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Upper extremity muscle thickness and grip strength following a boccia-based intervention in hemiparetic individuals

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Abstract

Introduction The global prevalence of stroke is increasing, highlighting the critical importance of effective post-stroke rehabilitation. Although boccia was originally designed for individuals with special needs, its potential benefits for stroke rehabilitation, particularly regarding task-related changes in ultrasound-observed muscle characteristics, have not been thoroughly investigated.

Purpose This study aimed to examine the association of an 8-week boccia-based intervention with changes in upper extremity muscle thickness and grip strength in individuals with hemiparesis following stroke.

Methods A total of 22 stroke survivors were randomly allocated to a boccia group (Boc, $n = 12$) or a control group (Ctrl, $n = 10$). While the control group received conventional physical therapy for eight weeks, the boccia group participated in both physical therapy and boccia-based intervention three times per week. Upper extremity muscle thickness and grip strength were assessed before and after the intervention.

Results In the control group, a significant increase was observed only in the triceps brachii muscle thickness. In contrast, the boccia group demonstrated statistically detectable increases in forearm muscles (flexor digitorum profundus, flexor digitorum superficialis, pronator teres, and brachioradialis), triceps brachii muscle thickness, and grip strength.

Conclusion Incorporating boccia-based intervention into the rehabilitation programs of individuals with hemiparesis after stroke may be associated with broader upper extremity muscle involvement and concurrent improvements in grip strength. These findings should be interpreted as exploratory and hypothesis-generating.

Trial registration The trial registration number: NCT07254273 (<https://clinicaltrials.gov/study/NCT07254273>), Unique Protocol Id: E-15604681-100-234561 and the date of registration: 2025/11/13 (<https://register.clinicaltrials.gov/prs/beta/studies/S000GEKF00000050/recordSummary>). Retrospectively registered.

Keywords Stroke, Ultrasound, Upper extremity, Hemiparetic, Muscle thickness

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Introduction

Hemiplegia, characterized by paralysis on one side of the body resulting from cerebral vascular pathology, is a significant global health concern with an increasing prevalence due to population aging and lifestyle-related diseases [1–4]. Stroke-induced hemiplegia causes muscle paralysis accompanied by morphological and neuromuscular changes, including muscle atrophy and altered muscle characteristics, which negatively affect recovery. Although disuse syndrome occurs bilaterally after stroke, it is more pronounced on the hemiplegic side and contributes to impaired circulation and muscle loss [5]. These changes highlight the importance of ultrasonographic monitoring of muscle characteristics during the rehabilitation process [6, 7].

Sarcopenia, the age-related decline in muscle mass and quality, hinders recovery in elderly hemiplegic patients by causing muscle loss, weakness, prolonged hospitalization, and poorer outcomes [8]. Ultrasonography is a widely used and non-invasive method for assessing muscle architecture and thickness, enabling the detection of muscle atrophy and the monitoring of rehabilitation-related adaptations. Previous studies have demonstrated significant muscle weakness and reductions in muscle thickness on the affected side in subacute stroke patients [7–16].

Appendicular skeletal muscle mass predicts poor outcomes, emphasizing the role of muscle strength in rehabilitation [17]. Grip strength loss, a key indicator of sarcopenia, reflects reduced functional independence and is particularly relevant in individuals with hemiplegia. Assessments combining lean muscle mass and grip strength provide a more accurate prediction of clinical outcomes than muscle mass alone [18, 19].

Hand grip strength results from the coordinated action of intrinsic hand muscles (thenar, hypothenar, and interossei) and extrinsic forearm flexors, including the flexor digitorum profundus, flexor digitorum superficialis, and flexor pollicis longus [20]. Although the relationship between forearm muscle thickness assessed by ultrasonography and grip strength remains complex and only partially explored, grip strength is widely accepted as an indicator of overall muscle function [21, 22]. This is particularly relevant in hemiplegic patients, in whom impaired voluntary muscle activation influences rehabilitation outcomes [23]. The association between sarcopenia and functional decline further underscores the importance of assessing and improving grip strength during therapy [18]. Moreover, evidence suggests that increased exercise intensity and frequency contribute to greater improvements in motor function following stroke [24].

Boccia, a precision-based sport, offers considerable rehabilitation potential for individuals with severe motor

impairments such as hemiplegia and sarcopenia by promoting upper extremity muscle activation. Suárez-Iglesias, Pérez, Mendoza-Laiz, and Villa [25] demonstrated that Boccia is a feasible and engaging intervention that improves fine motor skills, although observed improvements were limited to specific joint movements [25]. While upper extremity muscle thickness has been associated with strength [26], this link has not been extensively explored in the context of Boccia or disabled populations. Nonetheless, Yahagi, Kataoka, Ichiba, and Imura [27] reported that repetitive movements in Boccia activate multiple muscle groups, enhancing mobility and muscle activity [27]. Similarly, Mesci, Dogruoz, Mesci, and İçağasioğlu [28] emphasized that changes in muscle-related measures have been reported to be associated with functional outcomes and quality of life [28]. These findings suggest that Boccia serves as a therapeutic and enjoyable activity that may encourage task-related neuromuscular engagement in individuals with hemiplegia.

Boccia is a promising rehabilitation method for improving muscle strength and function in hemiplegic individuals. While muscle atrophy post-stroke has been widely studied [7, 9, 11, 13–15], to date no randomized controlled trial has examined the effects of boccia-based intervention in post-stroke patients with special needs, highlighting a critical research gap. This study aimed to explore the association between an 8-week boccia-based intervention, adjunctive to conventional therapy, and changes in upper extremity muscle thickness measures and grip strength in individuals with post-stroke hemiplegia.

Methods

Study design

This study was presented as an oral presentation at the 11th International Congress of Science, Culture, and Sports (March 31 – April 6). This study is registered as a randomized controlled trial at ClinicalTrials.gov.tr under the NCT number: NCT07254273. The study adheres to CONSORT guidelines. In this randomized controlled trial, a true experimental pretest-posttest control group design was adopted to examine the effects of an 8-week boccia-based intervention on upper extremity muscle architecture and grip strength in hemiparetic individuals, in addition to the ongoing rehabilitation program. Based on previous evidence suggesting that boccia-based activities may support motor skill development, the intervention was implemented for 8 weeks [29]. Hemiparetic participants attended physical therapy sessions at the rehabilitation center three times per week. The experimental group participated in boccia-based intervention sessions for one hour, three times per week in addition to their physical therapy, whereas the control group attended only the physical therapy sessions.

Upper extremity muscle thickness and grip strength of all participants were measured at the beginning and end of the boccia-based intervention program using the same standardized evaluation protocol. To ensure measurement standardization, participants refrained from physical therapy sessions within the 48 h prior to assessment and abstained from caffeine and alcohol for 24 h before measurements. Assessments were conducted in the same order and under identical conditions for each participant. To minimize measurement error, two independent evaluators were assigned: Evaluator 1 performed all measurements in a blinded manner, while Evaluator 2 solely administered the boccia-based intervention program. Participants were regularly monitored throughout the study to prevent possible injuries or complications. Individuals participating in boccia-based intervention trained under the supervision of a physiotherapist and a Boccia coach. The collected data were subjected to statistical analyses to determine differences between the experimental and control groups (Fig. 1).

Participants

This study was conducted at the Akran Academy Special Education Center located in Bayburt province. The

participants consisted of individuals diagnosed with hemiparesis who developed weakness, changes in muscle tone, and movement limitations on one side of the body following a stroke. Inclusion criteria were defined as being between 18 and 65 years of age, having experienced a stroke at least 12 months prior (chronic hemiparesis), exhibiting unilateral muscle weakness, and having a diagnosis confirmed by a neurology specialist. Individuals with musculoskeletal or cardiovascular diseases or injuries were excluded from the study. Informed consent was obtained from all participants prior to inclusion, and the study was conducted in accordance with the Helsinki Declaration. Furthermore, the research was carried out in compliance with relevant ethical guidelines and regulations, with confirmation that all participants provided consent. Since no prior randomized controlled trials have investigated the effects of boccia-based interventions on hemiparetic individuals, sample size determination was based on findings from other studies involving hemiparetic stroke patients. The sample size calculation was performed using GPower 3.1 software. During analysis, the effect size (eta squared, $\eta^2 = 0.6$) and statistical power ($1 - \beta = 0.80$) obtained from previous studies were considered to determine the number of participants [30]. At the start of the study, each group

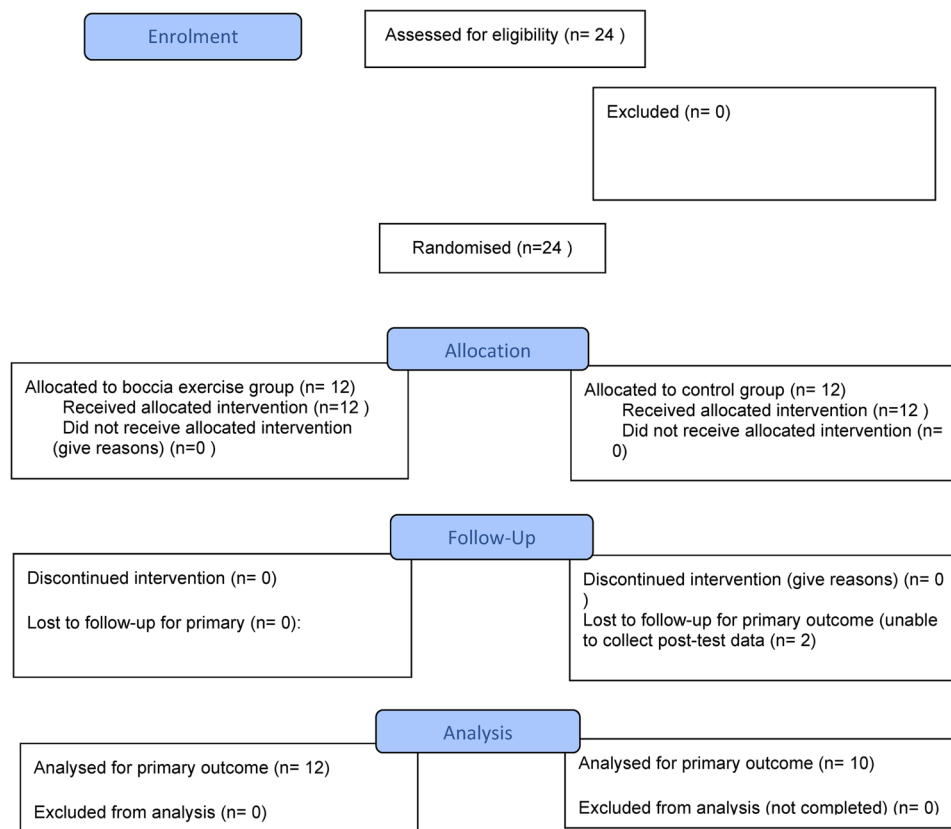


Fig. 1 Flowchart of the Study

Table 1 Demographic characteristics of the participants

Variable	Boccia Group (n = 12)	Control Group (n = 10)
Age (years)	46.41 ± 13.14	50.10 ± 10.94
Height (m)	167.75 ± 8.58	167.70 ± 7.70
Weight (kg)	72.41 ± 12.52	74.30 ± 12.00

Data are presented as mean ± standard deviation (SD)

included 12 individuals, resulting in a calculated GPower value of 0.8861608. However, as 2 participants in the control group were unable to continue, the study proceeded with 22 individuals. Although this reduced the power value to 0.8592425, it remained within the statistically acceptable range. Due to the small number of dropouts, analyses were performed on a per-protocol basis, and no intention-to-treat analysis was conducted. To minimize bias, participants were randomly assigned to intervention and control groups using a computer-generated randomization sequence, and allocation was concealed via sealed opaque envelopes prepared by an independent researcher. Participant enrollment was conducted by the rehabilitation center staff, while group allocation was performed by an independent researcher not involved in assessments or interventions. Groups were matched based on participants' baseline age, height, and weight. Additionally, demographic data of the participants are presented in Table 1. This research was approved by the Bayburt University Ethics Committee under decision number E-15604681-100-234561. In this study, the language model ChatGPT (OpenAI, GPT-4.0) was used. The artificial intelligence tool was used for language editing only, with no role in data analysis or interpretation.

Procedures: interventions

After random allocation of the groups, the participants assigned to the boccia-based intervention group received flexibility training three times per week. This training consisted of static stretching exercises targeting the upper body and an introduction to basic boccia throwing techniques, conducted over two weeks. Following the initial two weeks, all participants continued with a physical therapy program at the rehabilitation center three times weekly. The boccia group performed one boccia-based intervention session on the same days as the physical therapy sessions. After teaching the basic throwing techniques during the first two weeks, more complex boccia throwing techniques were applied throughout the subsequent four weeks. Additionally, a boccia match was played at the end of each intervention session. During the final four weeks, task complexity and repetition volume were progressively increased with a focus on throwing tactics. In addition, task complexity and repetition volume were progressively increased by incorporating a higher number of throws per session

Table 2 Boccia exercise intervention protocol for hemiparetic participants: preparation and 8-week training phases

Parameter	Boccia Group	Control Group
Preparation phase	Weeks 0–2: Static stretching + introduction to basic Boccia throwing techniques	Physical therapy only
Total intervention duration	8 weeks	8 weeks
Frequency	3 sessions/week	3 sessions/week (physical therapy only)
Session duration	45–60 min	45–60 min
Weeks 1–4 (Skill development)	More complex Boccia throwing techniques + Boccia match at end of each session	Physical therapy only
Weeks 5–8 (Performance & tactics)	Increased intensity, focus on throwing tactics + Boccia match at end of each session	Physical therapy only
Warm-up	5–10 min of upper body stretching and joint mobility	Same as Boccia group
Supervision	Boccia coach and physiotherapist	Physical therapist

and competition-like match procedures. All intervention sessions were supervised by a boccia coach and a physiotherapist. During the boccia-based intervention sessions, participants performed all throwing and rolling movements primarily with their hemiparetic upper extremity using a standard boccia ball. Intervention consisted mainly of underhand rolling and short-distance throwing movements, which are commonly used in boccia practice. The initial throwing distance was set at approximately 2–3 m and was progressively increased to 4–6 m according to individual capability and safety considerations. Each session included approximately 30–40 throws during the first four weeks, which was gradually increased to 60–80 throws per session during the final four weeks. Rest intervals between sets were standardized at 60–90 s.

The physical therapy program applied to both groups consisted of passive and active upper extremity range-of-motion intervention, stretching, and low-intensity functional activities, and did not include task-specific throwing, repetitive gripping, or resistance-based upper limb intervention. Therefore, the boccia intervention represented an additional task-oriented and repetitive activation of the hemiparetic upper extremity beyond standard rehabilitation care.

The control group did not participate in boccia-based intervention and received only the physical therapy program. The intervention lasted a total of eight weeks, as shown in Table 2. The final ultrasonographic and grip strength measurements were conducted at time points corresponding to the initial assessments, as shown in Fig. 2.



Fig. 2 Overview of the bocchia-based intervention within the rehabilitation program for individuals with hemiplegia

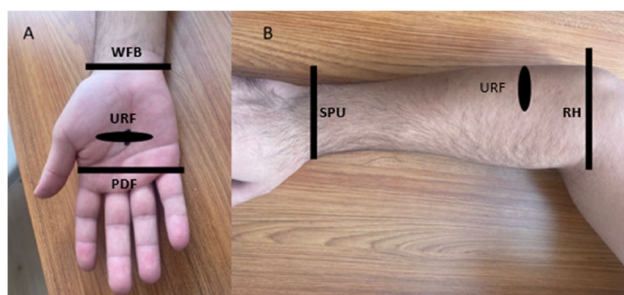


Fig. 3 Ultrasound measurement sites of the hand (A) and forearm (B). WFB: Wrist flexion bend. PDF: Palmar digital fold. URF: Ultrasound reference point. SPU: Styloid process of the ulna. RH: Radius head

Bocchia Bocchia-Based Intervention Protocol for Hemiparetic Participants: Preparation and 8-Week Training Phases.

Procedures: outcome measures

Upper extremity muscle thickness

The primary outcome of the study was the change in upper extremity muscle thickness assessed by ultrasonography, while grip strength was considered the secondary outcome measure. Muscle thickness measurements of the participants were performed using a SonoHealth brand dual-sector + linear probe B-mode ultrasound device. For the ultrasonographic imaging of upper

extremity muscle architecture, measurements were taken at a point marked at 55% of the distal distance between the palmar digital crease and the wrist flexion crease, as shown in Fig. 3 (A). The ultrasound images of the forearm muscles, depicted in Fig. 3 (B), were acquired at a point marked at 30% of the proximal distance between the ulnar styloid process and the radial head [31].

For the measurement of biceps brachii and brachialis muscle thickness, images were obtained from the mid-point of the muscle as described by García et al. [32]. Triceps brachii muscle thickness was measured at a point marked at 60% distal between the lateral epicondyle of the humerus and the acromial process of the shoulder [33]. Measurements of anterior deltoid muscle thickness were taken from a point marked 5 cm medial to the bicipital groove of the humerus, corresponding to the thickest region of the muscle.

After measuring limb length using anatomical landmarks, all measurement sites were marked with a skin-safe marker. During the measurements, participants kept their elbows in a relaxed position. The ultrasound scanning points were covered with a water-based transmission gel to ensure acoustic coupling and to minimize probe pressure for obtaining clear images. The probe was placed on the skin surface over the measurement region by an experienced operator applying minimal pressure, and transverse cross-sectional images of each muscle were acquired. Three images were taken from each site, and the average values for each region were used in data analysis. On the ultrasound images, the subcutaneous fat-muscle interface and the muscle-bone interface were identified, and the distance between these two interfaces was considered as the muscle thickness for limb muscles. The images were transferred to publicly available software (ImageJ v1.46; National Institutes of Health, Bethesda, MD, USA) for length measurements. Blinding was applied during the measurement process to minimize bias.

Although formal intra- and inter-rater reliability analyses were not conducted within the present study, all measurements were performed by the same experienced operator following a standardized protocol, and repeated measurements were averaged to reduce random error.

Grip strength

Grip strength of the hemiparetic upper extremity was measured using a standardized seated testing protocol, with participants seated in a chair with back support. The arm was positioned in adduction, the elbow flexed at 90°, the forearm in a neutral position, and the wrist extended between 0° and 30°. Grip strength measurements were taken three times using a Jamar Hydraulic Hand Dynamometer, and the highest value obtained was recorded [34].

Statistical analysis

Statistical analyses were conducted using IBM SPSS Statistics version 21.0. Descriptive statistics are presented as mean $\pm$ standard deviation or n (percentage). The normality of the data distribution was assessed using the Shapiro-Wilk test. Based on the assumption of normal distribution, categorical variables between groups were compared using the Chi-square test or Fisher's exact test. Separate two-way repeated measures ANOVAs (Time $\times$ Group) were conducted for each muscle and strength parameter. Given the exploratory nature of the study and the multiple outcome variables, p-values are reported as nominal without adjustment for multiple comparisons. Where a significant Time $\times$ Group interaction was detected, exploratory pairwise comparisons were performed to examine differences between pre- and post-test values in each group. A p-value of ≤ 0.05 was considered statistically significant for all analyses.

Results

According to the repeated measures ANOVA results, no significant changes were observed in M. Lumbricales muscle thickness with respect to time, group, or time $\times$ group interaction ($p > 0.05$). A significant main effect of time was found for M. Interosseous muscle thickness ($F(1,20) = 4.678$, $p = 0.043$, $\eta^2 = 0.190$), indicating a large effect of time, whereas group effect and time $\times$ group interaction were not statistically significant ($p > 0.05$). For radius MT muscle thickness, significant effects of time ($F(1,20) = 6.986$, $p = 0.016$, $\eta^2 = 0.259$) and time $\times$ group interaction ($F(1,20) = 5.547$, $p = 0.029$, $\eta^2 = 0.217$) were observed, representing large and moderate effects, respectively, while the group effect was not significant

($p = 0.772$). Similarly, for ulna MT muscle thickness, both time effect ($F(1,20) = 11.360$, $p = 0.003$, $\eta^2 = 0.362$) and time $\times$ group interaction ($F(1,20) = 7.338$, $p = 0.014$, $\eta^2 = 0.268$) were significant, indicating large effects, with no significant group effect ($p = 0.968$). A significant main effect of time was also observed for M. Triceps brachii muscle thickness ($F(1,20) = 8.071$, $p = 0.010$, $\eta^2 = 0.288$), reflecting a large effect of time, whereas the group effect was not significant ($p = 0.952$), and the time $\times$ group interaction approached significance ($p = 0.058$). No significant changes were found in M. Biceps brachii + M. Brachialis muscle thickness ($p > 0.05$). For M. Deltoideus muscle thickness, a significant group effect was observed ($F(1,20) = 6.052$, $p = 0.023$, $\eta^2 = 0.232$), indicating a large effect of group, while neither time nor time $\times$ group interaction effects were significant ($p > 0.05$), as shown in Table 3.

Regarding strength parameters, grip strength showed significant main effects of time ($F(1,20) = 12.282$, $p = 0.002$, $\eta^2 = 0.380$) and time $\times$ group interaction ($F(1,20) = 6.765$, $p = 0.017$, $\eta^2 = 0.253$), indicating large and moderate effects, respectively, while the group effect was not significant ($p = 0.990$). No significant changes were observed for pinching strength ($p > 0.05$), as presented in Table 4.

As shown in Table 5, the Boccia group exhibited significant increases in Radius and Ulna muscle thickness and handgrip strength between pre- and post-tests ($p < 0.05$). No significant changes were observed in the control group. The Time $\times$ Group interactions indicated that the increases in the Boccia group were significantly greater than those in the control group ($p < 0.05$).

Table 3 Repeated measures ANOVA results for time, group, and time $\times$ group interactions on upper extremity muscle thickness, along with pre-test and post-test mean $\pm$ standard deviation values

Muscle Thickness	Group	N	Pre-Test Mean $\pm$ SD	Post-Test Mean $\pm$ SD	Time Effect (F, p, η^2)	Group Effect (F, p, η^2)	Time $\times$ Group Interaction (F, p, η^2)
M. Lumbricales MT (mm)	Boc	12	4.58 $\pm$ 0.19	4.69 $\pm$ 0.24	$F(1,20) = 2.253$, $p = 0.149$, $\eta^2 = 0.101$	$F(1,20) = 1.297$, $p = 0.268$, $\eta^2 = 0.061$	$F(1,20) = 0.043$, $p = 0.838$, $\eta^2 = 0.002$
	Ctrl	10	4.21 $\pm$ 0.21	4.36 $\pm$ 0.26			
M. Interosseous MT (mm)	Boc	12	8.03 $\pm$ 0.35	8.54 $\pm$ 0.32	$F(1,20) = 4.678$, $p = 0.043$, $\eta^2 = 0.190$	$F(1,20) = 0.178$, $p = 0.677$, $\eta^2 = 0.009$	$F(1,20) = 3.903$, $p = 0.062$, $\eta^2 = 0.163$
	Ctrl	10	8.07 $\pm$ 0.38	8.10 $\pm$ 0.35			
Radius MT (mm)	Boc	12	17.55 $\pm$ 4.38	19.22 $\pm$ 4.18	$F(1,20) = 6.986$, $p = 0.016$, $\eta^2 = 0.259$	$F(1,20) = 0.086$, $p = 0.772$, $\eta^2 = 0.004$	$F(1,20) = 5.547$, $p = 0.029$, $\eta^2 = 0.217$
	Ctrl	10	17.81 $\pm$ 4.30	17.91 $\pm$ 4.06			
Ulna MT (mm)	Boc	12	28.63 $\pm$ 1.33	31.23 $\pm$ 1.39	$F(1,20) = 11.360$, $p = 0.003$, $\eta^2 = 0.362$	$F(1,20) = 0.002$, $p = 0.968$, $\eta^2 = 0.000$	$F(1,20) = 7.338$, $p = 0.014$, $\eta^2 = 0.268$
	Ctrl	10	29.87 $\pm$ 1.45	30.15 $\pm$ 1.52			
M. Triceps Brachii MT (mm)	Boc	12	17.18 $\pm$ 0.19	19.45 $\pm$ 0.24	$F(1,20) = 8.071$, $p = 0.010$, $\eta^2 = 0.288$	$F(1,20) = 0.004$, $p = 0.952$, $\eta^2 = 0.000$	$F(1,20) = 4.027$, $p = 0.058$, $\eta^2 = 0.168$
	Ctrl	10	18.00 $\pm$ 0.21	18.39 $\pm$ 0.26			
M. Biceps brachii + M. Brachialis MT (mm)	Boc	12	35.25 $\pm$ 8.00	37.02 $\pm$ 6.35	$F(1,20) = 1.759$, $p = 0.200$, $\eta^2 = 0.081$	$F(1,20) = 0.196$, $p = 0.663$, $\eta^2 = 0.010$	$F(1,20) = 1.467$, $p = 0.240$, $\eta^2 = 0.068$
	Ctrl	10	34.70 $\pm$ 7.79	34.78 $\pm$ 8.01			
M. Anterior Deltoideus MT (mm)	Boc	12	11.88 $\pm$ 0.51	11.87 $\pm$ 0.49	$F(1,20) = 0.013$, $p = 0.911$, $\eta^2 = 0.001$	$F(1,20) = 6.052$, $p = 0.023$, $\eta^2 = 0.232$	$F(1,20) = 0.003$, $p = 0.957$, $\eta^2 = 0.000$
	Ctrl	10	10.01 $\pm$ 0.56	9.99 $\pm$ 0.54			

MT Muscle Thickness Boc, Boccia group Ctrl: Control group $\bar{X} \pm S D$ $\bar{X} \pm S D$: Mean $\pm$ Standard Deviation F: F value p: Significance level η^2 2: Effect size (eta squared) Time effect, group effect, and time $\times$ group interactions were analyzed using repeated measures ANOVA. A significance level of $p < 0.05$ $p < 0.05$ was considered statistically significant

Table 4 Repeated measures ANOVA results for time, group, and time $\times$ group interactions on strength parameters, along with pre-test and post-test mean $\pm$ standard deviation values

Strength Parameters	Group	N	Pre-Test Mean $\pm$ SD	Post-Test Mean $\pm$ SD	Time Effect (F, p, η^2)	Group Effect (F, p, η^2)	Time $\times$ Group Interaction (F, p, η^2)
Grip Strength (kg)	Boc	12	11.583 $\pm$ 2.496	14.083 $\pm$ 2.818	F(1,20)=12.282, p=0.002, η^2 =0.380	F(1,20)=0.000, p=0.990, η^2 =0.000	F(1,20)=6.765, p=0.017, η^2 =0.253
	Ctrl	10	12.600 $\pm$ 2.735	12.970 $\pm$ 3.086			
Pinching Strength (kg)	Boc	12	5.850 $\pm$ 1.040	6.167 $\pm$ 1.062	F(1,20)=0.523, p=0.478, η^2 =0.025	F(1,20)=0.032, p=0.861, η^2 =0.002	F(1,20)=0.078, p=0.783, η^2 =0.004
	Ctrl	10	6.210 $\pm$ 1.140	6.350 $\pm$ 1.163			

Boccia group Ctrl: Control group $\bar{X} \pm S D$ $\bar{X} \pm SD$: Mean $\pm$ Standard Deviation F: F value p: Significance level η^2 : Effect size (eta squared) Time effect, group effect, and time $\times$ group interactions were analyzed using repeated measures ANOVA. A significance level of $p < 0.05$ was considered statistically significant

Table 5 Post hoc comparisons of pre- and post-test measurements and time $\times$ group effects in boccia and control groups

Variable	Group	Comparison	Mean Difference (I-J)	p (Bonferroni)	95% CI (Lower-Upper)
Radius MT (mm)	Boccia	Pre vs. Post	-1.67	0.016	-1.58 - -0.19
	Control	Pre vs. Post	-0.10	0.772	-3.20-4.24
	Time $\times$ Group	(Δ Boccia - Δ Control)	-1.57	0.029	-2.85 - -0.29
Ulna MT (mm)	Boccia	Pre vs. Post	-2.60	0.014	-4.79 - -0.41
	Control	Pre vs. Post	-0.28	0.968	-4.19-3.63
	Time $\times$ Group	(Δ Boccia - Δ Control)	-2.32	0.014	-4.38 - -0.26
Grip Strength (kg)	Boccia	Pre vs. Post	2.500*	0.002	0.581-2.289
	Control	Pre vs. Post	0.370	0.678	-0.581-1.321
	Time $\times$ Group	(Δ Boccia - Δ Control)	2.130*	0.017	0.348-3.912

Significant difference at $p < 0.05$ (Bonferroni-adjusted). Pre Pre-test, Post Post-test, Δ change from pre- to post-test

Figure 4 shows that no significant differences were observed between the Boccia and control groups in terms of muscle thickness ($p > 0.05$). Similarly, no significant time effects were detected for most muscles. However, at the pre-test, the Boccia group exhibited significantly greater muscle thickness in the M. interosseous and radius muscles compared with the control group ($p < 0.01$). This difference disappeared at the post-test ($p > 0.05$). For the M. lumbricales and ulna muscles, no significant changes were found across time or between groups ($p > 0.05$).

Figure 5 shows that the analysis revealed a significant difference between the Boccia and control groups in the pre-test measurements of the M. triceps brachii muscle ($p < 0.01$). However, this difference disappeared in the post-test, and no significant difference was found between the groups ($p > 0.05$). No significant changes over time were observed in either group ($p > 0.05$). For the M. biceps brachii + M. brachialis and M. deltoideus muscles, no significant effects of group or time were observed ($p > 0.05$).

Discussion

Numerous studies have investigated muscle atrophy in the upper limbs of hemiparetic individuals following stroke [7, 9, 11, 13–15]. However, there is a lack of research examining the effects of intervention programs specifically designed for individuals with special needs on muscle thickness in hemiparetic patients. Therefore,

the purpose of this study was to explore the association between participation in a boccia-based intervention and changes in upper extremity muscle thickness and grip strength in hemiparetic individuals. To the best of our knowledge, this study represents an exploratory investigation examining upper extremity muscle thickness assessed by ultrasonography in individuals with hemiparesis participating in boccia-related activities.

Although randomization was performed appropriately, baseline differences were observed in selected muscle thickness variables between the intervention and control groups. These differences do not invalidate the findings; however, they should be taken into consideration when interpreting between-group comparisons, as baseline muscle characteristics may have partially influenced the magnitude of observed changes.

Our results suggest that participation in the boccia intervention was associated with statistically significant changes over time in muscle thickness of the radius-related muscles (pronator teres and brachioradialis), ulna-related muscles (flexor digitorum profundus and flexor digitorum superficialis), and the triceps brachii, as well as improvements in grip strength. However, no significant effects were observed on the muscle thickness of the lumbricales, dorsal interosseous, biceps brachii + brachialis, deltoideus muscles, or on pinching strength.

Strength training has been shown to be effective in improving muscle strength and functional recovery in hemiparetic individuals [35]. In particular, structured resistance-based approaches such as Thera-Band and elastic resistance protocols have been associated with

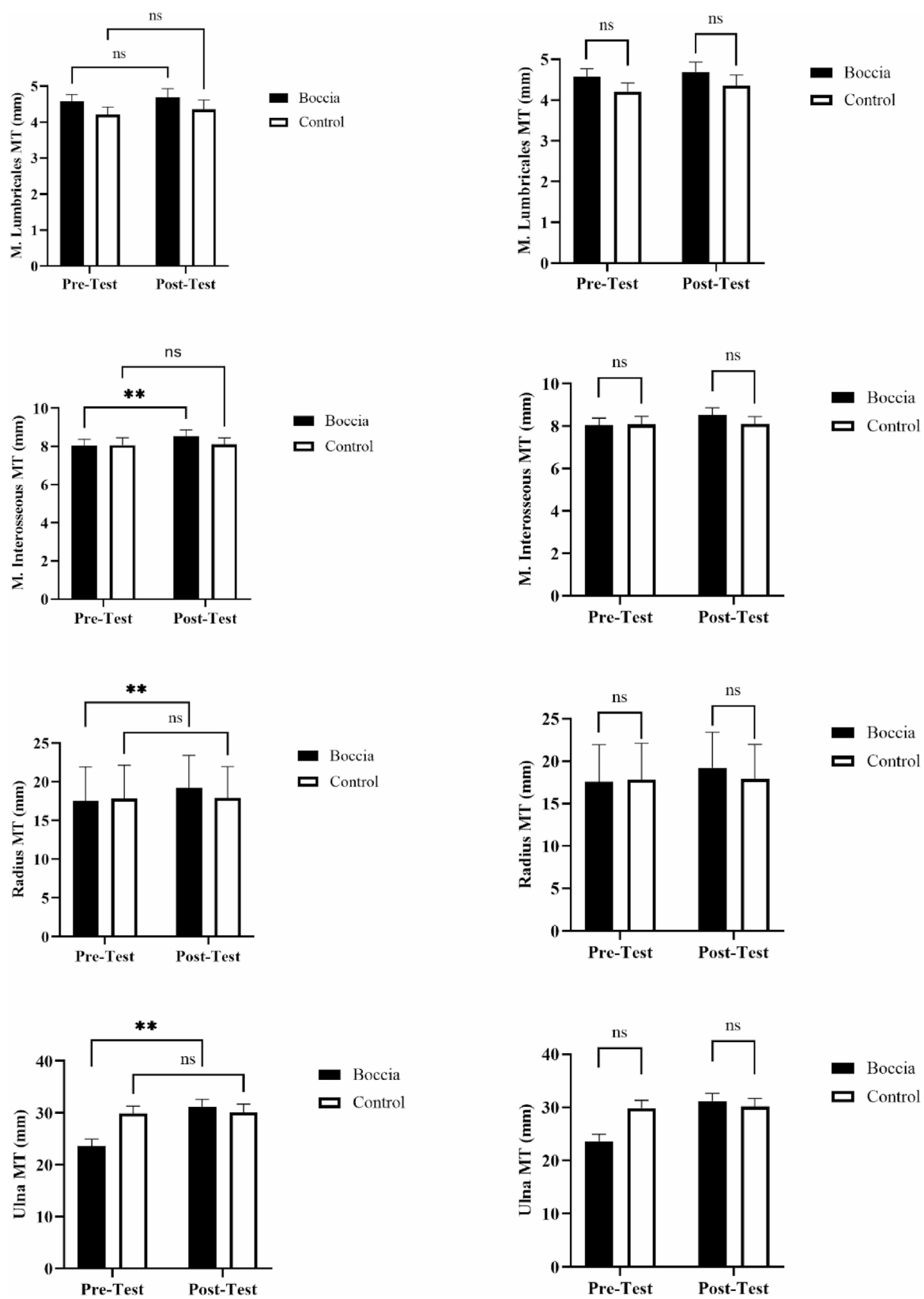


Fig. 4 Graphical presentation of muscle thickness of M. lumbricales, M. interosseus, radius, and ulna muscles over time and between groups

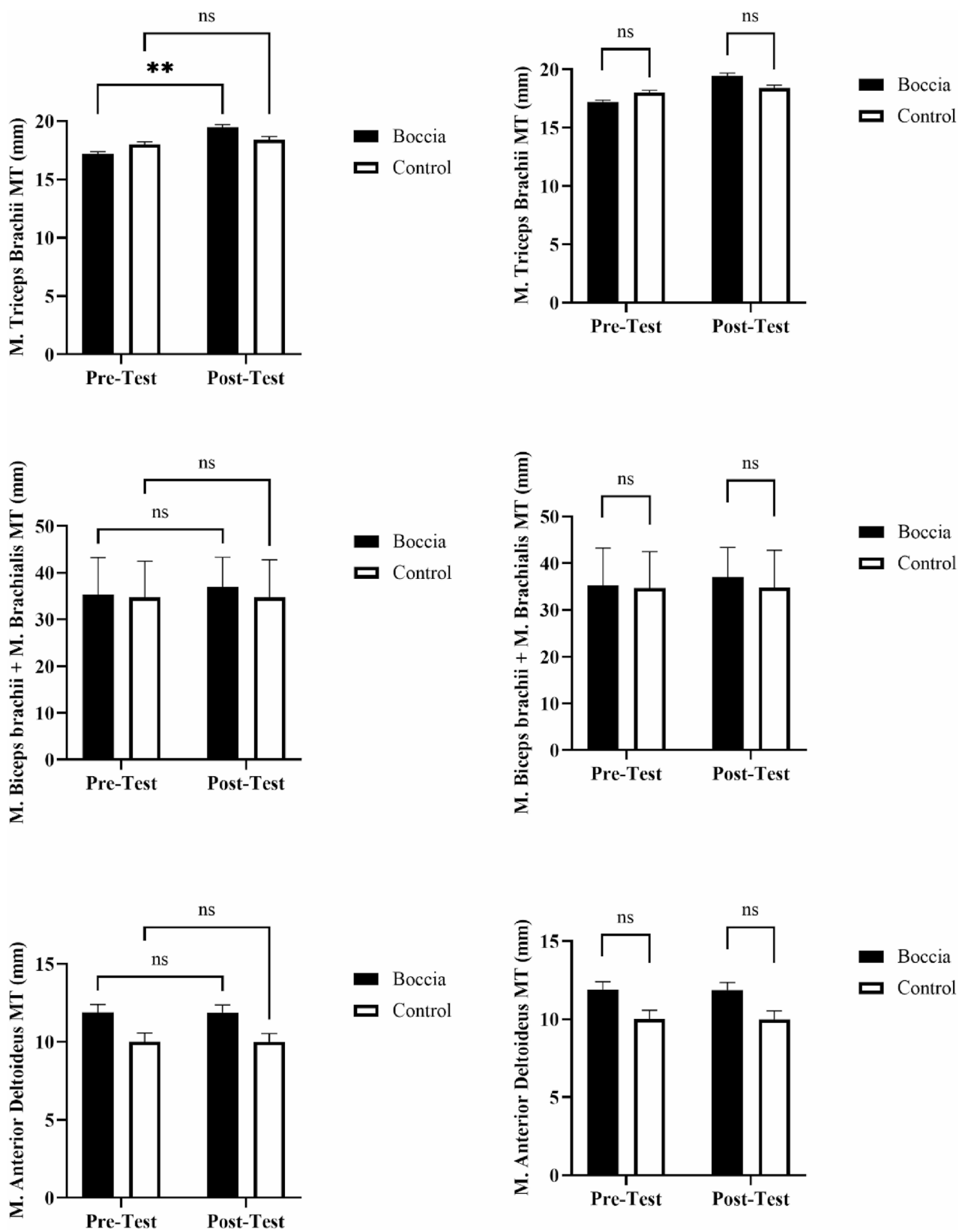


Fig. 5 Graphical presentation of muscle thickness of M. triceps brachii, M. biceps brachii+M. brachialis, and M. anterior deltoideus muscles over time and between groups

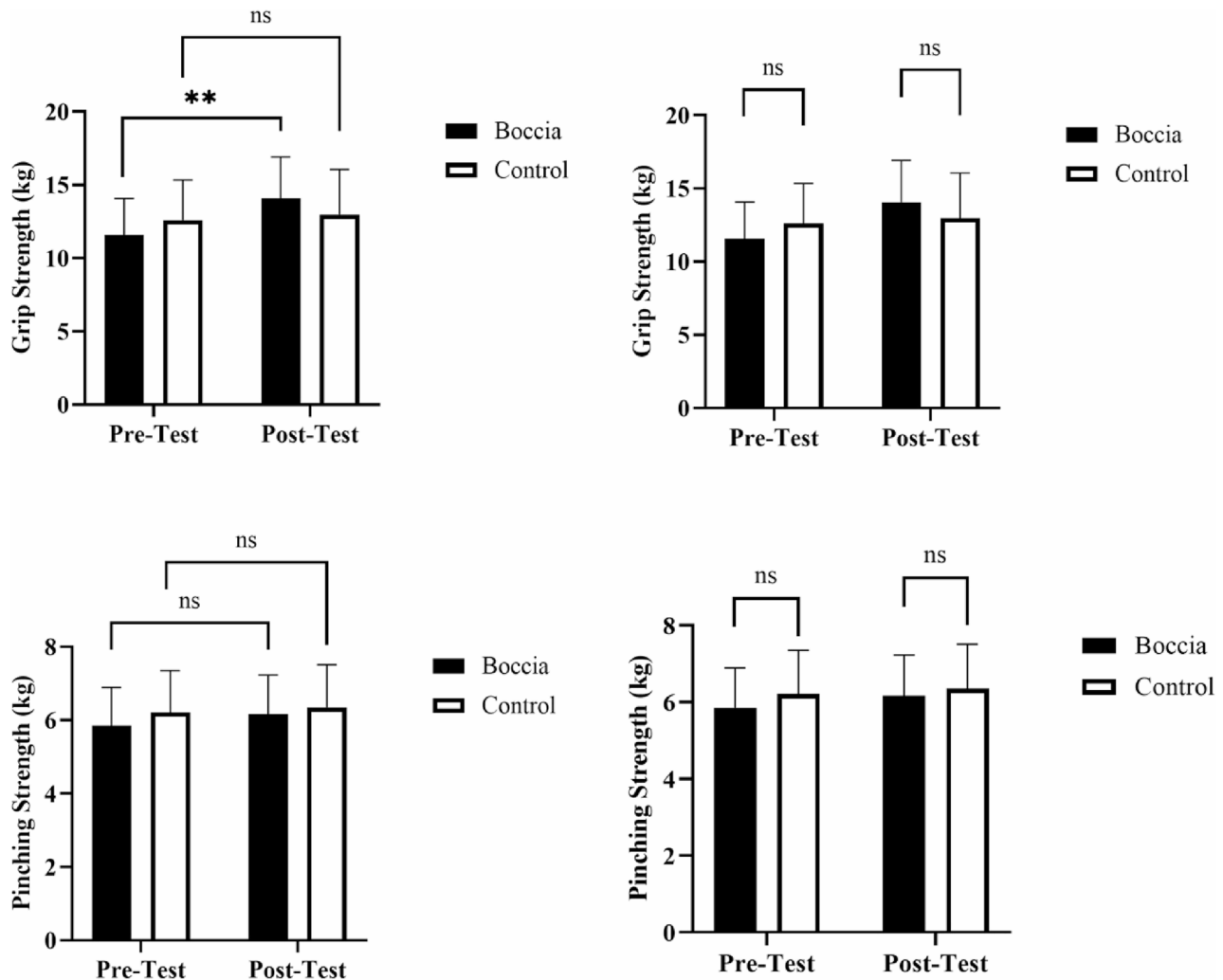


Fig. 6 Graphical presentation of grip and pinching strength over time and between groups

increased muscle activation and enhanced upper extremity function [36]. However, these interventions typically involve externally applied and progressively overloaded resistance, which differs from the low-load, coordination-focused nature of Boccia-based interventions. Task-oriented and resistance-focused training programs have also been reported to improve muscular balance and neuromuscular control [37–39], whereas Boccia primarily emphasizes precision, motor control, and repetitive movement patterns rather than maximal force production. Therefore, while resistance-based strength training may induce more pronounced structural and strength-related adaptations, the relatively modest changes observed in the present study may be attributed to the distinct mechanical and neuromuscular demands of the Boccia-based intervention.

On the other hand, boccia-based interventions have been proposed as a task-oriented activity that may support upper extremity function in individuals with

motor impairments. Studies have demonstrated that boccia training improves muscle strength, coordination, and range of motion in individuals with motor impairments [25].

The rolling and throwing actions inherent to boccia involve repetitive, goal-directed movements that engage upper extremity and trunk musculature, potentially facilitating motor control and movement efficiency [27]. However, these functional gains are likely mediated by neuromuscular coordination and task-specific motor learning, rather than by substantial morphological adaptations.

Additionally, the strategic components of boccia-based interventions may increase cognitive engagement, which could support motor coordination and task-specific motor performance. Compared to conventional upper extremity training approaches, boccia provides a game-based context that integrates physical activity with cognitive demands, potentially enhancing motivation and

adherence to rehabilitation programs. Beyond physical outcomes, participation in boccia may offer psychosocial benefits through increased social interaction and engagement in meaningful activity. Improvements in intrinsic hand muscle function and upper extremity strength can facilitate interaction with the environment and participation in daily living activities, which may indirectly support psychosocial well-being rather than constituting a direct causal effect.

In this context, the analysis of *M. lumbricales* muscle thickness showed no significant effects of time, group, or time $\times$ group interaction. These findings indicate that the applied intervention did not result in detectable changes in muscle thickness as assessed by ultrasonography. For the *M. interosseous* muscles, a significant main effect of time was observed, suggesting a change in muscle thickness across the study period in both groups. However, the absence of significant group and time $\times$ group interaction effects indicates that this change cannot be specifically attributed to the boccia-based intervention. Taken together, these results suggest that while minor time-dependent changes in intrinsic hand muscle thickness may occur, the applied intervention did not elicit intervention-specific structural alterations detectable with the present methodology.

The significant effects of time and time $\times$ group interaction observed in muscle thickness around the radius and ulna indicate that muscle thickness in these regions changed over time, with a more pronounced increase in the intervention group compared to the control group. However, these changes should not be interpreted as definitive hypertrophic adaptations. Given the low-load, skill-oriented nature of boccia, the observed increases in muscle thickness may reflect activity-related neuromuscular adaptations rather than classical load-induced hypertrophy. Short-term changes in ultrasound-measured muscle thickness may be influenced by multiple non-hypertrophic factors, including alterations in resting muscle tone, increased neural activation, changes in muscle coordination, or transient fluid redistribution within the muscle tissue. Therefore, the present findings should be interpreted as indicative of structural or neuromuscular responsiveness to repeated upper-limb activity, rather than evidence of targeted hypertrophic remodeling. This interpretation aligns with the exploratory nature of the study and acknowledges the physiological characteristics of boccia as a precision-based, low-resistance activity.

Abe et al. [20] demonstrated significant correlations between grip strength and the muscles surrounding the lateral forearm bones, namely the radius (e.g., pronator teres, brachioradialis) and ulna (e.g., flexor digitorum profundus, flexor digitorum superficialis) [20]. Similarly, in the present study, increases in muscle thickness around both the radius and ulna were observed following

boccia based intervention. The throwing motions performed during boccia require coordinated movement of the elbow and forearm, actively engaging the pronator teres muscle and potentially leading to measurable changes in muscle thickness associated with repeated task-specific use [40]. Additionally, this intervention, which involve simultaneous action of the hand and arm, activate the brachioradialis muscle, may contribute to improvements in force production through enhanced neuromuscular engagement.

Indeed, Yu et al. [41] reported that regular exercise improves the functional contribution of the brachioradialis muscle and overall upper extremity strength [41]. Furthermore, the repetitive gripping and throwing movements performed during boccia also engage the flexor digitorum profundus and flexor digitorum superficialis muscles surrounding the ulna, resulting in localized increases in muscle thickness in these regions. These changes may facilitate stronger and more controlled finger movements by supporting neuromuscular coordination and task-specific force generation. Collectively, these findings suggest that boccia boccia-based intervention may contribute to functionally relevant morphological and neuromuscular adaptations that support improvements in motor performance.

The absence of significant changes in the *M. biceps brachii* and *M. brachialis* muscles suggests that the applied boccia-based intervention was not associated with detectable alterations in muscle thickness in this region. Although these muscles are involved in ball pushing and control during boccia activities, the level of neuromuscular engagement elicited by the intervention may not have been sufficient to produce measurable thickness changes under the present conditions. Previous studies have reported that morphological responses of the biceps brachii vary depending on task characteristics, population, and methodological approach [42, 43]. However, evidence regarding consistent muscle thickness changes in this muscle group, particularly in neurologically impaired populations, remains limited.

In the present study, the poor muscle tissue quality commonly observed in hemiparetic individuals prevented clear visualization of the aponeurotic boundary between the biceps brachii and brachialis muscles. Consequently, muscle thickness was assessed as a combined region, which may have further limited sensitivity to subtle changes. Taken together, these findings suggest that the boccia-based intervention, as implemented in this protocol, was not associated with measurable changes in biceps brachii–brachialis muscle thickness.

The significant main effect of time and the borderline significant time $\times$ group interaction observed in the thickness of the *M. triceps brachii* suggest that this muscle demonstrates time-dependent development, with

potentially more pronounced but not statistically robust improvements in the intervention group. The non-significant group effect suggests that the two groups were comparable at baseline. Together, these findings indicate that changes in triceps brachii thickness occurred over time, but a clear intervention-specific effect could not be definitively established.

Previous studies have shown that low-load, repetitive upper-limb activities may be associated with increases in triceps brachii muscle thickness under certain conditions [44]. For example, Kikuchi and Nakazato [44] reported measurable increases in triceps brachii thickness following low-intensity bodyweight-based movement tasks [44]. Although the movement patterns involved in such tasks share superficial similarities with the repetitive and directional upper-limb actions performed during bocia, direct comparability remains limited. In the present study, increases in triceps brachii thickness were observed over time in both participants receiving standard physical therapy and those exposed to the additional bocia-based intervention. This pattern suggests that the observed changes may reflect general time-dependent or rehabilitation-related factors rather than a specific effect attributable solely to bocia. Accordingly, while the bocia-based intervention may contribute to upper-limb engagement, the present findings do not allow firm conclusions regarding its distinct influence on triceps brachii muscle thickness. Further studies with refined intervention characterization and analytical control are required to clarify this issue.

The significant group effect observed in M. deltoideus muscle thickness reflects a baseline difference between the intervention and control groups. In contrast, the absence of significant time and time $\times$ group interaction effects indicates that no meaningful change in deltoideus muscle thickness occurred over the study period. Accordingly, the findings do not support a time-dependent or intervention-specific alteration in anterior deltoideus thickness associated with the bocia-based intervention. In the present study, anterior deltoideus muscle thickness remained statistically unchanged across the intervention period ($p > 0.05$), suggesting that the applied bocia-based intervention did not provide a sufficient stimulus to elicit measurable structural modification in this muscle. These results should be interpreted cautiously, particularly in light of the pre-existing baseline differences between groups, which may confound group-level comparisons.

The present findings are consistent with previous reports indicating that changes in neuromuscular activation of the deltoideus do not necessarily correspond to detectable alterations in muscle thickness, especially in hemiparetic populations. Deniz et al. [45] demonstrated that EMG biofeedback-supported shoulder tasks

primarily modified activation patterns rather than muscle morphology [45]. Similarly, Campos et al. [46] reported that substantial anterior deltoideus activation is more commonly observed during traditional resistance-based tasks, whereas low-load, coordination-oriented activities are associated with limited structural engagement [46]. In addition, Xie et al. [47] reported no significant changes in anterior deltoideus thickness following upper-limb rehabilitation interventions in individuals with stroke [47]. Collectively, these findings suggest that the observed deltoideus responses in the present study are more likely attributable to baseline characteristics and general rehabilitation exposure rather than to a distinct structural effect of the bocia-based intervention.

Importantly, the baseline differences observed between groups should be considered a potential confounding factor when interpreting post-intervention outcomes, as these pre-existing disparities may have influenced the observed group effects independently of the bocia-based intervention. Taken together, these findings suggest that the low loading characteristics and high motor coordination demands inherent to the bocia-based intervention may be insufficient to induce detectable changes in anterior deltoideus muscle thickness in individuals with hemiparesis.

The significant effects of time and the time $\times$ group interaction on grip strength indicate a marked improvement in grip force among individuals in the based intervention group. The non-significant group effect suggests that both groups demonstrated comparable baseline strength levels. Conversely, the absence of significant changes in pinching strength indicates that the applied based intervention did not adequately address the specific neuromuscular requirements necessary to improve pinching performance. These findings are consistent with previous studies in the literature. Park and Park [21] reported that interventions integrated into the rehabilitation process effectively increased grip strength in hemiplegic stroke survivors [21]. Similarly, Stock vd. [22] attributed improvements in grip strength observed within the first year post-stroke to neuromuscular adaptations resulting from repetitive task-based activities [22]. Kataoka vd. [48] suggested that bocia may indirectly enhance grip strength by improving upper extremity strength and motor coordination [48]. In this context, the grip strength improvements observed in the present study are in line with existing literature. Moreover, Abe vd. [20] demonstrated a significant association between intrinsic hand and forearm muscle thickness and grip strength [20]. The concurrent increases in muscle thickness and grip strength observed in this study further support these findings. On the other hand, the lack of significant changes in pinching strength has also been reported previously. Chen vd. [49] indicated that

task-oriented hand-based interventions in stroke survivors moderately improved grip strength but had limited effects on pinching strength [49]. Similarly, Yahagi vd. [50] reported that specialized sports such as bocchia do not significantly influence this specific strength component [50]. Hwang vd. [51] emphasized that general strength-oriented interventions are more effective for improving grip strength compared to bocchia-like activities [51]. Finally, Fauzi vd. [52] highlighted the necessity of more targeted resistance-based interventions to achieve meaningful improvements in pinching strength [52].

Limitations

One of the limitations of this study is the relatively small sample size of hemiparetic participants. The Bocchia group was evaluated with 12 individuals, while the control group included 10 participants. This reduction in the control group was due to two participants being unable to continue the study because of health issues. Consequently, this limitation may restrict the generalizability of the findings. In addition, the severity of hemiparesis and the functional status of participants were not considered in the inclusion criteria, which might have contributed to variability in muscle characteristics among individuals. Furthermore, the level of adherence to the Bocchia based intervention program among participants was not standardized. Additionally, it should be acknowledged that the potential placebo effect of social engagement during Bocchia sessions may have partially contributed to the observed improvements, independent of the direct physiological effects of the based intervention. Finally, the effects of the Bocchia based intervention were assessed only in the short term, preventing any conclusions regarding long-term adaptations. Therefore, the results should be interpreted as exploratory, and the post hoc power analysis should be considered indicative rather than confirmatory.

In addition, a broad range of muscle thickness variables were analyzed without applying a correction for multiple comparisons. Accordingly, the findings should be interpreted as hypothesis-generating rather than confirmatory and are intended to inform future studies with larger samples and more targeted outcome measures.

Similarly, formal intra- or inter-rater reliability analyses were not conducted. Although ultrasound measurements were performed by an experienced examiner using a standardized protocol, this should be considered a methodological limitation. Future studies should include reliability analyses to strengthen measurement validity.

In addition, the trial was registered retrospectively, which should be considered when interpreting the findings; however, this information was transparently disclosed in accordance with reporting guidelines.

Conclusions

The present study indicates that incorporating a Bocchia-based intervention into standard physical therapy may be associated with measurable changes in forearm muscle thickness (flexor digitorum profundus, flexor digitorum superficialis, pronator teres, and brachioradialis) and triceps brachii, alongside improvements in grip strength in individuals with chronic hemiparesis. Rather than reflecting definitive structural remodeling, these changes may represent activity-related adaptations accompanying repetitive, task-oriented upper limb use. In this context, Bocchia may serve as a complementary rehabilitation activity that supports upper extremity engagement and functional performance. While the findings suggest potential benefits for maintaining muscle-related characteristics and hand function, they should be interpreted cautiously given the multifactorial nature of post-stroke recovery. Future studies with larger samples, longer follow-up periods, and detailed characterization of neuromuscular mechanisms are needed before drawing firm clinical recommendations.

Acknowledgements

The authors would like to thank all participants who participated in this study. Additionally, this study acknowledges the fund support from Princess Nourah bint Abdulrahman University Researchers Supporting Project number (PNURSP2026R424), Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia.

Authors' contributions

****Emre Berk Hazar**** : Conceptualization, Methodology, Investigation, Visualization, Data curation, writing—original draft, Writing—review & editing. ****Betül Canbolat Güder**** : Methodology, Investigation, review&editing. ****Kürşat Hazar**** : Supervision, Conceptualization, Methodology, Investigation, Writing—review & editing. ****Umut Diyar GÖK**** : Methodology, Investigation. ****Nouf H. Alkhamees**** : Funding acquisition, Writing—review & editing ****Zizi M. Ibrahim: **** Writing—review & editing ****Sameer Badri AL-MHANNA: **** Writing—review & editing. ****Alexios BATRAKOULIS: **** Conceptualization, Supervision, Writing—review & editing.

Funding

This study acknowledges the fund support from Princess Nourah bint Abdulrahman University Researchers Supporting Project number (PNURSP2026R424), Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia.

Data availability

The data that support the findings of this study are not publicly available due to ethical restrictions related to the protection of participants' personal health information. However, the datasets may be made available from the corresponding author on reasonable request, provided that such disclosure complies with ethical and legal requirements.

Declarations

Ethics approval and consent to participate

This research was approved by the Bayburt University Ethics Committee under decision number E-15604681-100-234561. Informed consent was obtained from all participants prior to inclusion, and the study was conducted in accordance with the Helsinki Declaration.

Consent for publication

Informed consent was obtained from all participants prior to inclusion. The participants gave written informed consent for their personal or clinical details along with any identifying images to be published in this study.

Competing interests

The authors declare no competing interests.

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Received: 18 November 2025 / Accepted: 9 February 2026

Published online: 16 February 2026

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