



Physical Activity and Repetitive Precision Tasks as Determinants of Biomechanical and Viscoelastic Adaptations of the Flexor Digitorum Superficialis Muscle in Professional Shooters

Sebastian Szajkowski  ^{1ABCDE}, Jarosław Pasek  ^{2ABD}, Grzegorz Cieślar  ^{3BD}, Michał Dwornik  ^{4BD}, Dominik Szymański  ^{4BD}, Sławomir Marszałek  ^{56ADE}

¹ Faculty of Medical Sciences, Medical Academy of Applied Sciences, Warszawa, Poland

² Collegium Medicum im dr Władysława Biegańskiego, Jan Długosz University in Częstochowa, Poland

³ Department of Internal Medicine, Angiology and Physical Medicine, Faculty of Medical Sciences, Medical University of Silesia in Katowice, Poland

⁴ Medical Rehabilitation and Osteopathy Clinic „REHApunkt”. Piastów, Poland

⁵ Department of Physiotherapy, University of Medical Sciences, Poznań, Poland

⁶ Department of Oncological Physiotherapy, Greater Poland Cancer Centre, Poznań, Poland

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Abstract: *Background:* This study aimed to assess the effects of long-term pistol use on the biomechanical and viscoelastic properties of the flexor digitorum superficialis (FDS) muscle, using myotonometry (MyotonPRO) to compare State Protection Service officers with individuals who do not use pistols. *Methods:* This cross-sectional study included 50 healthy adult males aged 30–40 years, of whom 25 were professional shooters and 25 were non-pistol users. The biomechanical and viscoelastic properties of the FDS muscle of the dominant hand were assessed using the MyotonPRO device at six contraction levels ranging from 0 to 100% of maximum voluntary contraction (MVC), based on grip strength measured with a digital dynamometer. *Results:* Professional shooters showed lower muscle tone, stiffness, and decrement values, suggesting greater elasticity; however, these differences were not statistically significant. Viscoelastic parameters, including relaxation time and creep, were generally higher. In unadjusted analyses, creep differed at 80% and 100% MVC ($p = 0.039$ and $p = 0.002$) with moderate effect sizes, but these differences were not significant after Benjamini–Hochberg correction. The lowest adjusted value was observed for creep at 100% MVC ($q = 0.060$), indicating a trend toward significance. *Conclusions:* Long term pistol use was not associated with increased muscle tone or stiffness of the FDS muscle. Although viscoelastic differences were observed, none remained significant after correction. Consistent patterns, particularly for creep at higher loads, may suggest subtle differences in muscle behavior; however, these findings should be interpreted with caution.

Keywords: skeletal, shooting sports, grip strength, biomechanics, muscle tonus

Corresponding author: Sebastian Szajkowski, e-mail: s.g.szajkowski@gmail.com

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INTRODUCTION

The mechanical properties of skeletal muscle are recognized as key indicators of muscle performance and joint stability during the execution of functional movements [1,2]. The functional status and efficiency of muscles responsible for grip, weapon stabilization, and precise trigger control play a crucial role in both sport and tactical shooting [3]. Continuous flexion and extension of the fingers, as well as a strong and sustained grip on the weapon, impose significant loads on the muscles of the hand and forearm. Chronic overload caused by repetitive upper limb movements, particularly involving the finger flexor muscles, may lead to alterations in their biomechanical and viscoelastic properties [4-6]. Such musculoskeletal strain occurs within specific occupational environments, where prolonged exposure to repetitive tasks and equipment-related stressors constitutes an important component of overall environmental load. In professional shooters, these factors form a unique occupational exposure profile that may influence long-term musculoskeletal health and performance. Therefore, understanding how regular pistol use affects the structure and function of these muscles is of considerable importance not only from the perspective of sports medicine, but also in terms of occupational ergonomics, injury prevention, and optimization of training protocols for uniformed services.

Repetitive precision tasks requiring sustained grip control, such as pistol shooting, impose specific neuromuscular demands on the forearm muscles. These activities involve prolonged low-intensity contractions combined with fine motor control and high stability requirements, which may lead to task-specific adaptations in muscle mechanical properties. In particular, repeated exposure to precision grip and static loading conditions may influence muscle stiffness, elasticity, and fatigue resistance. Therefore, shooting-specific loading should be considered a key factor modulating the functional and viscoelastic characteristics of forearm muscles in both occupational and sports settings [4].

Myotonometry is a reliable tool used to assess the functional status of muscles [5]. This modern, non-invasive method enables the evaluation of the biomechanical and viscoelastic properties of skeletal muscles. It is widely applied in occupational medicine, sports medicine, and rehabilitation, providing objective and quantitative data for scientific research [8-10]. Previous research has demonstrated that MyotonPRO provides high intra- and inter-rater reliability in assessing muscle mechanical properties. As such, it presents a reliable and practical option for quantifying these properties across various conditions [11,12]. The flexor digitorum superficialis (FDS) muscle plays a crucial role in finger movement and grip strength. In pistol shooting, the FDS muscle contributes to sustained grip and weapon stabilization under low-intensity, prolonged loading. This functional role makes it particularly relevant for investigating task-specific changes in muscle mechanical properties. Additionally, the FDS is located superficially which makes it a suitable muscle for myotonometric measurements [13]. Proper assessment of the functional status of a muscle should include measurements at different loading conditions, which in the case of FDS includes the use of a hand dynamometer to measure the maximal hand grip strength [14].

From a theoretical perspective, two opposing mechanisms may explain the effects of repetitive pistol use on muscle properties. Chronic repetitive loading may lead to overload-related changes, such as increased muscle tone and stiffness. In contrast, prolonged exposure to controlled, submaximal contractions may promote functional adaptation, resulting in improved viscoelastic properties. Therefore, the direction of potential changes remains unclear and likely depends on the nature of the applied load. The aim of the present study was to determine whether regular and long-term use of pistols may lead to overload-related changes in the finger flexor muscles, manifested by alterations in their biomechanical and viscoelastic properties. The research hypothesis assumes that significant differences will be observed in

myotonometric measurements between professional shooters and individuals with no experience in pistol use. These differences are expected to indicate increased muscle stiffness and tone, as well as reduced elasticity of the assessed muscles, resulting from overload associated with the specific activity of pistol handling.

MATERIAL AND METHODS

Participants and Setting

A total of 50 male participants took part in the study. The participants were divided into two groups, each consisting of 25 individuals. Group 1 included individuals recruited from Polish State Protection Service, who had been regularly using pistols for professional or training purposes for a minimum of five years. Group 2 consisted of individuals with no prior experience in handling pistols and served as the control group. Individuals in the control group did not perform occupations or activities involving repetitive precision grip or prolonged loading of the forearm muscles. Their physical activity was limited to general, non-specific forms of exercise and did not include training or tasks requiring sustained isometric contraction of the forearm. In Group 1 the primary pistol used was the Glock 17 - a modern and reliable sidearm known for its precision and ergonomic design. The professional shooters in this study were members of the State Protection Service, a special uniformed formation subordinate to the Ministry of the Interior and Administration. This formation was established in 2018 under a legislative act, replacing the Government Protection Bureau. Its primary mission is to provide protection to individuals holding the highest public offices in the state. Participants in both groups met inclusion criteria designed to ensure similar anthropometric characteristics, such as height, weight, and Body Mass Index (BMI), as well as demographic features, specifically age (30-40 years), to ensure the comparability of results. Participants with a BMI over 30 kg/m² were excluded from the study because increased subcutaneous tissue thickness could adversely affect the reliability of myotonometric measurements [13]. Only healthy individuals were included in the study. Exclusion criteria comprised confirmed orthopedic or neurological conditions, including a history of surgical procedures that could affect the biomechanical properties of the muscles under investigation. Upon arrival at the testing site, participants rested for 15 minutes under room temperature conditions. Throughout the testing procedure, consistent ambient conditions were maintained: air temperature at 22°C and relative humidity at 50%. Participants were instructed to refrain from engaging in any physical activity on the day preceding the examination as well as on the day of testing. All measurements were conducted between 12:00 and 13:00. Prior to the assessment, each participant was informed about the purpose and procedure of the study and provided written informed consent to participate.

The study was conducted in July 2025 at the Didactic and Scientific Centre of the Warsaw Medical Academy of Applied Sciences in Warsaw, Poland. The study was performed in accordance with the Declaration of Helsinki (1964), and its protocol was approved by the Bioethics Committee at the Medical University of Mazovia in Warsaw, Poland (approval reference number: 202506WAM04).

Study Design

This cross-sectional study allows for the identification of associations between variables but does not permit conclusions regarding causal relationships or long-term adaptations. The flexor digitorum superficialis FDS muscle of the dominant hand was selected as representative of hand musculature, due to its role as a primary extrinsic muscle significantly involved in hand functionality [15]. Only the dominant hand was assessed in order to standardize measurements and reflect the hand primarily used during shooting tasks. However, it should be acknowledged that hand dominance may influence muscle properties, and therefore the findings may not be

directly generalizable to the non-dominant limb. Muscle function was assessed using handgrip strength measurements. The biomechanical and viscoelastic properties of the FDS muscle were assessed using the MyotonPRO device in both group 1 and group 2, under resting conditions and during voluntary contraction. To assess different levels of muscle activation, the maximum voluntary contraction (MVC) of the FDS was first determined. Based on this reference, muscle contractions were examined at six intensity levels: 0%, 20%, 40%, 60%, 80% and 100% of MVC. These levels were quantified using a digital handgrip dynamometer [16].

Measurements

Biomechanical properties of the muscle were assessed using the MyotonPRO device (Myoton AS, Estonia), a digital myotonometer consisting of a handheld unit and a Ø3 mm probe [17]. The device employs the mechanical dynamic response method, applying a brief mechanical impulse and recording the tissue's oscillation response to determine biomechanical parameters: tone (Hz), stiffness (N/m) and decrement (log), the latter characterizing elasticity, and visco-elasticity; relaxation time of mechanical stress (ms), and the ratio of relaxation time to deformation time, characterizing creep (Deborah number). The probe was positioned perpendicularly to the skin, delivering a pre-load of 0.18 N followed by five automatic impulses (0.4 N, 15 ms) [18]. Oscillations were recorded via an integrated accelerometer. Measurements were repeated if the coefficient of variation (CV) exceeded 3%, following a short rest period. All assessments were performed by the same experienced examiner under standardized conditions to ensure measurement reliability. All procedures were conducted by a trained physiotherapist experienced in myotonometry and scientific research. Participants were seated with the dominant upper limb flexed at 90° at the elbow, the forearm was supinated and supported on a table to ensure stability, the hand was palm up. The region between the palmaris longus tendon and the flexor carpi ulnaris was palpated while the forearm remained relaxed. Next, participants were instructed to perform a maximal flexion of the middle and ring fingers, allowing the examiner to identify the point of greatest muscle belly displacement. This point typically corresponds to the midpoint between the medial epicondyle of the humerus and the styloid process of the ulna. This location was then marked with a temporary marker to serve as the reference site for the placement of the MyotonPRO probe during assessment [19].

Subsequently, each participant's maximal grip strength was assessed using a digital handgrip dynamometer (Baseline, Fabrication Enterprises, Inc., USA) to determine the maximum voluntary contraction MVC of the FDS muscle, defined as 100% MVC and expressed in [kg]. This value served as a reference for setting different contraction intensities, expressed as percentages of MVC (0%, 20%, 40%, 60%, and 80%). Initially, scanning was performed with the muscle in a resting state (0% MVC). Subsequently, participants were instructed to exert grip force on the dynamometer at randomly varied levels of 20%, 40%, 60%, 80% and 100% of their MVC to minimize potential sources of bias. Participants were instructed to squeeze the dynamometer until reaching the target force corresponding to each specified % MVC level and to sustain this force for approximately 3 seconds, a duration necessary to perform measurements with the MyotonPRO device. The protocol was conducted twice for each participant, with a three-minute rest interval between each force level and trial. The mean of the two trials was calculated and used for subsequent data analysis. The measurement setup is illustrated in Figure 1.



Figure 1. Muscle assessment under load using the Baseline handheld dynamometer and the MyotonPRO myotonometer.

Statistical analysis

Statistical analyses were conducted using PQStat version 1.8.6. Descriptive statistics were calculated to summarize the central tendency and variability of demographic and anthropometric characteristics and are presented as mean \pm standard deviation. Between-group differences for these variables were assessed using Student's t-test, as the data met the assumptions of normality. The normality of distribution for myotonometric variables was evaluated using the Shapiro–Wilk test. As these data did not follow a normal distribution, all outcome measures were expressed as medians with interquartile ranges (Q1–Q3). Intergroup comparisons were performed using the non-parametric Mann–Whitney U test. Effect sizes for between-group comparisons were calculated using the rank-based effect size (r), derived from the Z statistic. Additionally, the magnitude of differences between groups was quantified by calculating the median difference along with 95% confidence intervals (CI) estimated using bootstrap resampling procedures. Statistical significance for primary analyses was initially set at $p < 0.05$. To account for multiple comparisons across contraction levels and outcome variables, the false discovery rate (FDR) was controlled using the Benjamini–Hochberg procedure. This approach was selected as it provides a balance between controlling Type I error and maintaining statistical power in studies involving multiple related comparisons. Adjusted p-values (q-values) were calculated, and statistical significance after correction was set at $q < 0.05$.

The magnitude of effect sizes was interpreted according to conventional thresholds, with $r = 0.1$ indicating a small effect, $r = 0.3$ a moderate effect, and $r = 0.5$ a large effect. For clarity of presentation in Table 1 and Figure 2, grip strength levels originally expressed as percentages of MVC were normalized and presented as fractions ranging from 0 to 1 relative to MVC (e.g., 0 = 0%, 1 = 100% MVC). The selection of the assumed effect size was limited by the availability of relevant reference data. Only one study evaluating the stiffness of the flexor digitorum superficialis muscle using the MyotonPRO device was identified, and it did not report effect size values [18]. Additionally, no pilot data were available for the present study. A separate study assessing the sternocleidomastoideus muscle reported a large effect size (Cohen's $d = 0.82$) [20], indicating that the MyotonPRO device is capable of detecting moderate to large differences in muscle stiffness, although these findings are not directly transferable to forearm muscles. Given these limitations, an effect size

of Cohen's $d = 0.8$ was adopted for the a priori power analysis ($\alpha = 0.05$, $1 - \beta = 0.80$) to ensure sufficient statistical power. It is acknowledged that this assumption may represent an overestimation for physiological measurements; however, it was considered a pragmatic choice in the absence of more specific data. An a priori power analysis was performed using G*Power software (version 3.1.9.7; Heinrich Heine University Düsseldorf, Germany; <http://www.gpower.hhu.de>) [21]. The required sample size was 42 subjects (21 per group) to achieve an actual power of 0.82. To accommodate potential dropouts and maintain balanced group sizes, the sample size was set at 50 subjects (25 per group).

RESULTS

The mean age of participants in Group 1 (experienced pistol users) was 35.12 ± 3.30 years, while in Group 2 (non-users) it was 34.52 ± 3.34 years. The difference between the groups was not statistically significant ($p = 0.526$). The mean body mass index (BMI) was 25.68 ± 1.19 kg/m² in Group 1 and 25.96 ± 1.12 kg/m² in Group 2, with no statistically significant difference observed ($p = 0.392$). The average handgrip strength was 57.35 ± 5.46 kg in Group 1 and 57.12 ± 8.56 kg in Group 2, with no significant difference between groups ($p = 0.908$).

For myotonometric parameters, values are presented as medians with interquartile ranges. Lower values of muscle tone were observed in Group 1 compared to Group 2 across all loading conditions (0–100% grip strength); however, none of these differences reached statistical significance in either unadjusted or FDR-adjusted analyses ($p > 0.05$; $q > 0.05$). The median differences were small and the corresponding 95% confidence intervals were wide and included zero, indicating low precision of the estimates and lack of meaningful between-group differences. Effect sizes were trivial to small ($r = 0.01$ – 0.17).

Similarly, muscle stiffness values were generally lower in Group 1, but the differences between groups were not statistically significant at any load level after adjustment for multiple comparisons ($p > 0.05$; $q > 0.05$). The median differences were inconsistent in direction and associated with wide confidence intervals, further supporting the absence of clear between-group effects. Effect sizes ranged from negligible to small ($r = 0.03$ – 0.20).

Decrement values were consistently lower in Group 1, suggesting greater muscle elasticity; however, these differences were not statistically significant after FDR correction ($p > 0.05$; $q > 0.05$), and effect sizes remained small ($r = 0.02$ – 0.20), with confidence intervals including zero across all conditions.

In contrast, relaxation time values were generally higher in Group 1, although no statistically significant differences were observed in either unadjusted or adjusted analyses ($p > 0.05$; $q > 0.05$). Effect sizes were small ($r = 0.10$ – 0.19), and confidence intervals for median differences were wide and crossed zero, indicating considerable variability.

Creep values were consistently higher in Group 1 across all loading conditions. In the unadjusted analysis, between-group differences reached statistical significance at 80% and 100% grip strength ($p = 0.039$ and $p = 0.002$, respectively), with moderate effect sizes ($r = 0.29$ and $r = 0.43$). However, after controlling for multiple comparisons using the Benjamini–Hochberg procedure, these differences were no longer statistically significant ($q > 0.05$). The lowest adjusted p-value was observed for creep at 100% MVC ($q = 0.060$), indicating a trend toward significance. Notably, this finding was associated with a moderate effect size ($r = 0.43$), and although the confidence interval did not include zero, this finding should be interpreted with caution in light of the multiple comparison correction. The graphical presentation of between group differences in creep (Figure 2) illustrates the consistency of this pattern across contraction levels, with larger differences observed at higher loads despite the lack of statistical significance after correction.

For the remaining conditions, differences were not statistically significant and confidence intervals included zero. A comprehensive summary of all results is presented in Table 1.

Table 1. Biomechanical and viscoelastic muscle parameters assessed by MyotonPRO in professional shooters and non-users (median [Q1–Q3], median difference with 95% CI). Grip strength (GS) levels are expressed as fractions of MVC (0–1).

Parameters	GS	Group 1 Median (Q1–Q3)	Group 2 Median (Q1–Q3)	Median difference (95% CI)	Effect size (r)	U	Z	p	q-value (FDR)
Tone (Hz)	0	16.4 (16.1–17.7)	17.4 (15.7–19.1)	0.5 (–4.0 – 4.4)	0.15	257	1.06	0.285	0.595
	0.2	22.5 (21.2–24.1)	22.7 (21.4–24.4)	0.0 (–13.8 – 5.5)	0.01	309	0.05	0.953	0.953
	0.4	23.8 (22.3–26.4)	25.1 (21.8–26.6)	0.1 (–6.5 – 5.8)	0.02	305.5	0.12	0.899	0.938
	0.6	24.8 (23.2–27.5)	27 (22.6–29.1)	0.3 (–8.8 – 8.2)	0.04	297	0.29	0.771	0.906
	0.8	25.5 (24.9–27.2)	27.9 (24.3–28.8)	1.2 (–8.1 – 8.6)	0.17	250	1.2	0.228	0.535
	1	26.6 (24.6–29.7)	27.7 (24.3–30.5)	0.9 (–8.8 – 10.5)	0.10	273.5	0.74	0.454	0.657
Stiffness (N/m)	0	283 (272–318)	293 (285–311)	–10 (–99 – 69)	0.20	240.5	1.38	0.164	0.535
	0.2	497 (467–539)	499 (454–560)	–4 (–227 – 186)	0.04	299	0.25	0.801	0.906
	0.4	537 (489–570)	541 (522–630)	12 (–256 – 242)	0.06	288.5	0.45	0.648	0.845
	0.6	573 (523–615)	588 (555–700)	13 (–262 – 273)	0.13	265	0.91	0.361	0.595
	0.8	613 (555–669)	615 (570–776)	14 (–261 – 277)	0.09	277.5	0.66	0.503	0.686
	1	635 (601–771)	655 (599–767)	2 (–320 – 303)	0.03	300	0.23	0.815	0.906
Decrement (log)	0	1.11 (0.95–1.21)	1.12 (0.94–1.21)	–0.01 (–0.50 – 0.49)	0.02	306	0.11	0.907	0.938
	0.2	1.07 (0.86–1.19)	1.12 (0.98–1.21)	–0.08 (–0.61 – 0.47)	0.19	244.5	1.31	0.189	0.535
	0.4	1.11 (0.86–1.24)	1.19 (1.02–1.32)	–0.09 (–0.73 – 0.53)	0.20	239	1.41	0.156	0.535
	0.6	1.15 (0.9–1.2)	1.2 (0.96–1.37)	–0.09 (–0.75 – 0.66)	0.18	247	1.26	0.206	0.535
	0.8	1.18 (0.94–1.22)	1.19 (1–1.27)	–0.06 (–0.70 – 0.67)	0.19	242	1.35	0.173	0.535
	1	1.21 (0.98–1.29)	1.24 (0.92–1.32)	–0.02 (–0.83 – 0.89)	0.06	290.5	0.41	0.676	0.845
Relaxation (m/s)	0	18.4 (16.5–18.9)	17.6 (15.6–18.6)	–0.5 (–5.4 – 5.2)	0.12	266.5	0.88	0.377	0.595
	0.2	10.8 (10.1–11.7)	10.3 (9.3–10.9)	–0.3 (–11.8 – 5.4)	0.10	274	0.73	0.46	0.657
	0.4	9.8 (8.8–11)	9.4 (9–10.6)	–0.4 (–4.8 – 5.9)	0.13	263	0.95	0.341	0.595
	0.6	9.6 (8.3–10)	8.9 (7–9.9)	–0.3 (–5.1 – 5.9)	0.13	263	0.95	0.341	0.595
	0.8	9.2 (7.4–10)	8.1 (6.6–9.7)	–0.5 (–4.3 – 5.5)	0.17	250.5	1.19	0.232	0.535
	1	8.5 (7.3–10.1)	8.1 (6.7–9.2)	–0.6 (–5.5 – 3.7)	0.19	243.5	1.33	0.183	0.535
Creep (Deborah No.)	0	1.17 (1.05–1.21)	1.1 (1.03–1.16)	–0.05 (–0.45 – 0.27)	0.24	224.5	1.69	0.089	0.535
	0.2	0.67 (0.6–0.77)	0.64 (0.6–0.71)	–0.03 (–0.38 – 0.31)	0.15	258.5	1.03	0.298	0.595
	0.4	0.62 (0.57–0.7)	0.58 (0.49–0.65)	–0.06 (–0.41 – 0.28)	0.24	224	1.7	0.087	0.535
	0.6	0.61 (0.53–0.67)	0.56 (0.46–0.63)	–0.05 (–0.36 – 0.34)	0.19	242	1.35	0.174	0.535
	0.8	0.59 (0.54–0.67)	0.54 (0.43–0.62)	–0.07 (–0.40 – 0.24)	0.29	206	2.05	0.039	0.535
	1	0.63 (0.55–0.7)	0.53 (0.41–0.63)	–0.12 (–0.18 – –0.04)	0.43	155	3.04	0.002	0.060

GS – grip strength load level (0–1); Group 1, Group 2 – study groups; Median (Q1–Q3) – median and interquartile range (25th–75th percentile); Median difference (95% CI) – difference between group medians with 95% confidence interval; Effect size (r) – effect size calculated from the Mann–Whitney U test; U – test statistic; Z – standardized test statistic; p – significance level; q-value (FDR) – p-value adjusted for multiple comparisons using the Benjamini–Hochberg procedure;

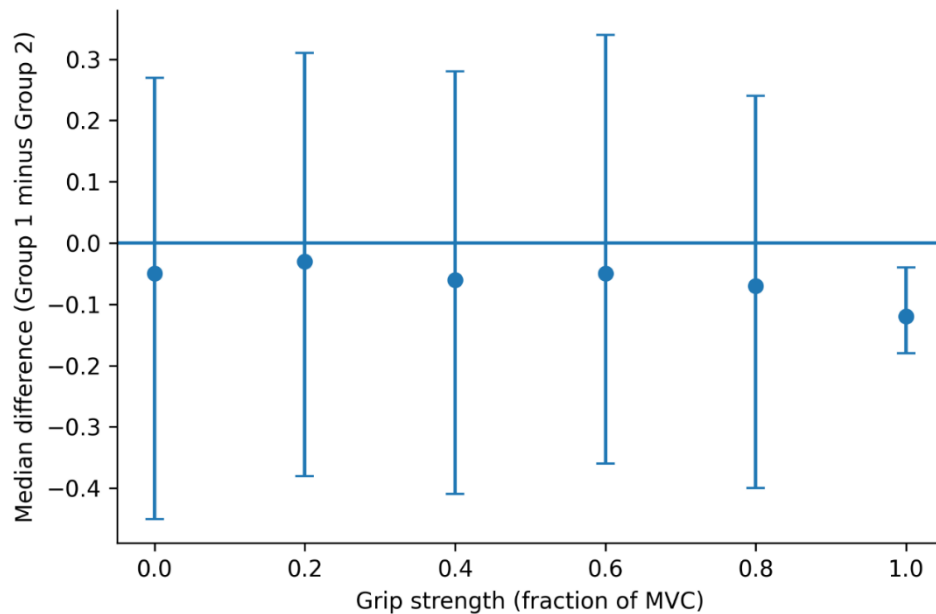


Figure 2. Between group differences in creep values across contraction levels expressed as median differences with 95% confidence intervals. Values are presented as Group 1 minus Group 2, with negative values indicating lower creep in the professional shooters group. Although no differences remained statistically significant after correction for multiple comparisons, a consistent pattern of larger differences at higher contraction levels can be observed.

DISCUSSION

The aim of the present study was to assess whether regular use of pistols is associated with alterations in the biomechanical and viscoelastic properties of the flexor digitorum superficialis muscle. Contrary to the initial hypothesis, the results did not demonstrate increased muscle tone or stiffness in professional shooters. Although consistently lower values of these parameters were observed in this group, both at rest and under progressively increasing loads, including maximum load, these differences were not statistically significant in either unadjusted or FDR-adjusted analyses. Furthermore, the wide confidence intervals and small effect sizes indicate limited precision and should be interpreted with caution.

Lower decrement values observed in the shooting group across all loading conditions may suggest reduced oscillation energy loss and potentially greater muscle elasticity; however, these findings were not statistically significant after correction for multiple comparisons. Similarly, although professional shooters exhibited higher values of relaxation time and creep, most between-group differences did not reach statistical significance following FDR adjustment.

In the unadjusted analysis, statistically significant differences were observed for creep at 80% and 100% contraction levels, accompanied by moderate effect sizes ($r = 0.29$ and $r = 0.43$). However, after controlling for multiple comparisons using the Benjamini–Hochberg procedure, these differences were no longer statistically significant. Notably, creep at 100% MVC demonstrated a trend toward significance ($q = 0.060$) with a moderate effect size, which may indicate a potentially meaningful difference under high-load conditions despite the lack of statistical significance after correction.

Taken together, the results suggest that prolonged pistol use is not associated with increased stiffness of the finger flexor muscles. However, the observed patterns may point toward subtle differences in viscoelastic properties, particularly under

higher load conditions. Given the lack of statistical significance after correction, these findings should be interpreted cautiously and considered preliminary.

Due to the limited number of studies addressing the effects of repetitive pistol use on muscle mechanical properties, direct comparisons remain scarce. Therefore, findings from related disciplines, such as archery, may provide indirect context. Previous studies have shown that technically advanced archers demonstrate greater repeatability in the activity of the flexor digitorum superficialis and extensor digitorum muscles during shooting, as assessed by electromyography (EMG), which is interpreted as a result of a more stable motor pattern [22,23]. Additionally, experienced archers exhibit increased activation of extensor muscles during shooting, suggesting a strategy of active grip control [24]. Similar observations have been reported during the release phase, where coordinated activation of forearm muscles contributes to movement precision [25].

Although the mechanics of archery and pistol shooting differ, both disciplines involve precise control of forearm musculature. Therefore, the differences observed in the present study may be related to task-specific motor demands rather than overload-related changes [26]. However, this interpretation remains speculative and requires confirmation in longitudinal studies.

The present findings are consistent with previous reports suggesting that repetitive motor activity may be associated with changes in muscle properties without clear signs of overload. However, given that none of the observed differences remained statistically significant after correction for multiple comparisons, these results should be interpreted with particular caution. Future studies with larger sample sizes and longitudinal designs are needed to determine whether the observed trends reflect true long-term adaptations or are influenced by other factors such as training protocols, hand dominance, or occupational loading patterns.

The present study is subject to several limitations. Due to its cross-sectional design, causal inferences and conclusions regarding long-term adaptations cannot be drawn. The level of general physical activity and occupational exposure was not controlled, which may have influenced the observed muscle properties. Moreover, the group of professional shooters was not further categorized according to training frequency, grip technique, or type of firearm, which could affect the functional characteristics of the muscles. Body composition and subcutaneous tissue thickness were not evaluated, potentially impacting the accuracy of the measurements. In addition, the relatively small sample size restricts the generalizability of the findings.

CONCLUSIONS

Long term pistol use was not associated with increased muscle tone or stiffness of the flexor digitorum superficialis muscle. Although some differences in viscoelastic parameters were observed, none of them remained statistically significant after controlling for multiple comparisons.

Nevertheless, consistent patterns in the results, particularly higher creep values at higher contraction levels, may suggest subtle differences in viscoelastic behavior under increased load. The presence of a trend toward significance accompanied by a moderate effect size indicates that these findings may still be physiologically relevant, however they should be interpreted with caution.

Overall, the results do not provide clear evidence of overload related changes in muscle mechanical properties. Instead, they may reflect task specific functional characteristics associated with prolonged pistol use. Further research, especially longitudinal studies with larger sample sizes, is needed to determine whether the observed trends represent true long term adaptations or are influenced by other factors such as training patterns or occupational exposure.

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