the quadriceps femoris. Ten healthy young adults (8 men and 2 women: Height: 173.3 ± 9.6 cm: Body mass: 69.84 ± 10.88 kg; Body fat: 19.47 ± 8.42%; Age: 25.3 ± 4.8 years) performed unilateral isotonic knee extension exercise, whereby each leg was randomly allocated to perform the eccentric phase of movement with a duration of either 2 seconds (G2S) or 4 seconds (G4S). Both conditions carried out the concentric phase of each repetition at a 1 second duration with no rest in the transition phases. Each condition performed 5 sets using 70% of 1 repetition maximum until muscle failure with 3 minutes of rest between sets for 8 weeks. The change in muscle strength was assessed by 1RM knee extension and muscle thickness was assessed by A-mode ultrasound. For each outcome variable, linear mixed-effects models were fit using restricted maximum likelihood. Hedges' g effect sizes were calculated to provide insights into the magnitude of effects. Results showed all muscles increased in size over time; mean effects were similar in all muscles except for the vastus medialis, which favored the G4S condition. Conversely, only a trivial and highly variable effect was observed between interventions for strength gain. Our results suggest different eccentric durations produce similar increases in hypertrophy of the vastus lateralis and rectus femoris; however, the vastus medialis showed greater growth from the slower eccentric duration. Eccentric duration did not differentially affect strength-related adaptations.

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INTRODUCTION

The manipulation of training variables is proposed to be important to strength and hypertrophy gains [1, 2]. Variables that can be manipulated include volume, load, rest interval duration, level of effort (proximity to achieving muscle failure), exercise selection, training frequency, and movement tempo, and different alterations in these variables promotes a distinct acute response [1, 2]. Of these variables, movement tempo has not been as well-researched as some of the others as to its effect on muscular adaptations. The American College of Sports Medicine position stand on resistance exercise proposes that untrained individuals should use slow and moderate movement tempos; intermediate trained subjects should use moderate tempos; and for advanced athletes, a variety of tempos from slow to fast velocities is recommended [3]. However, this proposition is based on anecdotal data provided from a limited number of studies [4], thus necessitating additional research to strengthen conclusions on the topic. Indeed, some evidence suggests that a moderate duration of the eccentric phase is superior to faster movements for promoting quadriceps hypertrophy [4].

Customarily, the duration of a repetition is denoted by a four-digit number with the first numeral representing the eccentric phase, the second numeral representing the isometric transition at the top of the movement, the third numeral representing the concentric phase, and the fourth numeral representing the transition at the bottom of the movement [5]. For example, a sequence of 1-0-2-0 would mean that the eccentric phase took 1 second and the concentric phase took 2 seconds with no static transition period between actions.

Bodybuilders and other resistance-training enthusiasts often believe that there is a benefit to performing eccentric actions slowly. This is based on the hypothesis that slower eccentric tempos induce a greater magnitude of muscle-damage and endocrine responses, and thus a higher consequent hypertrophic response [6]. Indeed, the literature suggests that the greater time under tension (TUT) promoted by slow eccentric phase increases the degree of micro-damage following resistance training (RT) [7, 8]. Provided that muscle damage does in fact enhance hypertrophy – a topic that remains controversial [9, 10] – it would stand to reason that a longer eccentric phase may optimize the hypertrophic response [10].

A recent meta-analysis sought to evaluate the influence of movement velocity on strength gains (10). The pooled results of the data indicated that RT performed at fast movement tempos favored superior gains in muscular strength compared to moderate-slow tempos, but the difference was not statistically significant. It is proposed that a strength gains result from a combination of neurological [11] and morphological adaptations [12]. A subsequent systematic review by the same laboratory concluded that moderate-slow movement duration (≥ 2 sec) are superior for promoting quadriceps hypertrophy while a fast movement duration (≤ 1 sec) is better for elbow flexor hypertrophy [4]. The mechanisms responsible for this difference have yet to be elucidated. However, it has been proposed that increased metabolic stress and muscle TUT are potential mechanisms for the hypertrophic response to RT [13]. It should be noted that both aforementioned papers did not distinguish between specific muscle actions, and a majority of included studies manipulated only the concentric portion of the repetition.

To our knowledge, only two previous studies have endeavored to determine the effect of different eccentric durations on muscular adaptations using isotonic training. Assis-Pereira et al. [14] randomly assigned 12 resistance-trained men to perform 3 sets of arm curl exercise at 8RM. One group performed the movement tempo at 4/0/1/0 while the other employed a 1/0/1/0 scheme. Results showed greater increases in muscle cross-sectional area with the 4-second versus 1-second eccentric duration, indicating a slower eccentric phase is superior from a hypertrophy standpoint. The authors speculated that findings may be explained by a greater TUT for the 4 second condition. Indeed, Burd et al. [13] provided evidence that a higher TUT, achieved by performing slower repetition cadences (6/0/6/0 vs 1/0/1/0), induces a greater post-exercise muscle protein synthesis response [13] when the number of repetitions are equated. Recently, Shibata et al. [15] randomized untrained young male athletes to perform the parallel back squat with either a 2/0/2/0 or 4/0/2/0 movement tempo. Training was carried out twice a week for 6 weeks using 75% of 1RM to muscular failure in each set for 3 sets per session. Results showed no differences in muscle hypertrophy between conditions, however the faster eccentric phase showed greater increases in 1RM squat performance. The differences observed between the studies of Assis-Pereira and Shibata could be due to the level of training experience (trained vs untrained subjects) or the limbs trained (upper vs lower limbs); additional research is needed to better understand what variables may influence the strength and hypertrophic responses. In respect to the possible difference between trained vs untrained subjects, the TUT and total number of repetitions have been shown to be differentially influenced by regular (2/0/2/0) and slow (6/0/4/0) tempos, but not for moderate tempos (5/0/3/0) [16]. Given the paucity of research on the topic, the purpose of this study was to compare muscular adaptations when performing an eccentric duration of 2 versus 4 seconds, while keeping concentric phase, %1RM, number of sets and rest duration variables constant. We hypothesized that a longer eccentric duration would improve strength and muscle cross-sectional area to a greater extent than shorter duration.

MATERIALS AND METHODS

Subjects

A convenience sample of 8 men and 2 women (Height: 173.3 ± 9.6 cm: Body mass: 69.84 ± 10.88 kg; Body fat: 19.47 ± 8.42%; Age: 25.3 ± 4.8 years) were recruited from a university population. We recruited a mixed sample to improve the statistical power, as evidence shows no differences in the hypertrophic response to RT between men and women [17, 18]. Participants were considered for inclusion if they met the following criteria: not engaged in RT for at least 3 months prior to the study; absent of any diseases that may compromise the health of the subjects; not currently using any sports supplement or anabolic agents; not performing regimented aerobic training. Once admitted into the study, participants were instructed to maintain their normal dietary habits and not to use any dietary supplements or stimulants during the study period. A within-subject research design was employed whereby participants trained one leg with a 2/0/1/0 tempo (G2S) and trained the contralateral leg with a 4/0/1/0 tempo (G4S). All subjects were right leg dominant and thus, to avoid confounding, we randomized 50% of the subjects to perform the slower eccentric movement (moderate tempo) [5] with the right leg and the other 50% with the left leg. Prior to training, muscle thickness (MT) of the rectus femoris (RF), vastus medialis (VM), and vastus lateralis (VL) was assessed by A-mode ultrasound and muscle strength was assessed via 1RM testing. The subjects were provided with a 2 week acclimation period to become familiarized with the movement duration, and then carried out 8-weeks of regimented training. Participants were reevaluated for MT and muscle strength following the 8-week training period. The study was carried out in accordance with the standards of the Helsinki Declaration and approved by the ethics committee of Federal University of São Paulo (2.577.069).

Body Composition

Participants reported to the laboratory for body composition testing after an overnight fast. They were instructed to be well-hydrated, abstain from alcohol and any nutritional supplementation, and restrict caffeine consumption in the 4 hours before the body composition analysis according to bioimpedance manufacturer instructions. Moreover, they were told to maintain a normal sleep pattern and not to perform any strenuous physical activity. Height was measured via a stadiometer (Sanny, Brazil) attached to the wall. Body mass and body fat percentage were measured via bioelectrical impedance analysis (Tanita®, brand Tetrapolar bioimpedance BC601, Japan) with the subjects in their underwear.

Maximum strength

Maximal strength was assessed unilaterally on a seated leg extension machine (REFORCE® model Elite) via 1RM testing [3]. The 1RM assessment was specific to the concentric action; no eccentric was performed during testing. Prior to testing, all subjects performed a specific warm-up comprised of 20 repetitions with a load of 40% to 50% of their subjective perception of effort. The initial load for testing was then estimated through the subjects' perceived exertion and the experience of the researcher. 1RM testing began at 90º of knee flexion and continued through a full range of motion to 0º (full extension). Participants were allowed to grip the seat with their hands for stability. The axis of rotation of the lever arm was aligned with the lateral epicondyle of the femur of the right leg. The hip joint angle was 120° between the trunk and the thigh for all subjects. The resistance pad at the end of the lever arm was aligned with the anterior tibia approximately 2.5 cm superior to the medial malleolus. A maximum of five attempts were afforded to determine 1RM, with five-minute rest intervals allowed to facilitate recovery between attempts.

Time Under Tension

The TUT was calculated as the product of the total number of repetitions performed over the 8 weeks of training and the eccentric action duration (two or four seconds). We did not consider the concentric duration (1 second for both groups) in the determination of the TUT as it was the same for both conditions.

Muscle thickness

MT was evaluated via A-mode ultrasound (Intelametrix, CA, EUA) using a linear 2.5 MHz frequency linear array probe [19]. MT was assessed at three sites on the quadriceps femoris muscle: rectus femoris (RF), vastus medialis (VM), and vastus lateralis (VL) before and after 8 weeks of training. Measurements were taken between the external muscle boundary and the band of connective tissue that runs longitudinally down the middle of the muscle as per Abe [20]. The measurement sites were precisely located and marked with a semi-permanent pen as follows: For the RF, measurements were taken at 50% on the line from the anterior spina iliaca superior to the superior part of the patella; for the VL, measurements were taken at 2/3 along the line from the anterior spina iliaca superior to the lateral side of the patella; and for the VM, measurements were taken at 80% along the line between the anterior spina iliaca superior and the joint space in front of the anterior border of the medial ligament.

Subjects remained supine throughout testing, with legs relaxed and extended. The same researcher with experience in musculoskeletal ultrasound testing applied a healthy amount of water-soluble gel to the ultrasound probe, and transverse images were obtained at the respective sites. Images were recorded and saved onto hard drive. Each site was scanned twice, and the average of both values was calculated to enhance accuracy. If the difference between measurements was greater than 2 mm, a third measurement was obtained, and the two closest values were averaged to obtain a final value. All evaluations were conducted at the same time of day, 96 hours after the final training session, and the participants were instructed to hydrate normally 24hrs before testing. The intraclass correlation coefficients for the VL, VM, and RF from our laboratory are 0.71, 0.92, and 0.96, respectively.

Training Protocol

Unilateral knee extension exercise was performed twice per week for 8 weeks, with no less than 72-hours between sessions. Subjects performed 5 sets at 70% of 1RM until muscle failure with 3 minutes rest afforded between sets. The G2S leg performed repetitions using 1s in the concentric phase, 0s in the transitional phase from the concentric to the eccentric phase, 2s in the eccentric phase and 0s in the transitional phase from the eccentric to the concentric phase (1-0-2-0). Alternatively, the G4S group performed repetitions using 1s in the concentric phase, 0s in the transitional phase from the concentric to the eccentric phase, 4s in the eccentric phase and 0s in the transitional phase from the eccentric to the concentric phase (1-0-4-0). Both legs were trained in the same session for the 8-week duration, alternating the leg that was exercised first. The duration of each phase of movement was controlled via a metronome (Metronomo Batidas, free software – Stonekick) that pulsed intermittently each 1 and 2 or 4 seconds, according to the condition. Therefore, the participants followed the metronome beat for the concentric and eccentric phase. When the concentric or eccentric phase was not carried out within the proposed time for 2 consecutive actions, we considered it as muscle failure, and therefore the set was terminated.

Statistical analysis

To assess the differential effects of G2S and G4S on strength and hypertrophy, all data were imported to R (version 3.5.0) for analyses [21]. For each outcome variable, linear mixed-effects models were fit using restricted maximum likelihood [22, 23]. In each model, the post-intervention score was the outcome measure (y_{ij}); condition (dummy coded such that G2S = 0 and G4S = 1) and pre-intervention scores were predictors ($x_{ij}^{condition}$ and x_{ij}^{pre}, respectively); and subjects received varied intercepts to control for interindividual differences, giving rise to the final linear mixed-effects model:

$$y_{ij} = \beta_0 + \beta_1 x_{ij}^{pre} + \beta_2 x_{ij}^{condition} + \varepsilon_{ij} + r_{0j},$$

where β_2, the effect of condition, is the effect of interest. The inclusion of pre-intervention scores controlled for regression to the mean and the varied, subject-specific intercepts (r_{0j}) ensured that all comparisons were within-subject. Ninety-five percent confidence intervals (CI) for condition effects were calculated using the bootstrap method (1,000 simulations).

Because the residuals were not normally distributed for all models, *p*-values were calculated using exact permutation testing. To this end, each pair of group assignments (i.e., within a single participant) were switched, for a total of 2^{10} = 1024 permutations. Following each permutation, the permuted effect of condition was obtained to build the permutation (or null) distribution. In other words, this procedure allowed for the creation of a null distribution, to which our data could be compared, and from which a *z*-score and *p*-value could be computed.

Hedges' *g* effect sizes were calculated by dividing the condition effect by the pre-pooled SD (SD_{pooled}^{pre}), which was calculated using the sample variances ($var = SD^2$) from the pre-intervention scores for each condition:

$$SD_{pooled}^{pre} = \sqrt{\frac{var_{con}^{pre} + var_{exp}^{pre}}{2}},$$

and multiplying the outcome by:

$$\frac{\Gamma\left({}^{df}/_{2}\right)}{\sqrt{{}^{df}/_{2}}\,\Gamma\left({}^{df-1}/_{2}\right)} \quad [24],$$

where *df* is the Satterthwaite-estimated degrees of freedom [23] and (x) is the gamma function. Hedges' *g* was interpreted in accordance with Batterham and Hopkins [25]: trivial, $0 \leq g < 0.2$; small, $0.2 \leq g < 0.6$; moderate, $0.6 \leq g < 1.2$; and high, > 1.2.

To avoid the dichotomous interpretation of study results, we did not set an*a priori* alpha, and did not employ the null hypothesis significance testing paradigm. Rather, evidence for or against an effect was judged on a continuum, taking into account not only the data, but also prior evidence, plausibility, theory, and other factors [26].

RESULTS

Raw pre- and post-intervention scores can be found in Table 1. On average, small effects were observed between G2S and G4S for all hypertrophy outcomes (Table 2). These effects were highly variable in all muscles and similar between conditions, except for the vastus medialis which favored the G4S condition (Table 2). Conversely, only a trivial and highly variable effect was observed between interventions for strength gain (Table 2). TUT across the study period was greater for G4S compared to G2S (2535.6 ± 654 seconds versus 1300.6 ± 357 seconds, respectively). However, the total number of repetitions (633.9 ± 163.4 versus 650.3 ± 178.4) was relatively similar between groups (Table 3).

DISCUSSION

The present study showed that the slower phase of movement during the eccentric portion of training promoted greater increases in MT of the vastus medialis, indicating that altering eccentric tempo

TABLE 1. Within-group pre- and post-intervention measures.

Outcome	G2S			G4S		
	Pre	Post	Change	Pre	Post	Change
Summed muscles (mm)	50.96 ± 5.36	59.63 ± 6.27	8.66 ± 3.81	49.16 ± 6.34	59.81 ± 8.68	10.65 ± 5.44
Rectus femoris (mm)	19.55 ± 1.93	21.57 ± 3.12	2.02 ± 2.10	19.06 ± 3.50	21.90 ± 3.98	2.84 ± 2.37
Vastus lateralis (mm)	15.67 ± 4.43	19.95 ± 3.29	4.28 ± 2.81	14.82 ± 4.25	18.35 ± 4.20	3.53 ± 2.86
Vastus medialis (mm)	15.74 ± 3.49	18.11 ± 4.2	2.37 ± 1.42	15.28 ± 4.00	19.56 ± 4.11	4.29 ± 1.97
Strength (kg)	56.40 ± 14.66	65.8 ± 14.12	9.40 ± 5.40	56.00 ± 16.80	65.40 ± 16.06	9.40 ± 9.79

All measures are mean ± SD.

TABLE 2. Between-group strength and hypertrophy analyses.

Outcome	Effect (95% CI)	z-score	p-value	Hedges' g	Interpretation
Summed muscles (mm)	1.87 (-2.07 – 6.11)	0.83	0.513	0.28	Small
Rectus femoris (mm)	0.81 (-0.41 – 2.03)	1.17	0.267	0.26	Small
Vastus lateralis (mm)	-1.05 (-3.02 – 1.01)	-0.98	0.355	-0.22	Small
Vastus medialis (mm)	1.93 (0.53 – 3.37)	2.00	0.018	0.47	Small
Strength (kg)	-0.26 (-2.22 – 1.76)	-0.24	0.790	-0.01	Trivial

Effects are the pre-intervention adjusted effect of condition, wherein positive suggests an effect in favor of the G4S condition, and negative suggests an effect in favor of the G2S condition.

TABLE 3. Between-group time under tension and number of repetitions analyses.

Outcome	p-value	Hedges' g	Interpretation
Time under tension	0.001	2.23 (1.08–3.53)	High
Number of repetitions	0.75	0.10 (-0.52–0.72)	Trivial

The positive effect size suggests an effect in favor of the G4S condition, and negative suggests an effect in favor of the G2S condition.

may influence regional muscular hypertrophy of the quadriceps femoris. However, eccentric durations of 2 and 4 seconds have similar overall effects on improvements in lower limb muscle mass and strength in untrained young men.

Consistent with the findings of a recent meta-analysis by Davies et al. [27] that was not specific to type of muscle action, we found similar strength gains irrespective of eccentric tempo. A possible explanation for this finding is that the total number of repetitions (volume) was similar between groups, which may have greater relevance for enhancing strength than TUT. Alternatively, our findings are in contrast to previous work by Assis-Pereira et al [14] who showed a 4-second eccentric tempo produced superior increases for strength in trained men compared with 1 a second eccentric tempo. Moreover, our findings conflict with those of Shibata et al [15], who reported greater strength gains in the back squat with a 2 versus 4 second eccentric tempo. Although the reasons for inconsistencies between studies are not readily apparent, we speculate that several factors may have contributed to discrepancies in results. Specifically, the study by Assis-Pereira et al [14] was carried out using upper limb exercise (biceps brachii) in individuals with previous RT experience, whereas the present study employed lower limb exercise in untrained subjects. Moreover, the greater hypertrophy achieved in the slower eccentric condition in Assis-Pereira et al [14] may have helped to promote greater strength adaptations, given the well-established association between the two variables [28]. With respect to Shibata et al, testing was carried out using a multi-joint lower body exercise (squat) whereas our protocol employed single-joint 1RM testing (leg extension). Both the Assis-Pereira et al [14] and Shibata et al. [15] studies employed a parallel group design, whereas our study used a within-subject protocol, which has the advantage of decreasing the extent of between-participant variability and thereby increasing statistical power [29]. How these variances between studies, or perhaps other unknown factors, differentially affected strength outcomes remains unclear.

Both conditions significantly increased 1RM strength, which, given the untrained status of participants, was likely resultant to an improved neural drive and heightened intramuscular coordination [30]. Although hypertrophy occurs during the early stages of a RT program, it does not appear to have a great contribution to strength improvement during this time period [8]. The higher TUT promoted by a 4-second eccentric tempo ($P < 0.001$) promotes greater mechanical stress than 2 seconds. We speculated that the greater mechanical stress could lead to improved strength since neural adaptations are dependent on this stimulus [30]. This hypothesis was refuted as both eccentric tempos induced equivalent strength gains in a relatively short-term RT program (8-weeks).

With respect to hypertrophy, we found no differences in the pooled response of MT for the quadriceps femoris. These findings contrast with those of Assis-Pereira et al. [14], who showed greater increases in biceps brachii cross sectional area when employing a 4 versus 1 second eccentric tempo. Given previous work showing a longer TUT positively influences the muscle protein synthetic response to RT [13], we had hypothesized that the greater TUT in the slower tempo condition would favor muscle growth; this hypothesis was refuted. Our results are consistent with those of Shibata et al [15], who found similar changes in muscle cross sectional area of the thigh musculature when training with 2 versus 4 second eccentric tempos in the back squat performed twice a week for 6 weeks using 3 sets at 75% 1RM weight to momentary failure. Although we did not attempt to investigate mechanisms of action, it can be speculated that the greater hypertrophy for the slower tempo condition in the study by Assis-Pereira et al. [14] may have been due to the fact that the 1-second tempo employed in that study may not have allowed the muscles enough time to actively resist gravity on the eccentric actions, conceivably causing an impaired adaptive response compared to the 4-second eccentric tempo via a reduction in mechanical tension [31]. In contrast, the 2-second tempo used in the present study seemingly was sufficient for the target muscles to resist gravity and cause an equally robust hypertrophic stimulus to the 4-second eccentric tempo. Thus, it is possible that eccentric duration of 2 seconds is adequate to ensure that the muscles work sufficiently against gravity to promote a maximal hypertrophic response and obviate the need for a slower eccentric duration in the quadriceps femoris [27].

Intriguingly, while the hypertrophic response was similar between groups for vastus lateralis and rectus femoris, the vastus medialis displayed somewhat greater gains in muscle mass for G4S compared to G2S. Nonuniform hypertrophy is a phenomenon whereby different regions of a particular muscle respond distinctly to different exercises [32]. Differential nonuniform hypertrophic responses have been shown intramuscularly in the vastus lateralis when using eccentric versus concentric actions [33], and intermuscularly across the different heads of the quadriceps femoris when employing variations in exercise selection [1]. However, to the best of our knowledge, no study has shown such regional hypertrophic differences from variations in RT tempo. The reasons for this phenomenon are unclear, and require further study to elucidate the underlying explanatory mechanisms. From a practical standpoint, our findings indicate that practitioners and coaches should consider employing different eccentric tempos to optimize muscle-specific hypertrophy. It should be emphasized that these results are specific to novice exercisers and may not be applicable to those experienced in RT. That said, the overall magnitude of effect was relatively modest (Hedges' g = 0.47), calling into question the practical meaningfulness of the finding.

Our study had some limitations that must be acknowledged. First, the within-subject design can be considered a strength since it substantially reduces biological variability and thus provides greater statistical power to detect differences and draw practical inferences. However, a cross education effect has been noted in the literature whereby training one limb results in an increased ability to produce force in the contralateral limb [34]. Thus, we cannot rule out that such an effect did not confound the strength results in our study. Second, we assessed 1RM strength only on the concentric portion of the repetition. Thus, we cannot necessarily infer how results would transfer to maximal eccentric force capacity [35,36]. Third, although subjects were instructed to adhere to their usual and customary diets, we did not monitor nutritional status across the study period. It is therefore possible that nutritional alterations may have confounded results, although this would seem unlikely given the within-subject design. Finally, our findings are specific to young, untrained individuals and thus cannot necessarily be extrapolated to adolescents, the elderly, and those who regularly engage in RT.

CONCLUSIONS

We conclude that both a 2 second and 4 second eccentric duration promote similar improvements in whole muscle hypertrophy and strength of the lower limbs. The greater TUT in G4 was not a key modulator in altering general muscular adaptations. The slower eccentric duration showed a beneficial effect on hypertrophy of the vastus medialis muscle, indicating that varying eccentric duration may help to promote favorable muscle growth in this aspect of the quadriceps femoris.

Declaration of Interests

The authors declare no conflicts of interest with this manuscript.

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