applied sciences

MDPI

Article

Acute Effects of Different Intensities during Bench Press Exercise on the Mechanical Properties of Triceps Brachii Long Head

Robert Trybulski [1,2], Grzegorz Wojdała [3], Dan Iulian Alexe [4], Zuzanna Komarek [5], Piotr Aschenbrenner [6], Michał Wilk [3], Adam Zając [3] and Michał Krzysztofik [3,*]

1 Provita Zory Medical Center, 44-240 Zory, Poland; rtrybulski@o2.pl
2 Department of Medical Sciences, The Wojciech Korfanty School of Economics, 40-659 Katowice, Poland
3 Institute of Sport Sciences, The Jerzy Kukuczka Academy of Physical Education in Katowice, 40-065 Katowice, Poland; g.wojdala@awf.katowice.pl (G.W.); m.wilk@awf.katowice.pl (M.W.); a.zajac@awf.katowice.pl (A.Z.)
4 Department of Physical Education and Sports Performance, Faculty of Movement, Sports and Health, Sciences, "Vasile Alecsandri" University of Bacau, 600115 Bacau, Romania; alexedaniulian@yahoo.com
5 Nutrition and Sports Performance Research Group, The Jerzy Kukuczka Academy of Physical Education in Katowice, 40-065 Katowice, Poland; 43680@awfkatowice.edu.pl
6 Faculty of Physical Education, Gdansk University of Physical Education and Sport, 80-336 Gdansk, Poland; piotr.aschenbrenner@awf.gda.pl
* Correspondence: m.krzysztofik@awf.katowice.pl

Abstract: This study aimed to analyze acute changes in the muscle mechanical properties of the triceps brachii long head after bench press exercise performed at different external loads and with different intensities of effort along with power performance. Ten resistance-trained males (age: 27.7 ± 3.7 yr, body mass: 90.1 ± 17.1 kg, height: 184 ± 4 cm; experience in resistance training: 5.8 ± 2.6 yr, relative one-repetition maximum (1RM) in the bench press: 1.23 ± 0.22 kg/body mass) performed two different testing conditions in a randomized order. During the experimental session, participants performed four successive sets of two repetitions of the bench press exercise at: 50, 70, and 90% 1RM, respectively, followed by a set at 70% 1RM performed until failure, with a 4 min rest interval between each set. Immediately before and after each set, muscle mechanical properties of the dominant limb triceps brachii long head were assessed via a Myoton device. To determine fatigue, peak and average barbell velocity were measured at 70% 1RM and at 70% 1RM until failure (only first and second repetition). In the control condition, only muscle mechanical properties at the same time points after the warm-up were assessed. The intraclass correlation coefficients indicated "poor" to "excellent" reliability for decrement, relaxation time, and creep. Therefore, these variables were excluded from further analysis. Three-way ANOVAs (2 groups $\times$ 2 times $\times$ 4 loads) indicated a statistically significant group $\times$ time interaction for muscle tone ($p = 0.008$). Post hoc tests revealed a statistically significant increase in muscle tone after 70% 1RM ($p = 0.034$; ES = 0.32) and 90% 1RM ($p = 0.011$; ES = 0.56). No significant changes were found for stiffness. The *t*-tests indicated a significant decrease in peak ($p = 0.001$; ES = 1.02) and average barbell velocity ($p = 0.008$; ES = 0.8) during the first two repetitions of a set at 70% 1RM until failure in comparison to the set at 70% 1RM. The results indicate that low-volume, high-load resistance exercise immediately increases muscle tone but not stiffness. Despite no significant changes in the mechanical properties of the muscle being registered simultaneously with a decrease in barbell velocity, there was a trend of increased muscle tone. Therefore, further studies with larger samples are required to verify whether muscle tone could be a sensitive marker to detect acute muscle fatigue.

Keywords: myotonometry; muscle fatigue; potentiation; muscle stiffness; performance

check for updates

Citation: Trybulski, R.; Wojdała, G.; Alexe, D.I.; Komarek, Z.; Aschenbrenner, P.; Wilk, M.; Zając, A.; Krzysztofik, M. Acute Effects of Different Intensities during Bench Press Exercise on the Mechanical Properties of Triceps Brachii Long Head. *Appl. Sci.* **2022**, *12*, 3197. https://doi.org/10.3390/app12063197

Academic Editor: Iori Sakakibara

Received: 1 March 2022
Accepted: 19 March 2022
Published: 21 March 2022

1. Introduction

Long-term adaptation to training is due to the cumulative effects of repeated single bouts of exercise. These single bouts of resistance exercise lead to acute physiological responses, which may be significant mediators of adaptation to the imposed stimuli [1]. The magnitude of these acute responses may be affected by several factors, such as the training variables (i.e., volume and intensity, exercise order) [2,3], as well as exercise type [4,5]. One of the basic exercises used to develop upper body strength and power is the bench press [6,7]. Seeking optimal power output adaptations, a range of 30–60% one-repetition maximum (1RM) has been suggested for the bench press exercise [8–10]. Nevertheless, power-oriented training should combine a wide range of loads to target the entire force–velocity curve properly. In addition, repetitions should be executed at maximum velocity until slight velocity losses of 10–20% to maintain the maximum power output production and to develop explosive performance optimally [11]. Hence, proper management of fatigue levels is necessary to avoid undesirable adaptive changes, such as those related to muscular endurance [12].

Although many studies have analyzed muscle electromyography [13–15], metabolic and endocrine changes [16–18] as indicators of fatigue arising during and after resistance exercise, there is less research investigating the impact of resistance exercise on the mechanical properties of muscle [19–21]. Non-invasive methods, such as tensiomyography and myotonometry, assess muscles' contractile and mechanical properties, respectively. However, it seems that tensiomyography has been used more often [19,20,22–25] than myotonometry [21,26], despite the fact that the device for myotonometry measurement (the Myoton) is more practical, being faster due to no electrical stimulation being needed, as is the case with tensiomyography (after electrode placement, the protocol consists of increasing intensity, i.e., five steps of 10 mA with a 10 s interval in between to avoid potentiation and fatigue [27]), and the device is much smaller, making it easier to transport. Moreover, the Myoton device has been validated for measurement of muscle tone and stiffness in healthy participants with "good" to "excellent" (intra- and inter-rater) reliability [28] and shows a high level of agreement compared with measurements from shear-wave ultrasound elastography [29,30]. Furthermore, Lohr et al. [31] indicate much higher reliability measures for myotonometry in repeated testing than tensiomyography.

Acute changes in muscle mechanical properties (measured by Myoton) due to exercise were indicated as fatigue or potentiation (acute muscle function improvement due to previous muscle activity) [21,26,27]. Studies in which the Myoton device was used show mainly increases in muscle stiffness due to the fatiguing protocols (Wang et al., 2016, 2017; Klich et al., 2019; 2020). For instance, Klich et al. [32] reported an acute increase in vastus lateralis stiffness after all-out 200 m and 4000 m track cycling, with a higher increase after 200 m. An exception is the study by Hill et al. [21], which indicated an acute decrease in vastus lateralis and gastrocnemius lateralis muscle stiffness induced by a fatiguing protocol consisting of five sets of 20 drop jumps. Furthermore, a study by Pożarowszczyk et al. [26] found an acute increase in Achilles' tendon stiffness and elasticity after back squats with increasing external load (from 60 to 100% one-repetition maximum (1RM), with 10% steps). Nonetheless, the impact of particular resistance exercise intensity (load) on muscle mechanical properties is unknown. Additionally, Pożarowszczyk et al. [26] did not assess physical performance level (i.e., countermovement jump); thus, it is unestablished whether the changes in muscle mechanical properties could be related to performance outcomes. These results [21,26,32] indicate that the type of exercise, as well as intensity and volume, may have different effects on muscle mechanical properties; however, this is still a scientifically unexplored area.

Therefore, it seems justified to analyze muscle mechanical properties simultaneously with the analysis of performance changes to determine whether a difference in muscle properties can be a reliable indicator of performance potential. However, as far as we know, no study has compared the acute effects of different external loads used during resistance exercise on muscle mechanical properties and tried to assess the ability of the Myoton to detect muscle fatigue induced by resistance exercise. Therefore, the purpose of the present study was to analyze acute changes in power performance and muscle mechanical properties of the triceps brachii long head after bench press exercises performed at different external loads with different intensities of effort in male strength-trained athletes. We hypothesized that different loads, as well as intensities, exert distinct impacts on muscle mechanical properties and that they will coincide with changes in performance.

2. Materials and Methods

2.1. Experimental Approach to the Problem

All participants took part in a familiarization session and two experimental sessions with a one-week interval in between. The familiarization session included the determination of the 1RM bench press. During the experimental sessions (EXP), each participant completed three successive sets of two repetitions of the bench press at a load of 50, 70, 90% 1RM followed by a single set until failure at a load of 70% 1RM. Immediately before and after each set, muscle mechanical properties of the triceps brachii long head (dominant limb) were assessed via Myoton. Under the control condition (CTRL), muscle mechanical properties were measured at corresponding time points to the experimental condition, but after a warm-up the participants rested while sitting and did not perform any exercise. Sessions were conducted in random order.

2.2. Subjects

Ten resistance-trained male certified personal trainers participated in this study. Their mean ± SD age, body mass, height, experience in resistance training, and absolute and relative 1RM in the bench press were: 27.7 ± 3.7 yr; 90.1 ± 17.1 kg; 184 ± 4 cm; 5.8 ± 2.6 yr; 108 ± 15.8 kg; 1.23 ± 0.22 kg/body mass, respectively. The inclusion criteria were as follows: (i) free from neuromuscular and musculoskeletal disorders, (ii) at least two years' experience in resistance training, (iii) consider themselves safe to participate in the exercise as determined by the self-administered Physical Activity Readiness Questionnaire (PAR-Q). Participants were excluded if they reported: (i) more than two weeks of resistance-training absences in the past year, (ii) that they had no experience of high-loaded bench press performance until failure or (iii) that they had no experience of bench presses executed in an explosive manner. Moreover, the participants were instructed not to perform any additional resistance exercises 72 h before each testing session to avoid fatigue, to maintain their usual dietary and sleeping habits, and not to use any stimulants or alcoholic beverages throughout the study. Participants were allowed to withdraw from the experiment at any moment and were informed about the benefits and potential risks of the study before providing their written informed consent for participation. The participants were not informed about the expected study outcomes. All participants completed the experiment. The study protocol was approved by the Bioethics Committee for Scientific Research at the Academy of Physical Education in Katowice, Poland (1/2021) and performed according to the ethical standards of the Declaration of Helsinki 2013. All testing was performed in the morning (between 9:00 and 11:00 am) in October at the Strength and Power Laboratory of the Academy of Physical Education in Katowice, Poland, under controlled ambient conditions (~21 °C). The sample size was calculated a priori based on a statistical power of 0.8, an effect size of g = 0.46 [21], and a significance level of 0.05, taking acute changes in stiffness after exercise as a reference variable. A minimum sample size of 10 individuals was obtained (G*Power (version 3.1.9.2), Dusseldorf, Germany).

2.3. Procedures

2.3.1. Familiarization Session and 1RM Strength Tests

Before the main experimental sessions, the 1RM bench press tests were performed according to the recommendations proposed by Wilk et al. [33,34]. The participants arrived in the laboratory in the morning at the same time of day as the upcoming experimental sessions (±1 h). Throughout the study, an Eleiko IPF Powerlifting Competition barbell and weight plates (Eleiko, Sport AB Sweden) were used. Two certified and experienced strength and conditioning coaches supervised the bench press technique. Hand placement on the barbell was set at 150% individual bi-acromial distance and carefully replicated in each set. All repetitions were performed without bouncing the barbell off the chest, without intentionally pausing at the transition between the eccentric and concentric phases, and without raising the hips off the bench [4]. Participants performed a standardized warm-up as described elsewhere [4]. Next, the participants performed 10, 8, and 4 repetitions at 30%, 50%, and 70% of their estimated 1RM. The first testing load was set to an estimated 80% 1RM and was increased by 2.5–5 kg for each subsequent attempt until the participant would not perform a lift with the proper technique. Participants were instructed to perform each repetition with a 2 s duration of the eccentric phase and maximal velocity in the concentric phase of the movement. The 1RM was defined as the highest load completed without any help from the spotters. Five-minute rest intervals were allowed between the 1RM attempts, and all 1RM values were obtained within five attempts. Following the 1RM test, all participants performed four successive sets of two repetitions of the bench press at 50, 70, and 90% 1RM and 70% 1RM until failure with four-minute rest intervals in between as a familiarization session.

2.3.2. Experimental Sessions

After an identical warm-up to that performed before the 1RM tests, the participants performed two different testing conditions (one week apart) in a randomized order. The EXP condition included successive sets of two repetitions of the bench press exercises at progressive loads: 50, 70, and 90% 1RM. Furthermore, a fourth set was also executed at 70% 1RM until failure (UF) in order to: (i) assess differences in barbell velocity between the second and fourth set; thus, only the first two repetitions from the last set were analyzed; and (ii) compare acute changes in muscle mechanical properties in the initial repetitions of the first three sets and the fourth executed until voluntary failure (Figure 1). Voluntary failure was defined as the inability to perform another concentric movement in its entire range of motion. Participants were instructed to perform each repetition with a 2 s duration of the eccentric phase and maximal velocity in the concentric phase of the movement. Four-minute rest-intervals were allowed between each set. Immediately before and after each set, muscle mechanical properties of triceps brachii long head (dominant limb) were assessed. This muscle was chosen because it is substantially activated during the bench press exercise [6]. In the CTRL condition, the participants performed the warm-up, and then they were rested while sitting. Muscle mechanical properties were measured at corresponding time points to the EXP session.

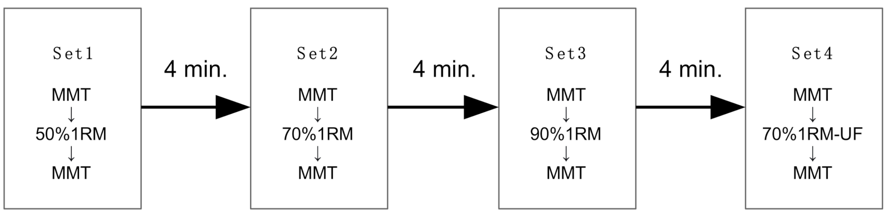

Figure 1. Study design. MMT—myotonometry assessment; 1RM—one-repetition maximum; UF—until failure.

2.3.3. Measurement of Barbell Velocity during the Bench Press Exercise

The average and peak barbell velocity during the bench press was controlled by a GymAware Powertool (Kinetic Performance Technology, Canberra, Australia), a linear position transducer. The device was placed on the floor directly under the barbell, and the external end of the cable was attached to the side of the barbell. The velocity of the barbell was recorded at 50 Hz. The GymAware Powertool provides reliable and valid data [35]. The best peak (the fastest point during positive work) and average (mean for the velocity over entire positive work) barbell velocity obtained during each set were maintained for further analysis. Additionally, barbell velocity obtained during the second and fourth (70% 1RM vs. first and second repetition from 70% 1RM UF) sets were compared to assess the effect of a set at 90% 1RM on performance and muscle mechanical properties.

2.3.4. Measurement of Muscle Mechanical Properties

The MyotonPRO, a hand-held myometer (MyotonPRO, Myoton AS, Tallinn, Estonia), was used to assess biomechanical characteristics of the triceps brachii long head. All measurements were made on the dominant side, as described below [36]. The MyotonPRO is a non-invasive, portable device that uses superficial mechanical deformation of soft tissues [37]. The following muscle mechanical properties were measured: muscle tone (oscillation frequency (Hz)), stiffness (N/m), elasticity (logarithmic decrement, its decrease means an increase in elasticity), mechanical stress relaxation time (ms), and creep (ratio of deformation and relaxation time). The Myoton's accelerometer was set at 3200 Hz with an average value obtained from five consecutive measurements (0.4 N for 15 ms).

3. Statistical Analyses

All statistical analyses were performed using SPSS (version 25.0; SPSS, Inc., Chicago, IL, USA) and were shown as means with standard deviations (±SD) with their 95% confidence intervals (CI). The relative (two-way mixed effects, absolute agreement, single rater intraclass correlation coefficient) and absolute (coefficient of variation and standard error of measurement) reliability were calculated. The thresholds for interpreting intraclass correlation coefficient results were: <0.5 "poor", 0.5–0.75 "moderate", 0.75–0.9 "good", and >0.90 "excellent" [38]. For coefficient of variation results, they were: <10% "very good", 10–20% "good", 20–30% "acceptable", >30% "not acceptable" [39]. Statistical significance was set at $p < 0.05$. The normality of data distributions was checked using Shapiro–Wilk tests. The three-way ANOVAs (2 groups (EXP and CTRL) × 2 times (pre–post measure) × 4 load (50, 70, 90, and 70% 1RM-UF (until failure))) were used to determine the influence of load on muscle mechanical properties. When a significant main effect or interaction was found, pairwise comparisons were conducted using a Bonferroni test. Additionally, to establish the influence of a set at 90% 1RM, paired sample *t*-tests were used to assess changes in barbell velocity during the bench press at sets with 70% 1RM. The magnitude of mean differences was expressed with standardized effect sizes. Thresholds for qualitative descriptors of Hedges g was interpreted as ≤0.20 "small", 0.21–0.9 "medium", and >0.80 as "large".

4. Results

4.1. Muscle Mechanical Properties

The intraclass correlation coefficient values for the muscle mechanical properties measurements evidenced "good" to "excellent" reliability for oscillation frequency and stiffness. At the same time, they were "poor" to "excellent" for decrement, relaxation time, and creep. The coefficients of variation were "very good" for all muscle mechanical properties data (Table 1).

Table 1. Intersession reliability of the muscle mechanical properties data.

Variable	ICC (95%CI)	CV (%)	SEM
Oscillation Frequency	0.94 (0.77–0.98)	2.8	0.3 Hz
Stiffness	0.96 (0.84–0.99)	3.4	7.9 N/m
Decrement	0.83 (0.28–0.96)	6.6	0.1
Relaxation Time	0.83 (0.18–0.96)	5.2	0.65 ms
Creep	0.82 (0.24–0.96)	4.3	0.06

ICC—intraclass correlation coefficient; CI—confidence interval; CV—coefficient of variation; SEM—standard error of measurement.

4.1.1. Oscillation Frequency

The three-way ANOVA indicated a statistically significant interaction between the effect of group and time (p = 0.008; F = 11.674; η^2 = 0.565). Simple main effects analysis showed that time had a statistically significant effect on increasing oscillation frequency after bench press (p = 0.016; F = 8.796; η^2 = 0.494). No other interactions or main effects were found. The post hoc comparisons revealed a statistically significant increase after 70% 1RM (p = 0.034; ES = 0.32) and 90% 1RM (p = 0.011; ES = 0.56) during the EXP condition (Table 2).

Table 2. Muscle mechanical properties responses of triceps brachii long head to the different loads of the bench press exercise.

	PRE 50% 1RM	POST 50% 1RM	PRE 70% 1RM	POST 70% 1RM	PRE 90% 1RM	POST 90% 1RM	PRE 70% 1RM-UF	POST 70% 1RM-UF
				Oscillation Frequency (Hz)				
EXP	12.86 ± 1.05 (12.11 to 13.61)	13.07 ± 1.37 (12.09 to 14.06)	12.72 ± 0.95 (12.04 to 13.39)	13.11 ± 1.32 * (12.16 to 14.05)	12.77 ± 1.11 (11.98 to 13.56)	13.43 ± 1.15 * (12.61 to 14.25)	13.17 ± 1.53 (12.08 to 14.26)	13.5 ± 1.59 (12.36 to 14.63)
CTRL	12.81 ± 1.15 (11.98 to 13.63)	12.85 ± 0.99 (12.14 to 13.57)	12.87 ± 1.39 (11.87 to 13.87)	12.66 ± 1.18 (11.81 to 13.5)	12.86 ± 1.05 (12.11 to 13.61)	12.95 ± 1.25 (12.06 to 13.84)	12.78 ± 1.13 (11.97 to 13.59)	12.99 ± 1.18 (12.14 to 13.83)
				Stiffness (N/m)				
EXP	187 ± 26 (168 to 205)	189 ± 24 (172 to 207)	192 ± 20 (177 to 206)	196 ± 24 (179 to 214)	203 ± 33 (179 to 227)	209 ± 39 (181 to 237)	197 ± 26 (178 to 215)	206 ± 27 (187 to 225)
CTRL	187 ± 28 (167 to 208)	187 ± 28 (167 to 207)	189 ± 27 (170 to 209)	186 ± 27 (167 to 205)	188 ± 21 (173 to 203)	190 ± 30 (168 to 212)	188 ± 28 (167 to 208)	189 ± 30 (168 to 211)

* Significant difference compared to the value before at the given intensity $p < 0.05$.

4.1.2. Stiffness

The three-way ANOVA indicated that there was no statistically significant interaction, nor main effect.

4.2. Bench Press Performance

Paired sample t-tests indicated a significant decrease in peak (pre: 0.86 ± 0.13 m/s vs. post: 0.71 ± 0.15 m/s; p = 0.001; ES = 1.02) and average barbell velocity (pre: 0.61 ± 0.08 vs. post: 0.53 ± 0.07; p = 0.008; ES = 0.8) during the set at 70% 1RM UF in comparison to the set at 70% 1RM (Figure 2).

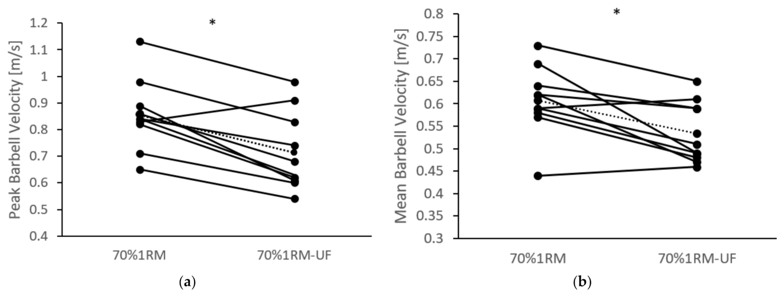

Figure 2. Inter-individual changes in the peak (**a**) and average (**b**) barbell velocity during the bench press set at 70% 1RM and the first two repetitions in the set at 70% 1RM performed until failure. * Significant difference $p < 0.05$. The dashed line represents the group mean response.

5. Discussion

This study aimed to analyze acute changes in muscle mechanical properties of the triceps brachii long head after the bench press exercise performed at different external loads and with different intensities of effort along with power performance in male strength-trained athletes. The results showed that the external load used during the bench press had an overall effect of increasing muscle tone after the performed sets but not for stiffness. In addition, there was a significant decrease in peak and average barbell velocity during the bench press in a set at 70% 1RM compared to the first two repetitions in a set at 70% 1RM UF. However, the reported changes in muscle tone did not significantly coincide with the significant decrease in power performance.

First, we have to state that this study showed a "poor" to "excellent" intraclass coefficient for elasticity (decrement), relaxation time, and creep, while for stiffness and muscle tone, it was "good" to "excellent" (Table 1). Therefore, it seems that the Myoton device is inappropriate in assessing changes in elasticity, relaxation time, and creep following resistance exercises. Consequently, we recommend that future research pay special attention to checking and reporting the reliability of measurements made via the Myoton.

The reported changes in muscle tone partially confirmed our initial hypothesis about the impact of external load used on differences in mechanical muscle properties. After the set at 50% 1RM, no significant changes were noted in muscle tone or stiffness. Only after the set at 70% 1RM and 90% 1RM was a statistically significant immediate increase in muscle tone noted. The same trend was noticed in the case of stiffness; however, it did not reach the level of significance. Previous studies found that increases in muscle tone and stiffness have been associated with fatigue and decreased performance [32,40–42]; therefore, this might indicate that some degree of fatigue has occurred. Interestingly, despite significant differences in volume compared to other sets (2 vs. ~13 repetitions), the changes after the set at 70% 1RM UF had a similar yet insignificant trend. It is also interesting that a similar level of muscle tone after the set at 90% 1RM and at 70% 1RM UF was noted. Therefore, it could be speculated that other mechanisms were responsible for these changes. Muscle tone might depend on both active (dependent of neural activity) and passive (independent of neural activity) muscle components. It seems that the reported increase in muscle tone after the bench press set at 70% 1RM and 90% 1RM may be related to the increase in neural drive. The comparable level reached after the set at 70% 1RM UF could be caused by the rise of intramuscular pressure because of increased intracellular fluid due to the intense effort [43]. Nevertheless, it cannot be ruled out that if a higher volume were used, e.g., several consecutive sets or sets until failure, a significant change in the stiffness or a higher increase in muscle tone would occur.

Furthermore, it is worth noting that the muscle tone level before the 70% 1RM UF was slightly higher, which may have been a residual from the set at 90% 1RM, indicating some degree of fatigue. This potential state could be manifested by a significant decrease in barbell velocity observed during the first two repetitions in the set at 70% 1RM UF compared to the set at 70% 1RM. A decrease in velocity has been previously revealed as an indicator of neuromuscular fatigue during resistance training [44]; thus, the results suggest that substantial fatigue has occurred. They indicate that three subsequent sets of two repetitions at 50, 70, and 90% 1RM, respectively, with a 4 min rest in between, impair power performance and increase muscle tone among resistance-trained males. This trend of simultaneous muscle tone increase and performance impairment may suggest that muscle tone may be a sensitive marker for detecting acute fatigue. Nonetheless, a further study with a larger sample size is warranted to verify this statement and assess the true effect.

The results of this study should be viewed in light of certain limitations. First of all, this study may not be sufficiently powerful to detect a small effect due to the small sample size. Secondly, only one muscle (triceps brachii long head) was analyzed; as this study involved multi-joint exercises, it cannot be ruled out that the results could be different for other muscles. Therefore, to better understand the effect of resistance exercise on the behavior of muscle mechanical properties and the interactions with physical performance, future studies in more isolated conditions, such as isokinetic dynamometry muscle testing, are needed. Moreover, residual fatigue or potentiation could have influenced the measurements because participants performed one set after another. In addition, the influence of different muscle contractions (i.e., comparison of concentric-, eccentric-only, and concentric–eccentric), types of exercises (i.e., plyometric vs. high-loaded), and a wider range of intensities and volumes of resistance training (i.e., single vs. multiset) on muscle mechanical property changes have to be explored.

6. Conclusions

The purpose of this study was to analyze acute changes in muscle mechanical properties of the triceps brachii long head after the bench press exercise performed at different external loads and with different intensities of effort along with power performance in male strength-trained athletes. The results indicated that low-volume, high-load resistance exercise immediately increases muscle tone but not stiffness. Despite no significant changes in the muscle mechanical properties being noticed simultaneously with the decrease in barbell velocity, there was a trend for increased muscle tone. Therefore, further studies with larger samples are required to verify whether muscle tone could be a sensitive marker to detect acute muscle fatigue.

Author Contributions: Conceptualization, G.W. and M.W.; methodology, R.T. and M.W.; software, P.A.; validation, R.T. and P.A.; formal analysis, M.K. and D.I.A.; investigation, G.W. and Z.K.; data curation, Z.K. and D.I.A.; writing—original draft preparation, M.K. and R.T.; writing—review and editing, M.K. and G.W.; supervision, A.Z. and M.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of Academy of Physical Education in Katowice (01/2021).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kraemer, W.J.; Ratamess, N.A. Fundamentals of Resistance Training: Progression and Exercise Prescription. *Med. Sci. Sports Exerc.* **2004**, *36*, 674–688. [CrossRef] [PubMed]
2. da Conceição, R.R.; Simão, R.; Silveira, A.L.B.; Silva, G.C.; Nobre, M.; Salerno, V.P.; Novaes, J. Acute Endocrine Responses to Different Strength Exercise Order in Men. *J. Hum. Kinet.* **2014**, *44*, 111–120. [CrossRef] [PubMed]
3. Wilk, M.; Petr, M.; Krzysztofik, M.; Zajac, A.; Stastny, P. Endocrine Response to High Intensity Barbell Squats Performed with Constant Movement Tempo and Variable Training Volume. *Neuroendocrinol. Lett.* **2018**, *39*, 342–348. [PubMed]
4. Krzysztofik, M.; Wilk, M. The Effects of Plyometric Conditioning on Post-Activation Bench Press Performance. *J. Hum. Kinet.* **2020**, *74*, 99–108. [CrossRef]
5. Wilk, M.; Krzysztofik, M.; Filip, A.; Zajac, A.; Bogdanis, G.C.; Lockie, R.G. Short-Term Blood Flow Restriction Increases Power Output and Bar Velocity during the Bench Press. *J. Strength Cond. Res.* **2020**. Publish Ahead of Print. [CrossRef]
6. Stastny, P.; Gołaś, A.; Blazek, D.; Maszczyk, A.; Wilk, M.; Pietraszewski, P.; Petr, M.; Uhlir, P.; Zając, A. A Systematic Review of Surface Electromyography Analyses of the Bench Press Movement Task. *PLoS ONE* **2017**, *12*, e0171632. [CrossRef]
7. Krzysztofik, M.; Wilk, M.; Golas, A.; Lockie, R.G.; Maszczyk, A.; Zajac, A. Does Eccentric-Only and Concentric-Only Activation Increase Power Output? *Med. Sci. Sports Exerc.* **2020**, *52*, 484–489. [CrossRef]
8. McMaster, D.T.; Gill, N.; Cronin, J.; McGuigan, M. A Brief Review of Strength and Ballistic Assessment Methodologies in Sport. *Sports Med.* **2014**, *44*, 603–623. [CrossRef]
9. Newton, R.U.; Murphy, A.J.; Humphries, B.J.; Wilson, G.J.; Kraemer, W.J.; Hakkinen, K. Influence of Load and Stretch Shortening Cycle on the Kinematics, Kinetics and Muscle Activation That Occurs during Explosive Upper-Body Movements. *Eur. J. Appl. Physiol.* **1997**, *75*, 333–342. [CrossRef]
10. Jandacka, D.; Uchytil, J. Optimal Load Maximizes the Mean Mechanical Power Output during Upper Extremity Exercise in Highly Trained Soccer Players. *J. Strength Cond. Res.* **2011**, *25*, 2764–2772. [CrossRef]
11. Legaz-Arrese, A.; Reverter-Masía, J.; Munguía-Izquierdo, D.; Ceballos-Gurrola, O. An Analysis of Resistance Training Based on the Maintenance of Mechanical Power. *J. Sports Med. Phys. Fitness* **2007**, *47*, 427–436.
12. Fry, A.C. The Role of Resistance Exercise Intensity on Muscle Fibre Adaptations. *Sports Med.* **2004**, *34*, 663–679. [CrossRef]
13. Dimitrova, N.A.; Dimitrov, G.V. Interpretation of EMG Changes with Fatigue: Facts, Pitfalls, and Fallacies. *J. Electromyogr. Kinesiol.* **2003**, *13*, 13–36. [CrossRef]
14. Enoka, R.M.; Duchateau, J. Muscle Fatigue: What, Why and How It Influences Muscle Function: Muscle Fatigue. *J. Physiol.* **2008**, *586*, 11–23. [CrossRef]

15. Krzysztofik, M.; Jarosz, J.; Matykiewicz, P.; Wilk, M.; Bialas, M.; Zajac, A.; Golas, A. A Comparison of Muscle Activity of the Dominant and Non-Dominant Side of the Body during Low versus High Loaded Bench Press Exercise Performed to Muscular Failure. *J. Electromyogr. Kinesiol.* **2021**, *56*, 102513. [CrossRef]
16. Hicks, A.L.; Kent-Braun, J.; Ditor, D.S. Sex Differences in Human Skeletal Muscle Fatigue. *Exerc. Sport Sci. Rev.* **2001**, *29*, 109–112. [CrossRef]
17. Chiu, L.Z.F.; Barnes, J.L. The Fitness-Fatigue Model Revisited: Implications for Planning Short- and Long-Term Training. *Strength Cond. J.* **2003**, *25*, 42–51. [CrossRef]
18. Hargreaves, M.; Spriet, L.L. Skeletal Muscle Energy Metabolism during Exercise. *Nat. Metab.* **2020**, *2*, 817–828. [CrossRef]
19. Hunter, A.M.; Galloway, S.D.; Smith, I.J.; Tallent, J.; Ditroilo, M.; Fairweather, M.M.; Howatson, G. Assessment of Eccentric Exercise-Induced Muscle Damage of the Elbow Flexors by Tensiomyography. *J. Electromyogr. Kinesiol.* **2012**, *22*, 334–341. [CrossRef]
20. de Paula Simola, R.Á.; Harms, N.; Raeder, C.; Kellmann, M.; Meyer, T.; Pfeiffer, M.; Ferrauti, A. Assessment of Neuromuscular Function After Different Strength Training Protocols Using Tensiomyography. *J. Strength Cond. Res.* **2015**, *29*, 1339–1348. [CrossRef]
21. Hill, M.; Rosicka, K.; Wdowski, M. Effect of Sex and Fatigue on Quiet Standing and Dynamic Balance and Lower Extremity Muscle Stiffness. *Eur. J. Appl. Physiol.* **2021**. [CrossRef] [PubMed]
22. García-Manso, J.M.; Rodríguez-Matoso, D.; Sarmiento, S.; de Saa, Y.; Vaamonde, D.; Rodríguez-Ruiz, D.; Da Silva-Grigoletto, M.E. Effect of High-Load and High-Volume Resistance Exercise on the Tensiomyographic Twitch Response of Biceps Brachii. *J. Electromyogr. Kinesiol.* **2012**, *22*, 612–619. [CrossRef]
23. Pereira, L.A.; Ramirez-Campillo, R.; Martín-Rodríguez, S.; Kobal, R.; Abad, C.C.C.; Arruda, A.F.S.; Guerriero, A.; Loturco, I. Is Tensiomyography-Derived Velocity of Contraction a Sensitive Marker to Detect Acute Performance Changes in Elite Team-Sport Athletes? *Int. J. Sports Physiol. Perform.* **2020**, *15*, 31–37. [CrossRef] [PubMed]
24. Herring, C.H.; Goldstein, E.R.; Fukuda, D.H. Use of Tensiomyography in Evaluating Sex-Based Differences in Resistance-Trained Individuals After Plyometric and Isometric Midthigh Pull Postactivation Potentiation Protocols. *J. Strength Cond. Res.* **2021**, *35*, 1527–1534. [CrossRef]
25. Redd, M.J.; Starling-Smith, T.M.; Herring, C.H.; Stock, M.S.; Wells, A.J.; Stout, J.R.; Fukuda, D.H. Tensiomyographic Responses to Warm-Up Protocols in Collegiate Male Soccer Athletes. *JFMK* **2021**, *6*, 80. [CrossRef] [PubMed]
26. Pożarowszczyk, B.; Gołaś, A.; Chen, A.; Zając, A.; Kawczyński, A. The Impact of Post Activation Potentiation on Achilles Tendon Stiffness, Elasticity and Thickness among Basketball Players. *Sports* **2018**, *6*, 117. [CrossRef]
27. Tous-Fajardo, J.; Moras, G.; Rodríguez-Jiménez, S.; Usach, R.; Doutres, D.M.; Maffiuletti, N.A. Inter-Rater Reliability of Muscle Contractile Property Measurements Using Non-Invasive Tensiomyography. *J. Electromyogr. Kinesiol.* **2010**, *20*, 761–766. [CrossRef]
28. Chen, G.; Wu, J.; Chen, G.; Lu, Y.; Ren, W.; Xu, W.; Xu, X.; Wu, Z.; Guan, Y.; Zheng, Y.; et al. Reliability of a Portable Device for Quantifying Tone and Stiffness of Quadriceps Femoris and Patellar Tendon at Different Knee Flexion Angles. *PLoS ONE* **2019**, *14*, e0220521. [CrossRef]
29. Feng, Y.N.; Li, Y.P.; Liu, C.L.; Zhang, Z.J. Assessing the Elastic Properties of Skeletal Muscle and Tendon Using Shearwave Ultrasound Elastography and MyotonPRO. *Sci. Rep.* **2018**, *8*, 17064. [CrossRef]
30. Kelly, J.P.; Koppenhaver, S.L.; Michener, L.A.; Proulx, L.; Bisagni, F.; Cleland, J.A. Characterization of Tissue Stiffness of the Infraspinatus, Erector Spinae, and Gastrocnemius Muscle Using Ultrasound Shear Wave Elastography and Superficial Mechanical Deformation. *J. Electromyogr. Kinesiol.* **2018**, *38*, 73–80. [CrossRef]
31. Lohr, C.; Braumann, K.-M.; Reer, R.; Schroeder, J.; Schmidt, T. Reliability of Tensiomyography and Myotonometry in Detecting Mechanical and Contractile Characteristics of the Lumbar Erector Spinae in Healthy Volunteers. *Eur. J. Appl. Physiol.* **2018**, *118*, 1349–1359. [CrossRef]
32. Klich, S.; Ficek, K.; Krymski, I.; Klimek, A.; Kawczyński, A.; Madeleine, P.; Fernández-de-las-Peñas, C. Quadriceps and Patellar Tendon Thickness and Stiffness in Elite Track Cyclists: An Ultrasonographic and Myotonometric Evaluation. *Front. Physiol.* **2020**, *11*, 607208. [CrossRef]
33. Wilk, M.; Golas, A.; Zmijewski, P.; Krzysztofik, M.; Filip, A.; Coso, J.D.; Tufano, J.J. The Effects of the Movement Tempo on the One-Repetition Maximum Bench Press Results. *J. Hum. Kinet.* **2020**, *72*, 151–159. [CrossRef]
34. Wilk, M.; Gepfert, M.; Krzysztofik, M.; Mostowik, A.; Filip, A.; Hajduk, G.; Zajac, A. Impact of Duration of Eccentric Movement in the One-Repetition Maximum Test Result in the Bench Press among Women. *J. Sports Sci. Med.* **2020**, *19*, 317–322.
35. Banyard, H.G.; Nosaka, K.; Sato, K.; Haff, G.G. Validity of Various Methods for Determining Velocity, Force, and Power in the Back Squat. *Int. J. Sports Physiol. Perform.* **2017**, *12*, 1170–1176. [CrossRef]
36. Chuang, L.-L.; Lin, K.-C.; Wu, C.-Y.; Chang, C.-W.; Chen, H.-C.; Yin, H.-P.; Wang, L. Relative and Absolute Reliabilities of the Myotonometric Measurements of Hemiparetic Arms in Patients with Stroke. *Arch. Phys. Med. Rehabil.* **2013**, *94*, 459–466. [CrossRef] [PubMed]
37. Cè, E.; Longo, S.; Limonta, E.; Coratella, G.; Rampichini, S.; Esposito, F. Peripheral Fatigue: New Mechanistic Insights from Recent Technologies. *Eur. J. Appl. Physiol.* **2020**, *120*, 17–39. [CrossRef]
38. Koo, T.K.; Li, M.Y. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J. Chiropr. Med.* **2016**, *15*, 155–163. [CrossRef] [PubMed]

39. Campbell, M.J.; Walters, S.J.K.; Machin, D. *Medical Statistics: A Textbook for the Health Sciences*, 5th ed.; John Wiley Blackwell: Hoboken, NJ, USA, 2021; ISBN 978-1-119-42364-5.
40. Klich, S.; Pietraszewski, B.; Zago, M.; Galli, M.; Lovecchio, N.; Kawczyński, A. Ultrasonographic and Myotonometric Evaluation of the Shoulder Girdle After an Isokinetic Muscle Fatigue Protocol. *J. Sport Rehabil.* **2020**, *29*, 1047–1052. [CrossRef]
41. Wang, J.-S. Therapeutic Effects of Massage and Electrotherapy on Muscle Tone, Stiffness and Muscle Contraction Following Gastrocnemius Muscle Fatigue. *J. Phys. Ther. Sci.* **2017**, *29*, 144–147. [CrossRef]
42. Wang, D.; De Vito, G.; Ditroilo, M.; Delahunt, E. Effect of Sex and Fatigue on Muscle Stiffness and Musculoarticular Stiffness of the Knee Joint in a Young Active Population. *J. Sports Sci.* **2016**, 1–10. [CrossRef] [PubMed]
43. Sleboda, D.A.; Wold, E.S.; Roberts, T.J. Passive Muscle Tension Increases in Proportion to Intramuscular Fluid Volume. *J. Exp. Biol.* **2019**, *222*, jeb.209668. [CrossRef] [PubMed]
44. Sánchez-Medina, L.; González-Badillo, J.J. Velocity Loss as an Indicator of Neuromuscular Fatigue during Resistance Training. *Med. Sci. Sports Exerc.* **2011**, *43*, 1725–1734. [CrossRef] [PubMed]