

# Effects of resistance training on hypertrophy, strength and tensiomyography parameters of elbow flexors: role of eccentric phase duration

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**ABSTRACT:** The aim of the study was to compare the effects of two different training protocols, which differ in the duration of the eccentric phase, on the one-repetition maximum (1RM), thickness and contractile properties of elbow flexors. Twenty untrained college students were randomly divided into two experimental groups, based on the training tempo: FEG (Faster Eccentric Group: 1/0/1/0) and SEG (Slower Eccentric Group: 4/0/1/0). Training intervention was a biceps bending exercise, conducted twice a week for 7 weeks. The intensity (60–70% RM), sets (3–4) and rest intervals (120 s) were held constant, while repetitions were performed until it was not possible to maintain a set duration. In the initial and final measurements, 1RM, muscle thickness and tensiomyography parameters – contraction time (Tc) and radial deformation (Dm) – were evaluated. An ANCOVA model (using baseline outcomes as covariates) was applied to determine between-group differences at post-test, while Pearson's product-moment correlation coefficient was used to investigate the relationship between absolute changes in muscle thickness and Dm. Muscle strength increase was greater for SEG than for FEG ( $6.0 \pm 1.76$  vs.  $3.30 \pm 2.26$  kg,  $p < 0.01$ ). In both groups muscle thickness increased equally (FEG:  $3.24 \pm 2.01$  vs. SEG:  $3.57 \pm 1.17$  mm,  $p < 0.01$ ), while an overall reduction in Dm was observed (FEG:  $1.99 \pm 1.20$  vs. SEG:  $2.26 \pm 1.03$  mm,  $p < 0.01$ ). Values of Tc remained unchanged. A significant negative relationship was observed between changes in muscle thickness and Dm ( $r = -0.763$ ,  $\text{Adj.}R^2 = 0.560$ ,  $p < 0.01$ ). These results indicate that the duration of the eccentric phase has no effect on muscle hypertrophy in untrained subjects, but that slower eccentric movement significantly increases 1RM.

**CITATION:** Kojić F, Ranisavljev I, Ćosić D. Effects of resistance training on hypertrophy, strength and tensiomyography parameters of elbow flexors: role of eccentric phase duration. *Biol Sport.* 2021;38(4):587–594.

Received: 2020-06-13; Reviewed: 2020-07-19; Re-submitted: 2020-08-04; Accepted: 2020-08-31; Published: 2021-01-14.

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**Key words:**

Training tempo

Muscle thickness

Muscle stiffness

1RM

Tensiomyography

## INTRODUCTION

Isotonic resistance training has been widely applied in sport and exercise. Design of resistance training programmes depends on numerous training variables, such as intensity, volume, time under tension (TUT), repetition duration (tempo), etc. [1]. Some researchers indicate that manipulation of tempo and TUT variables can produce different morphological and contractile adaptation of skeletal muscle [2,3].

The tempo (or repetition duration), represented as the ratio between phases of the movement in seconds (eccentric [s] / isometric [s] / concentric [s] / isometric [s]), is directly related to the TUT [4,5]. Considering that muscle can resist 20-60% more force in the eccentric phase compared to the concentric [6], there are certain assumptions that increasing the eccentric load or longer duration in

the eccentric phase can induce greater muscle growth and strength development [7, 8]. Longer TUT significantly affects protein synthesis and muscle hypertrophy [9,10], and slower eccentric contractions (3-6 s) leads to the emergence of metabolic stress indicators [8,11,12], which are one of the major mechanisms in muscle growth [7]. Previous research indicates that low load, super slow training (>10 s per repetitions) is inferior from a hypertrophy standpoint [4,13] and that fast ( $\leq 2$  s) and medium (or moderate) slow (3-5 s) eccentric contractions seem to be optimal for muscle grow and strength gains [4,14]. Tanimoto et al. [2] found that there were no significant differences in whole-body muscle thickness and 1RM strength, between medium slow (3/0/3/0; 55-60%; 8RM) and fast (1/1/1/1; 80-90% 1RM; 8RM) movement tempo, when whole-

body resistance training (3 sets; twice per week; 13 weeks) was applied. However, in a study by Nogueira et al. [15], training (40–60% RM; 3 sets x 8 reps; twice per week; 10 weeks) with medium slow eccentric and fast concentric movement (3/0/1/0) produced greater increases in muscle thickness, compared to tempo with equal durations of eccentric and concentric phases (3/0/3/0). Longer eccentric duration combined with fast concentric (4/0/1/0) resulted in significantly higher hypertrophy and strength gains, compared to faster (1/0/1/0), when repetitions were performed until muscle failure (3 sets x 8 RM; twice per week; 12 weeks) [16]. However, when faster (2/0/2/0) and slower (4/0/2/0) contractions were identical by total work [17,18] or TUT [19] the effects were equal. Recent studies detected muscle failure as the most potent stimulus for hypertrophy, regardless of the load size [1,20,21]. From such a perspective, Pereira et al. [16] showed that longer durations of the eccentric phase appear to be superior for gaining muscle mass and developing strength in biceps brachii muscle (BB) in well-trained men.

In recent years there has been growing interest in involuntary muscle contractions produced by tensiomyography (TMG) and examination of contraction time [Tc] and radial deformation [Dm] in function of muscle adaptive changes. The studies related to these topics are still limited [22], but it has been shown that reduced Dm could be an indicator of muscle stiffness, damage and fatigue [22–24]. Tc has been correlated with fibre type proportions, where lower values of Tc are linked with slow twitch muscle fibres [22,25]. Higher Dm values have been associated with muscle atrophy [26], while lower Dm values indicated muscle hypertrophy after exposure to longer TUT training [27].

Davies et al. [14] concluded that fast and moderately slow repetitions produce similar gains in muscle strength. However, in the mentioned meta-analysis, most of the included studies used either equal duration of eccentric and concentric phases or only the concentric phase was manipulated, and there is a paucity of data showing how 1RM is affected by eccentric phase duration. Based on the current literature, the influence of eccentric phase duration on muscle growth, strength increase and TMG changes on untrained subjects is still poorly specified. Therefore, the aims of the study were: i) to explore the influence of eccentric phase tempo on strength, hypertrophy, and TMG parameters of elbow flexors; and ii) to determine possible relations between TMG parameters and accompanying size changes within BB. We hypothesized that: (1) slower eccentric contractions, compared to faster, would contribute greater strength and hypertrophy gains of BB; (2) muscle stiffness would be greater following slower tempo, compared to faster, and (3) there would be a significant correlation between changes in muscle size and the Dm parameter.

## MATERIALS AND METHODS

### *Experimental design*

The subjects were assigned to two experimental groups, based on the duration of the eccentric muscle contraction in resistance train-

ing: the Faster Eccentric Group (FEG) and the Slower Eccentric Group (SEG). The training intervention was performed twice per week for a 7-week period. Muscle size, muscle strength and TMG parameters were determined before and after the training intervention. The number of repetitions, training volume (number of repetitions x number of series), and TUT were recorded after the first session of the training intervention for both groups.

### *Subjects*

Twenty-four students (12 females and 12 males), without resistance training experience, volunteered to participate in this study. Prior to testing, the subjects were randomly divided into two experimental groups, based on the training tempo: FEG (Faster Eccentric Group: 1 second concentric, 1 second eccentric phase) and SEG (Slower Eccentric Group: 4 seconds eccentric, 1 second concentric phase). Four participants were excluded (3 females and 1 male), due to failing to complete all training sessions. The final sample included 20 volunteers (11 men and 9 women, age:  $24.1 \pm 1.7$  years, height:  $1.75 \pm 0.08$  m, weight:  $70.4 \pm 12.3$  kg) who successfully completed the experimental protocol. Body height was taken using a portable Martin's anthropometer (Siber-Hegner, Switzerland), with 0.1 cm accuracy. Body composition variables were measured with an InBody720 analyser (Biospace Co., Seoul, Korea) using Direct Segmental Multi frequency–Bioelectrical Impedance Analysis (DSM–BIA method).

Participants were healthy, without a history of upper body musculoskeletal injuries. All participants were fully informed about the experimental procedures and potential risks and they signed written informed consent prior to participation in the study. During the experimental period, the subjects were advised to stick to the usual diet and to avoid the use of supplementation. The study was approved by the Institutional Ethics Committee and performed in accordance with the Declaration of Helsinki.

### *1RM test*

Muscle strength (one repetition maximum – 1RM) was assessed by the elbow flexion test on a Scott bench according to the standard procedure [28]. Subjects were advised to avoid any form of physical activity for a minimum of 48 hours prior to testing. The test was preceded by a 10-minute warm-up (light running and warm-up exercises) followed by 8–10 repetitions of exercise with a load of ~50% RM and 2–3 repetitions of exercise with a load of 60–80% RM. Each subject had 5 attempts to lift the maximum weight. The pauses between trials were set at 3 minutes [20]. Pre-test and post-test were conducted 2 days before and 2 days after the training intervention, respectively.

The exercise was performed using a curling (EZ) bar, in a supination position, with a full range of movement. Subjects were in the sitting position, with the axillae and back of the arms resting on the pad. The height of the bench was adjusted for each subject so the trunk was straight and both feet were on the floor.

*Muscle thickness*

All measurements were performed in the sitting position, holding the dominant arm supinated and extended with arm muscles relaxed. The BB thickness was measured at two-thirds of the distance from the acromion to the antecubital crease using ultrasound with a high-resolution linear-array transducer (Siemens Antares, Erlangen, Germany), with variable high frequency (from 7 MHz to 13 MHz). The transducer was held vertically with minimal pressure against the skin and water-soluble transmission gel was used between the transducer and the skin to ensure optimal image quality. All the measurements were performed by the same specialized musculoskeletal radiologist. The muscle thickness included the distance (mm) from the superficial to deep fascia layers [29] and the average distance of the two measurements was used for statistical analysis. Ultrasound diagnostics was conducted 2 days before and after the experimental intervention. To determine the repeatability of the ultrasound measurement, test-retest was conducted on ten participants on two separate days.

*Tensiomyography measurements*

The contractile properties of BB muscle were evaluated by tensiomyography according to the manufacturer's instructions (TMG-BMC, Ljubljana, Slovenia). The values of contraction time (Tc) and radial deformation (Dm) were taken for analysis. Testing of these parameters was conducted 5 days before and after the experiment [25]. During testing subjects were in a sitting position with the dominant arm bent at 90°. The tested arm was placed on a support, to ensure a neutral shoulder position during testing [23,24]. Subjects were asked to perform a voluntary contraction, in order to mark the point of placement of the TMG sensor by the palpation method [24]. Two self-adhesive electrodes (Pals Platinum, model 895220 with multi-stick gel, Axelgaard Manufacturing Co. Ltd) were placed proximal and distal at 3 cm from the marked point, emitting an electrical impulse. A sensor (GK40, Panoptik, Ljubljana, Slovenia) was placed

between the electrodes to detect muscle changes initiated by electrical stimulation. The initial impulse was 25 mA and it increased proportionally by 10 mA, until the maximum (muscle no longer responds to electrical stimulus). The pause between the pulses was 10 seconds, to allow the muscle enough time to relax [23]. The two best results were preserved and software calculated the mean [25]. Both TMG (pre-test-post-test) tests were conducted in the morning and by the same experienced specialist. Also, to determine the repeatability of the TMG measurement, test-retest was conducted on ten participants on two separate days.

*Experimental training intervention*

The training intervention was preceded by a 2-week familiarization period [2]. The difference in training protocols was in the duration of the eccentric phase – 1/0/1/0 (FEG) and 4/0/1/0 (SEG). Both experimental groups performed a biceps curl exercise on a Scott bench (Scott Bench-PA06, TechnoGym), with a minimum 48 h rest between sessions on the same days during the week. All sessions were performed at the same time (13-15 h), controlled by the same experienced examiner. In the first week of training intervention, the number of repetitions and TUTs for each group were recorded. For both groups, the duration of each repetition was controlled by an audio metronome (DB-90, Boss). The intensity of load (1RM%) and number of sets were as follows: in the first three weeks the subjects performed biceps curl exercise with ~60% of 1RM in 3 sets, while during the next four weeks the exercise load was set at ~70% of 1RM in 4 sets. All repetitions were performed until failure. The pause between sets was 2 minutes.

*Statistical analysis*

Statistical analysis was processed using the IBM SPSS Statistics software package (Version 20, SPSS Inc, Chicago, IL, USA). Test-retest repeatability for ultrasound and TMG measurement were assessed using the intra-class correlation coefficient (ICC). Prior to

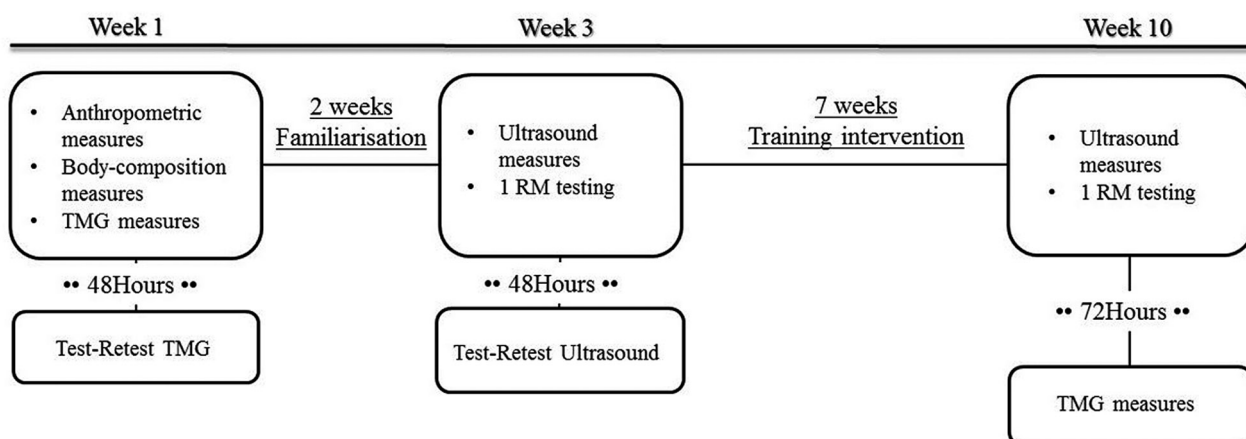


FIG. 1. Experimental protocol 1RM - one repetition maximum, TMG - tensiomyography

analysis data were checked for normality and that the relevant assumptions for each test were met. The Shapiro-Wilk test was used to evaluate the normality of the distribution. Between-group differences at baseline were tested using the independent t-test. Homogeneity of variances and homogeneity of regression slopes were tested by Levene's test and by interaction between covariate and independent variable, respectively.

Differences in the number of repetitions of each series, training volume, and the TUT between the FEG and SEG were determined by the independent t-test. Effect sizes (ES) were determined using G-power software (University of Kiel, Kiel, Germany, version 3.1), based on the recommendations proposed by Rhea et al. [30] for untrained individuals; ES were considered as: trivial: <0.50, small: 0.50-1.25, moderate: 1.25-1.90 and large: >2.0. One-way ANCOVA (using baseline values as covariates) was used to examine differences in the tested variables, between the FEG and SEG. If ANCOVA showed statistical significance, the Bonferroni post-hoc test was used for further estimation of differences between groups. ES were determined using G-power software through partial eta squared obtained from the ANCOVA. Additionally, using gender as a between-group factor and baseline values as covariates, ANCOVA was used to determine possible differences between males and females in BB thickness change, 1RM and TMG parameters. Pearson's correlation coefficient was used to examine the association of pre-to-post changes ( $\Delta$ ) for Dm and thickness BB. All data are presented by means  $\pm$  SD.  $p \leq 0.05$  was taken as a statistically significant determinant.

## RESULTS

Both measurement techniques showed excellent reliability (ultrasound: ICC = 0.997, CI = 0.986–0.999,  $p < 0.01$ ; TMG parameters Tc: ICC = 0.928, CI = 0.713–0.982,  $p < 0.01$  and Dm: ICC = 0.951, CI = 0.804–0.988,  $p < 0.01$ ). Sample characteristics, including age and body composition, for each group are presented in Table 1 (all  $p > 0.05$ ).

**TABLE 1.** Sample characteristics

	FEG	SEG
Age(years)	24.5 $\pm$ 2.2	23.6 $\pm$ 0.92
BH (m)	1.78 $\pm$ 0.07	1.72 $\pm$ 0.08
BM (kg)	72.2 $\pm$ 13.52	68.6 $\pm$ 11.61
BMI (kg/m <sup>2</sup> )	22.6 $\pm$ 2.61	22.9 $\pm$ 1.99
SMM (kg)	34.29 $\pm$ 7.52	32.16 $\pm$ 7.67
PBF (%)	15.34 $\pm$ 6.61	17.62 $\pm$ 7.98

BH – body height; BM-body mass; BMI-body mass index; SMM-skeletal muscle mass, PBF-percent of body fat.

**TABLE 2.** Training volume and time under tension

	FEG	SEG
I SET (reps)	14.2 $\pm$ 2.3	12.1 $\pm$ 2.6
II SET (reps)	13.2 $\pm$ 2.4**	9.7 $\pm$ 2.2
III SET (reps)	10.9 $\pm$ 2.2*	8.2 $\pm$ 2.0
VOLUME (sets x reps)	38.4 $\pm$ 5.1**	30.1 $\pm$ 6.3
TUT(s)	76.7 $\pm$ 10.1	150.6 $\pm$ 31.5**

\* – indicates a significant difference between FEG and SEG ( $p < 0.05$ ); \*\*-indicates a significant difference between FEG and SEG ( $p < 0.01$ ).

### Training volume and TUT

FEG achieved a higher training volume ( $8.25 \pm 2.87$ ,  $p < 0.01$ ). In the second and third set, the number of repetitions was significantly higher in favour of the FEG ( $3.5 \pm 1.12$  reps,  $p < 0.01$  and  $2.63 \pm 1.06$  reps,  $p < 0.05$ , respectively). Conversely, TUT was significantly higher in the SEG ( $73.88 \pm 11.72$  s,  $p < 0.01$ ) (Table 2).

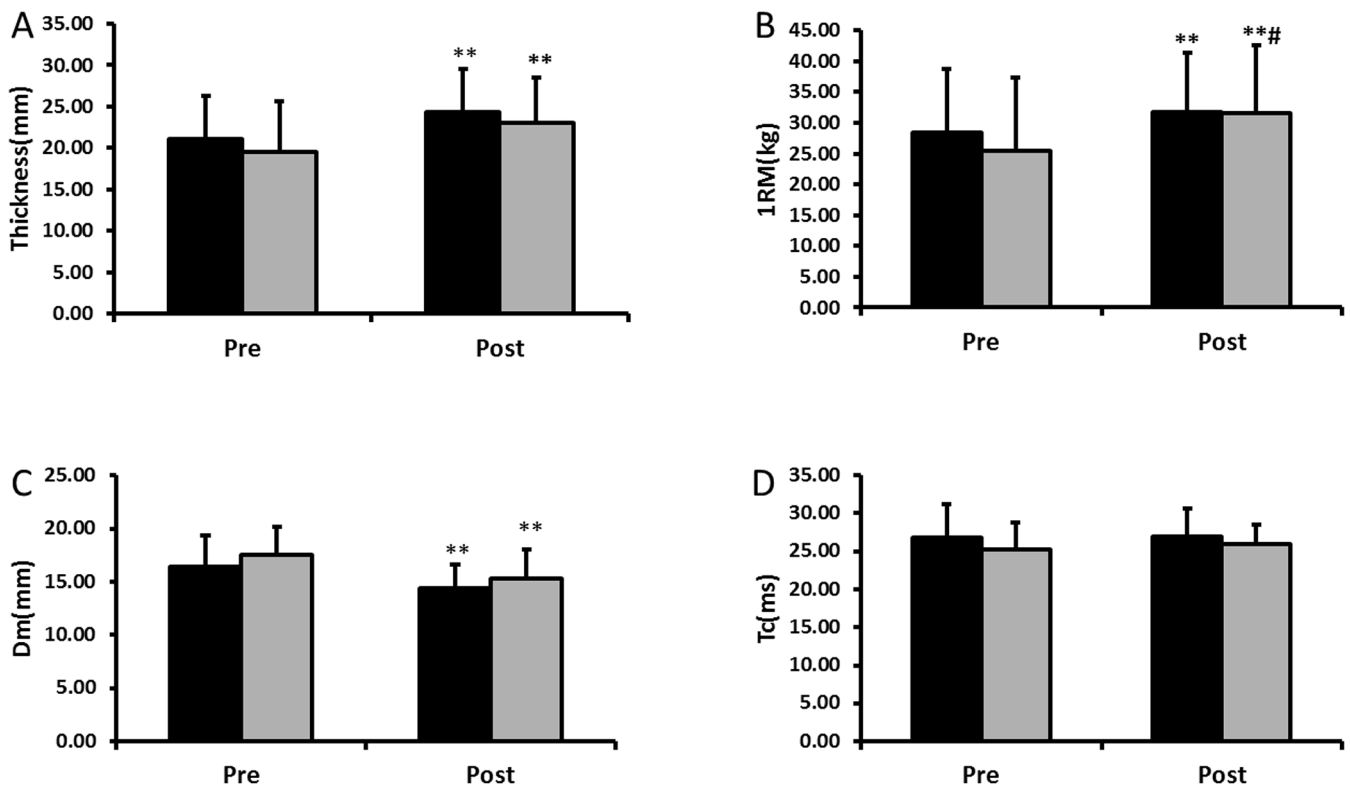
### Biceps brachii thickness, 1RM and TMG variables

There were no significant baseline differences, between FEG and SEG, for BB thickness ( $p = 0.556$ ), 1RM ( $p = 0.569$ ), or TMG parameters – Dm ( $p = 0.390$ ) and Tc ( $p = 0.418$ ). Both males and females demonstrated similar pre-to-post changes, without gender differences in 1RM ( $F[1,17] = 1.787$ ,  $p = 0.199$ , ES = 0.32), BB thickness ( $F[1,17] = 2.509$ ,  $p = 0.132$ , ES = 0.38) or TMG parameters Dm ( $F[1,17] = 0.246$ ,  $p = 0.626$ , ES = 0.12) and Tc ( $F[1,17] = 0.180$ ,  $p = 0.677$ , ES = 0.10).

FEG and SEG had significantly increased BB thickness relative to pre-test by 15.4% ( $3.24 \pm 2.01$  mm,  $p < 0.01$ , ES = 1.61) and 18.3% ( $3.57 \pm 1.17$  mm,  $p < 0.01$ , ES = 3.03), respectively. No significant between-group differences were observed at post-test ( $F[1,17] = 0.05$ ,  $p = 0.825$ , ES = 0.17) (Figure 2A).

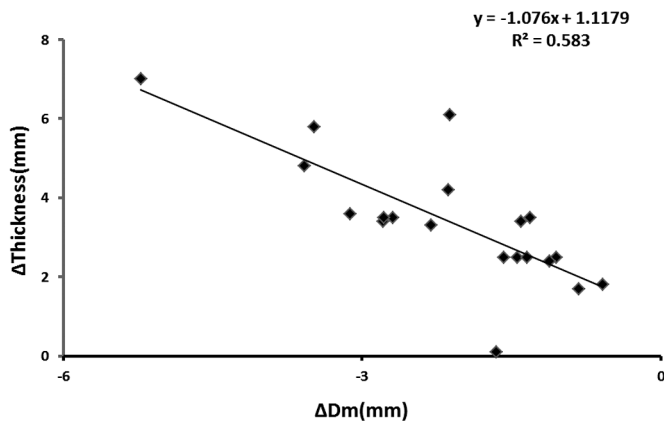
In both groups the 1RM significantly increased, by 11.6% ( $3.30 \pm 2.26$  kg,  $p < 0.01$ , ES = 1.45) and 23.5% ( $6.00 \pm 1.76$  kg,  $p < 0.01$ , ES = 3.33), respectively. One-repetition maximum had a greater increase in SEG compared to FEG ( $F[1,17] = 8.60$ ,  $p < 0.01$ , ES = 0.71) (Figure 2B). In both groups there was a significant decrease in the Dm values by 12.1% ( $1.99 \pm 1.20$  mm,  $p < 0.01$ , ES = 1.54) and 12.8% ( $2.26 \pm 1.03$  mm,  $p < 0.01$ , ES = 2.15), without a difference between groups ( $F[1,17] = 0.01$ ,  $p = 0.912$ , ES = 0.10) (Figure 2C). There were no significant pre-to-post-test changes for Tc values in either group ( $p = 0.780$  and  $p = 0.501$ ) (Figure 2D).

There was a significant negative correlation between absolute differences in initial and final measurements for the variables  $\Delta$ Muscle thickness and  $\Delta$ Dm ( $r = -0.763$ , Adj.  $R^2 = 0.560$ ,  $p < 0.01$ ) (Figure 3).



**FIG. 2.** Pre-to-post intervention changes in BB muscle size (A– thickness), strength (B – 1RM) and TMG parameters (C – radial displacement – Dm and D – contraction time – Tc) for FEG (black fill) and SEG (grey fill).

\*\* Significantly greater than pre-training ( $p < 0.01$ ); # Significantly greater than corresponding group ( $p < 0.01$ ).



**FIG. 3.** Correlation for absolute changes ( $\Delta$ ) of BB muscle thickness and radial displacement between pre- and post-test.

**DISCUSSION**

The purpose of the study was to compare the muscle morphological and contractile adaptations induced by two resistance training tempos, in untrained men and women. While there are a few other studies that have investigated the effects of eccentric phase duration

on hypertrophy and 1RM, to the best of our knowledge, this is the first study to include contractile properties of elbow flexors. The main results indicate that medium slow eccentric tempo produced significantly larger 1RM strength gains, while both tempos had an equal effect on hypertrophy of muscle BB. A similar decrease in Dm values was observed after both training protocols. Also, increased muscle thickness was accompanied with reduced Dm values.

Weight training conducted twice a week led to significant muscle hypertrophy in both experimental groups. The present findings support the results of previous studies showing that training twice per week is a sufficient stimulus for significant muscle hypertrophy [19,31]. Also, both males and females demonstrated similar gains in muscle size and strength, which is in accordance with previous reports that there are no gender differences in muscle adaptations during the initial weeks of resistance training [32].

In the present study, both groups showed a significant increase in BB thickness from pre-test, whereas ANCOVA revealed no differences between groups. In contrast, Pereira et al. [16] reported that a slower tempo (4/0/1/0) caused greater hypertrophy than faster (1/0/1/0) in trained subjects with 8 maximum repetitions per sets and equal training volume (sets x reps). Wilk et al. [33] and Pryor et al. [34] reported that rapid eccentric contractions led to more efficient



use of elastic energy in the concentric phase, which resulted in more repetitions and higher training volume, which was also the case in our FEG. FEG produced higher training volume, but less TUT. The same group showed a greater increase of muscle thickness than strength, by ~15% and ~11%, respectively, which indicates that increased muscle mass was mainly by sarcoplasmic hypertrophy. This is in agreement with Haun *et al.* [35], who reported that muscle hypertrophy, in response to high volume resistance training, is largely attributable to sarcoplasmic hypertrophy. On the other hand, the SEG had significantly higher TUT, but this did not lead to greater biceps hypertrophy. The results of this study support the findings that the duration of the eccentric phase has no effect on muscle size [19], and that repetitions between 2 and 5 s, regardless of different duration of the eccentric phase, produce the same outcome for hypertrophy in novice subjects. Most of the participants stopped working due to their inability to maintain the set tempo in the concentric phase (1s). Such a situation leads to the conclusion that performing a repetition, until the moment when the velocity in the concentric phase decreases, is sufficient to cause muscular hypertrophy.

A slower tempo (4/0/1/0) caused a significant increase in 1RM, compared to a faster one (1/0/1/0). This finding differs from results obtained by Mike and coworkers [18], who reported that the increase in strength was not altered by manipulation of eccentric phase duration. Although they did not observe significant differences between faster and slower tempo, they found a greater increase in squat 1RM (13.2 vs. 8.8%) following medium slow (4/0/2/0) vs. fast (2/0/2/0) movement tempo, after 4 weeks of training. Apart from the dimensions and muscle architecture, the nervous system plays a significant role in strength performance and development in strength; in the first weeks of resistance training, it is presumably produced by adaptation in the central nervous system [36]. Furthermore, many authors suggest that the neural component has over 50% representation in the expression of 1RM [36,37]. Considering that a much larger increase in strength was observed after slower tempo resistance training, the assumption is that the longer duration of the eccentric phase contributed to greater neural involvement. Also, certain observations indicate that the response of the central component varies, depending on the velocity of contractions [38,39]. Thus, Kulig *et al.* [38] showed that during flexion in the elbow joint, slower eccentric contractions cause greater involvement of synergist muscles (*i.e.* brachialis). Since the fibres of the biceps brachii are oriented in parallel, and its predominant role is in faster movement [40], there is a high probability that during slower eccentric contractions, muscles activated for maintenance of the posture (pennate) have a greater involvement than during faster contractions. Unfortunately, we only monitored the characteristics of BB, and it is impossible to discuss whether a slower tempo caused additional involvement of other muscle groups.

Both experimental protocols elicited a decrease in BB Dm, regardless of the resistance training tempo. Earlier studies indicated that muscle stiffness increases after resistance [24,27] or plyometric training [25]. Paula-Simola *et al.* [27] reported that the largest changes

in Dm were observed immediately after training with increased TUT. In chronic terms, this is not the case, as we observed a decrease in the Dm parameter equally in both groups, and from these results we can conclude that resistance training leads to an increase in muscle stiffness, regardless of TUT. Absolute changes in BB radial displacement were negatively correlated with BB thickness changes. Pišot *et al.* [26] reported that higher values of the variable Dm can be used in the detection of muscle atrophy, following 35 days of bed rest. Also, Than *et al.* [41] investigated the influence of resistance exercise on BB muscle size and contractile properties, accessed by mechanomyography (MMG). Changes in muscle size and contractile properties were monitored during 8 weeks of training and 8 weeks of de-training. The authors concluded that changes in muscle size could be followed by the MMG method, specifically the parameter Dm. The present results show that the TMG method, as well, could be a useful tool for detecting upper limb changes in muscle size, produced by resistance training. However, more research is needed to confirm these results, especially for muscles with different architecture.

According to Wilk *et al.* [42], the % RM value should be determined based on the 1RM test trial at a specific movement tempo. They found that prolonging the eccentric phase has an inverse effect on performing the 1RM test and that bench press 1RM was about 5.8% lower during medium tempo (5 seconds eccentric phase) compared to fast (2 seconds eccentric phase). Given that in our experiment movement tempo was not controlled during 1RM testing, we cannot rule out that relative intensity in FEG was lower compared to SEG, which is the main limitation of the study. Although this could have some implications with elite athletes [39], we strongly believe that the difference of ~1.5 kg (5.8%) did not produce a sufficient stimulus to cause additional strength development and interfere with the study results. The other limitation refers to the absence of a control group and that the training volume and TUT were recorded only at the first training session. From the aspect of muscle hypertrophy, muscle thickness was determined at one measuring site. Considering the existence of regional hypertrophy along the length of the muscle [40], it is possible that growth of BB was non-uniform. We recommend that future studies be supplemented with data regarding muscle size in proximal, middle and distal regions. In addition, a recent review by Hackett *et al.* [21] hypothesized that resistance exercise tempo may elicit different morpho-functional muscle responses, depending on the architecture and composition of the muscle itself. Therefore, different (upper and lower body) muscle groups should be included in future studies to test this assumption.

The results of the present study promote the use of accentuated slower eccentric tempo during upper body movements for significant improvement of 1RM in both genders. Thus, we recommend that coaches use a longer eccentric phase duration to enhance greater muscle adaptations in strength when they apply resistance training to muscular failure. If the goal is muscle hypertrophy itself, duration of the eccentric phase has no significant effect on muscle growth in untrained individuals. In the real situation of resistance training in

fitness, probably both ways of training (1/0/1/0 and 4/0/1/0) would give good results in the first few months and then there would be stagnation in hypertrophy. Using the results of this study, we could prevent stagnation by periodically, at intervals of several months, alternating training where relatively fast repetitions are done (1/0/1/0), with training where eccentric contractions are medium slow (4/0/1/0). The TMG method is a sensitive and useful tool for monitoring resistance training effectiveness, and the parameter Dm could be used to detect upper limb changes in muscle size adaptation.

### CONCLUSIONS

In conclusion, a slower eccentric phase seems to be significantly better for 1RM improvement than the widespread 1 second tempo. Still, longer duration of the eccentric phase leads to higher TUT and

produces a smaller training volume, but this does not change the hypertrophic response of the biceps brachii muscle. Additionally, reduced Dm values after both protocols indicate an increase in muscle stiffness as a result of muscle size adaptation.

### Conflicts of interest

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

### Acknowledgments

The paper is a part of the project III47015, funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

### REFERENCES

- Baechle TR, Earle RW. Essentials of strength training and conditioning [3rd ed.]. Champaign, IL: Human Kinetics, 2008.
- Burd NA, Andrews RJ, West DWD, et al. Muscle time under tension during resistance exercise stimulates differential muscle protein sub-fractional synthetic responses in men. *J Physiol* 2012; 590:351–362.
- Calixto RD, Verenglia R, Crisp AH, et al. Acute effects of movement velocity on blood lactate and growth hormone responses after eccentric bench press exercise in resistance-trained men. *Biol Sport* 2014; 31:289–294.
- Cureton K, Collins M, Hill D, McElhannon F. Muscle hypertrophy in men and women. *Med Sci Sports Exerc* 1988; 20:338–344.
- Damas F, Barcelos S, Nobrega SR, et al. Individual muscle hypertrophy and strength responses to high vs. low resistance training frequencies. *J Strength Cond Res* 2019; 33:897–901.
- Davies TB, Kuang K, Orr R, Halaki M, Hackett D. Effect of movement velocity during resistance training on dynamic muscular strength: a systematic review and meta-analysis. *Sports Med* 2017. 47:1603–1617
- Dias CP, Toscan R, de Camargo M, et al. Effects of eccentric-focused and convectional resistance training on strength and functional capacity of older adults. *Age* 2015; 37:1–8.
- Ema R, Akagi R, Wakahara T, Kawakami Y. Training induced changes in architecture of human skeletal muscles: Current evidence and unresolved issues. *J Phys Fitness Sports Med* 2016; 5:37–46.
- Folland JP, Williams AG. Morphological and neurological contribution to increased strength. *Sports Med* 2007; 37:145–168.
- Garcia-Manso JM, Garcia-Matoso D, Sarmiento S. Effects of high load and high volume resistance exercise on tensiomyographic twitch response of biceps brachii. *J Electromyography Kines* 2012; 22:612–619.
- Gumucio JP, Sugg KB, Mendias CL. TGF- $\beta$  superfamily signaling in muscle and tendon adaptations to resistance exercise. *Exerc Sci Sport Rev* 2015; 43:93–99.
- Hackett DA, Davies TB, Orr R, Kuang K, Halaki M. Effect of movement velocity during resistance training on muscle specific hypertrophy: A systematic review. *Eur J Sport Sci* 2018; 18:473–482.
- Haun CT, Vann CG, Osburn SC, et al. Muscle fiber hypertrophy in response to 6 weeks of high-volume resistance training in trained young men is largely attributed to sarcoplasmic hypertrophy. *PLoS one* 2019; 14(6):1–22.
- Howe LP, Read P, Waldron M. Muscle hypertrophy: A narrative review on training principles for increasing muscle mass. *Strength Cond J* 2017; 39:72–81.
- Hunter AM, Galloway SDR, Smith IJ, et al. Assessment of eccentric exercise induced muscle damage of the elbow flexor by tensiomyography. *J Electromyography Kines* 2012; 22:334–341.
- Kulig K, Powers CM, Shellock FG, Terk M. The effects of eccentric velocity on activation of elbow flexors: evaluation by magnetic resonance imaging. *Med Sci Sports Exerc* 2001; 33:196–200.
- Macgregor LJ, Hunter AM, Orizio C, Fairweather MM, Ditriolo M. Assessment of skeletal muscle contractile properties by radial displacement: The case for tensiomyography. *Sports Med* 2018; 48:1607–1620.
- Mike JN, Cole N, Herrera C, VanDusseldorp T, Kravitz L, Kersick CM. The effect of eccentric contraction duration on muscle strength, power, vertical jump and soreness. *J Strength Cond Res* 2017; 31:773–786.
- Narici MV, Roi GS, Landoni L, Minetti CE, Cerretelli M. Changes in force, cross-sectional area and neural activation during strength training and detraining of human quadriceps. *Eur J Appl Physiol* 1989; 59:310–319.
- Nogueira W, Gentil P, Mello SN, Oliveira RJ, Bezerra, AJ, Bottaro M. Effects of power training on muscle thickness of older men. *Int J Sports Med* 2016; 30: 200–204.
- Paula-Simola RA, Harms N, Raeder C, et al. Assessment of neuromuscular function after different strength training protocols using tensiomyography. *J Strength Cond Res* 2015; 29:1339–1348.
- Pereira PEA, Motoyama YL, Esteves GJ, et al. Resistance training with slow speed of movement is better for muscle hypertrophy and strength gains than fast speed of movement. *Int J Appl Exerc Physiol* 2016; 5:37–43.
- Pišot R, Narici MV, Šimunič B, et al. Whole muscle contractile parameters and thickness loss during 35-day bed rest. *Eur J Appl Physiol* 2008; 104:409–414.
- Pryor RR, Sforzo GA, King DL. Optimizing power output by varying repetition tempo. *J Strength Cond Res* 2011; 25:3029–3034.
- Perkisas S, Baudry S, Bauer J, et al. Application of ultrasound for muscle assessment in sarcopenia: towards standardized measurements. *Eur Geriatric Med* 2018; 9:739–757.
- Ratamess NA, Alvar BA, Evetoch TA. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 2008; 41:687–708.

27. Rhea MR. Determining the magnitude of treatment effects in strength training research through the use of the effect size. *J Strength Cond Res* 2004; 18:918–920.
28. Schoenfeld BJ, Ogborn DI, Krieger JW. Effect of repetition duration during resistance training on muscle hypertrophy: A systematic review and meta-analysis. *Sports Med* 2015; 45:577–585.
29. Schoenfeld BJ, Peterson MD, Ogborn D, Contreras B, Sonmez GT. Effects of low-vs. high-load resistance training on muscle strength and hypertrophy in well-trained men. *J Strength Cond Res* 2015; 29:2954–2963.
30. Schoenfeld, BJ. The mechanism of muscle hypertrophy and their application to resistance training. *J Strength Cond Res* 2010; 24:2857–2872.
31. Schuenke MD, Herman JR, Gliders RM, et al. Early-phase muscular adaptations in response to slow-speed versus traditional resistance-training regimens. *Eur J Appl Physiol* 2012. 112:3585–3595
32. Sheikholeslami-Vatani D, Ahmadi D, Chehri B, Tadibi T. The effect of changes in concentric-eccentric contraction time ratio on hormonal response to resistance exercise in trained men. *Sci Sports* 2016; 33:164–168.
33. Shibata T, Tarizawa K, Nosaka K, Mizuno M. Effects of prolonging eccentric phase duration in parallel back-squat training to momentary failure on muscle cross-sectional area, squat one repetition maximum and performance tests in university soccer players. *J Strength Cond Res* 2018.
34. Tanimoto M, Sanada K, Yamamoto K, et al. Effects of whole-body low-intensity resistance training with slow-movement and tonic force generation on muscular size and strength in young men. *J Strength Cond Res* 2008; 22:1926–1938.
35. Tax AAM, van der Gom DJJ, Gielen CCAM, Kleyne M. Differences in central control of m. biceps brachii in movement task and force tasks. *Exp Brain Res* 1990; 79:138–142.
36. Than C, Tošović D, Seidl L, Brown JM. The effect of exercise hypertrophy and disuse atrophy on muscle contractile properties: a mechanomyographic analysis. *Eur J Appl Physiol* 2016; 116:2115–2165.
37. Usui S, Maeo S, Tayashiki K, Nakatani M, Kanehisa H. Low load slow movement squat training increases muscle size and strength but not power. *Int J Sports Med* 2016; 37:305–312.
38. Wilk M, Golas A, Krzystofik M, Nawrocka M, Zajec A. The effects of eccentric cadence on power and velocity of the bar during concentric phase of the bench press movement. *J Sport Sci Med* 2019; 18:191–197.
39. Wilk M, Golas A, Zmijewski P, et al. The effects of the movement tempo on the one-repetition maximum bench press results. *J Human Kin* 2020; 72:151–159
40. Wilk M, Stastny P, Golaš A, et al. Physiological responses to different neuromuscular movement tasks during eccentric bench press. *Neuroendocrin Lett* 2018; 39:26–32.
41. Wilk M, Tufano JJ, Zajac A. The influence of movement tempo on acute neuromuscular, hormonal and mechanical response to resistance exercise- A mini review. *J Strength Cond Res* 2020.
42. Zubac D, Šimunič B. Skeletal muscle contraction time and tone decrease after 8 week of plyometric training. *J Strength Cond Res* 2017; 31:1610–1619.