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ORIGINAL ARTICLE

Effects of a high-volume static stretching programme on plantar-flexor muscle strength and architecture

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Abstract

Purpose Static stretching (SS) is performed in various settings, but there is no consensus about the effects of SS programmes on changes in muscle morphofunction. This study aimed to investigate the effects of a high-volume SS programme on muscle strength and architecture.

Methods Sixteen healthy young male adults participated, and the dominant leg was defined as the intervention side, with the non-dominant leg as the control side. Stretching exercises were performed two times per week (6 sets of 5 min, totally 30 min per session,) for 5-week using a stretching board under the supervision of the research team. Before and after SS intervention programme, plantar-flexor strength (maximum voluntary isometric contraction, MVC-ISO; maximum voluntary concentric contraction, MVC-CON) and architecture (muscle thickness, pennation angle, and fascicle length) were measured via dynamometer and ultrasound, respectively.

Results Following the SS-training programme, significant increases were observed for stretching side in MVIC-ISO at neutral ankle position ($p=0.02$, $d=0.31$, $\Delta=6.4\pm9.9\%$) and MVC-CON at 120°/s ($p=0.02$, $d=0.30$, $\Delta=7.8\pm9.1\%$), with no significant change on the control side. There was no significant change in any measure of muscle architecture for both intervention and control sides.

Conclusion Five-week high-volume SS induced positive changes on some measures of muscle strength but not hypertrophy of plantar-flexor muscles. Even with a volume much greater than already tested, the low strain offered by the SS per set seems be insufficient to induce architectural changes on skeletal muscle.

Keywords Ultrasound · Maximal voluntary isometric contraction · Muscle thickness · Pennation angle · Fascicle length · Stretch training

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Abbreviations

CV	Coefficient variation
ES	Effect size
ICC	Intraclass correlation coefficient
MVC-CON	Maximal voluntary concentric contraction
MVC-ISO	Maximal voluntary isometric contraction
POST	After static stretching programme session
PRE	Baseline measurement
RFD	Rate of force development
ROM	Range of motion
SD	Standard deviations
SS	Static stretching

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Introduction

Static stretching (SS) is performed in various sports and rehabilitation settings to increase joint range of motion (ROM) and decrease muscle stiffness (Nakamura et al. 2012, 2020), as well as improve muscle morphofunction (Simpson et al. 2017). Several previous studies have shown that ROM increases significantly after some weeks of SS intervention (Konrad and Tilp 2014b; Nakamura et al. 2012, 2020; Thomas et al. 2018). Also, although there was no significant change in muscle stiffness after ballistic stretching or proprioceptive neuromuscular facilitation stretching programmes (Konrad and Tilp 2014a; Konrad et al. 2015), following SS interventions, significant decreases in muscle stiffness have been observed on hamstrings (Ichihashi et al. 2016), and plantar flexors mainly (Blazevich et al. 2014; Nakamura et al. 2017, 2020).

Following an acute session of SS, studies often report decreases in muscle strength and athletic performance, such as when jumping and sprinting (Behm and Chaouachi 2011; Kay and Blazevich 2012; Simic et al. 2013)—this phenomenon is called "stretching-induced force deficit", and it explains why it may be better not to perform SS during pre-activity warm-up (Simic et al. 2013). Conversely, following weeks of SS training, significant improvements in muscle strength or athletic performance have been reported (Chen et al. 2011; Medeiros and Lima 2017; Nelson et al. 2012), although findings are not consistent (Akagi and Takahashi 2014; Blazevich et al. 2014; Konrad and Tilp 2014b). Regarding changes in muscle architecture (muscle thickness, pennation angle, and fascicle length) after an SS intervention programme, some studies reported significant changes (Freitas and Mil-Homens 2015; Mizuno 2019; Simpson et al. 2017), whereas others did not (Akagi and Takahashi 2014; Beltrão et al. 2019; Blazevich et al. 2014; Konrad and Tilp 2014b; Nakamura et al. 2012; Sato et al. 2020). The addition of external load (Simpson et al. 2017) or active muscle contraction via electrical stimulation (Mizuno 2019) to an SS intervention programme may help improve muscle architecture, whereas almost no change has been reported after SS training solely (Nunes et al. 2020b). It can be concluded that to date, it is not clear if an SS intervention can affect strength and/or muscle architecture parameters in the long-term intervention.

Animal studies indicated significant hypertrophy after SS (Goldberg et al. 1975; Goldspink et al. 1995). The discrepancy between human and animal studies could be a result of differences in the duration of SS interventions per week. For example, the larger SS weekly volume observed in human studies was 36 min (3 sets of 2 min per day; 6 days/week) in Akagi and Takahashi (2014), which could not have been a sufficient volume of muscle stimulation to cause an increase in muscle strength and change muscle architecture in vivo. Moreover, several studies investigating resistance training showed that increasing total work by increasing the time under tension, even at low intensity, could induce muscle hypertrophy and increase muscle strength (Mitchell et al. 2012; Ikezoe et al. 2017; Grgic et al. 2018). Thus, it may be presumed that in situations of an extremely low level of muscle strain, such as SS, significant effects could be seen only under with longer sets and a high-volume condition. However, to date, no study explored such a high-volume SS programme (e.g., 60 min stretching/muscle tendon unit/week) on the muscle strength and muscle architecture. Therefore, this study aimed to investigate the effects of a high-volume SS intervention programme (6 sets of 5 min per day; 2 days/week; resulting in 60 min/week) on plantar-flexors' muscle strength and architecture.

Methods

Experimental design

Participants completed a familiarisation session 1 week before baseline (PRE) measurement. Muscle architecture (muscle thickness, pennation angle, and fascicle length) and muscle strength (maximal voluntary isometric and concentric contractions) in both dominant and non-dominant legs were measured by ultrasound and dynamometer, respectively. After PRE-measurement, the dominant leg (preferred for kicking a ball) was defined as the intervention side, with the non-dominant leg as the control side. For all participants, the intervention side performed two times per week for 5 weeks using a stretching board (Asahi stretching board, Asahi Corp., Gifu, Japan). To prevent any residual effects, all measurements were repeated at least 3 days after the final SS programme session (POST-measurement). Participants were instructed not to perform any resistance training or stretching other than the SS programme during the study period. This study was conducted under the auspices of the Declaration of Helsinki and approved by the Niigata University of Health and Welfare, Niigata, Japan.

Participants

Sixteen healthy young male adults participated in the study (age 21.4 ± 1.5 years, height 170.3 ± 5.3 cm, and body weight 62.9 ± 7.9 kg). Inclusion criteria were as follows: no regular resistance training within the past 6 months, no neuromuscular disease, and no history of orthopaedic disease. All participants were fully informed about the procedures and purposes of this study, and they provided written informed consent. The sample size required for a two-way repeated analysis of variance (ANOVA) (effect size = 0.40 [large], α error = 0.05, and power = 0.80) was calculated using G* power 3.1 software (Heinrich Heine University, Düsseldorf, Germany) based on the previous study (Chen et al. 2011), and the required number of participants was more than 14 participants in this study.

Maximum voluntary isometric contraction (MVC-ISO) measurements

Participants were seated in an isokinetic dynamometer chair at a 0° knee angle (that is, the anatomical position—knee extended) with adjustable belts fixed over their trunk and pelvis (Biodex System 3.0, Biodex Medical Systems, Inc., Shirley, NY, USA). Participants were reclined (70° hip angle; 0° = full extension) to prevent tension in the posterior knee. The trunk and pelvis were firmly fixed with straps, and trunk movement was restricted by holding the handle with both hands. The maximal voluntary isometric contraction (MVC-ISO) of the plantar flexor was measured with the ankle joint at 30° plantar flexion and at the neutral position (neutral anatomical position = 0°). To obtain measurements, the ankle joint of the tested leg was securely attached to the footplate of the dynamometer using a velcro strap. A soft cloth was inserted between the velcro strap and instep to prevent movement of the ankle joint. After several warm-up submaximal plantar-flexion contractions, two MVC-ISOs were performed for 3 s at each ankle position with 60-s intervals. The subjects were instructed to perform plantar flexion as fast and as hard as possible at the established position, for about 3 s. The average value of two MVC-ISO used for analyses in each angle. Strong verbal encouragement was provided to promote participants' maximal effort during contractions. The test–retest reliability of MVC-ISO measurements was confirmed by coefficient variation (CV) and intraclass correlation coefficient (ICC) for ten participants in different days. The CVs for MVC-ISO at 30° plantar flexion and the neutral positions were 11.1 ± 9.0%, and 2.9 ± 1.3%, respectively, and ICC were 0.80, and 0.93, respectively.

Additionally, the rate of force development (RFD) was calculated in the neutral position. The onset of plantar flexion was defined as the point at which torque increased two standard deviations (SDs) above baseline and did not fall below baseline throughout the contraction. RFD was defined as the slope of the filtered time–torque curve over time intervals of 0–30, 0–50, 0–100, 0–150, and 0–200 ms from the onset of plantar flexion (Aagaard et al. 2002; Ema et al. 2016). CVs for the RFD of all time periods were 17.4% ± 10.9%, 12.0% ± 11.3%, 5.1% ± 7.1%, 4.1% ± 3.2%, and 4.2% ± 2.7%, respectively. ICCs for the RFD were 0.89, 0.93, 0.98, 0.96, and 0.92, respectively.

Maximal voluntary concentric contraction (MVC-CON) measurements

Concentric muscle strength of plantar flexors was measured in the same position as that in MVC-ISO measurements. ROM was from 10° of dorsiflexion to 20° of plantar flexion, with an angular velocity of 30°/s and 120°/s. Additionally, concentric contraction protocols were applied five times in each sequence. Throughout the measurement, participants were verbally encouraged during muscle contraction to promote maximal efforts. Maximum torque was measured during both concentric contraction velocities. In this study, maximum torque in both concentric contraction velocities was obtained between 10° of dorsiflexion and 20° of plantar flexion. CVs for MVC-CON at 30°/s and 120°/s were 1.9% ± 1.6% and 5.5% ± 4.5%, respectively; and ICCs for MVC-CON were 0.97 and 0.76, respectively.

Muscle thickness, pennation angle, and fascicle length

Participants were instructed to lie relaxed on the treatment table in the prone position with hip and knee angle at 0° with ankle angle at slight plantar flexion. B-mode ultrasonography (LOGIQ e V2; GE Healthcare Japan, Tokyo, Japan) with an 8 MHz linear array probe was used to evaluate the muscle thickness and pennation angle of the medial and lateral gastrocnemius muscle (MG and LG, respectively). Longitudinal ultrasound images were obtained for the MG and LG at 30% of the lower leg length, measured from the popliteal crease to the lateral malleolus near the point of the maximal cross-sectional area of the lower leg (Akagi and Takahashi 2013; Nakamura et al. 2014). Additionally, a longitudinal ultrasound image of the soleus muscle was obtained at 50% of the lower leg length (Kubo et al. 2014, 2017). Muscle thickness and pennation angle were determined using image processing software (ImageJ, National Institutes of Health, Bethesda, MD, USA). Muscle thickness was determined as the mean of the distances between the deep and superficial aponeuroses measured at both ends of each image (Blazevich et al. 2006; Ema et al. 2013). Additionally, pennation angle was determined as the mean of the three fascicles at the angle between fascicle and deep aponeurosis. Fascicle length was calculated using muscle thickness/sin (pennation angle) (Kumagai et al. 2000; Nakamura et al. 2012). CVs for muscle thickness were 1.4% ± 2.3% in MG, 0.8% ± 0.6% in LG, and 0.4% ± 0.3% in soleus. ICCs for muscle thickness were 0.94 in MG, 0.99 in LG, and 0.99 in soleus. CVs for pennation angle were 2.6% ± 2.5% in MG and 4.7% ± 3.4% in LG. ICCs for pennation angle were 0.82 in MG and 0.77 in LG.

SS programme

Participants were instructed to perform the SS programme on the intervention side for 5 weeks using the stretching board (Fig. 1). Participants stood erect with one foot on the stretching board, the other foot on its edge, and both arms against a wall in front of the body to provide balance (Akagi and Takahashi 2013, 2014). Stretching intensity was defined as the greatest tolerated dorsiflexion angle, determined during a test conducted on the stretching board. Participants who could tolerate > 35° dorsiflexion, which was the maximal angle permitted by the stretching board, were instructed to maintain the stretching intensity by moving their body mass forward. All SS sessions were performed in the laboratory under the direct supervision of the research team where the study was conducted. The SS intervention included 6 sets with 5 min, with 60 s intervals; a total of 30 min in each session, 60 min per week. The SS programme was performed 2 days/week for 5 weeks at 3–4 day intervals (10 sessions; total programme volume of 300 min). This weekly volume is about 2-to-13 times greater to what have been tested in the literature (Nunes et al. 2020a, b).

Fig. 1 Set-up for static stretching intervention

Statistical analyses

SPSS version 24.0 (IBM Corp., Armonk, NY, USA) was used to conduct statistical analyses. The normal distribution of the data was confirmed using the Shapiro–Wilk test. Differences in muscle strength and muscle architecture between the intervention and control sides were investigated at PRE-assessment using paired *t* tests. For all variables, a two-way repeated analysis of variance (ANOVA) using two factors [time (PRE versus POST evaluation) and side (intervention versus control side)] was used to determine the interaction and main effect. If ANOVA was significant, a *post hoc* analysis was conducted using a paired *t* test on each side to determine differences between PRE and POST values. Effect size (ES) was calculated as a difference in the mean value between PRE and POST divided by the pooled SD (Cohen 1988). ES of 0.00–0.19 was considered trivial, 0.20–0.49 was small, 0.50–0.79 was moderate, and ≥ 0.80 was large. Statistical significance was defined as $p < 0.05$. Descriptive data were reported as mean ± SD.

Results

All participants completed the SS programme with 100% of training attendance. Paired *t* tests showed no significant differences between the intervention and control sides for all variables in PRE.

Effects of SS programmes on MVC-ISO, MVC-CON, and RFD

Table 1 shows the effects of the SS programme on MVC-ISO and MVC-CON on both sides. MVC-ISO at 30° plantar flexion showed a significant main effect of time ($p = 0.011$, $\eta_p^2 = 0.362$), but no significant interaction effect ($p = 0.134$, $\eta_p^2 = 0.143$). The *post hoc* test showed no significant differences between PRE and POST values on both sides ($p = 0.315$, $d = 0.11$ and $p = 0.229$, $d = 0.39$, respectively). MVC-ISO at in the neutral position showed an interaction effect ($p = 0.019$, $\eta_p^2 = 0.315$). The *post hoc* test showed a significant increase after the SS-training programme on the intervention side ($p = 0.02$, $d = 0.31$), with no significant change on the control side ($p = 0.643$, $d = 0.05$). In addition, MVC-CON at 30°/s showed no significant interaction effect and main time effect ($p = 0.49$, $\eta_p^2 = 0.032$, and $p = 0.894$, $\eta_p^2 < 0.01$, respectively). Conversely, although MVC-CON at 120°/s showed no significant interaction effect ($p = 0.069$, $\eta_p^2 = 0.203$), there was significant main effect of time ($p = 0.011$, $\eta_p^2 = 0.356$), whereby the *post hoc* test showed a significant increase after the SS-training programme on the intervention side ($p = 0.02$, $d = 0.30$), with no significant change on the control side ($p = 0.514$, $d = 0.09$). Table 2 shows the changes in the RFD at all intervals. Results showed no significant interaction or main time effects for the RFD.

Effects of SS programmes on muscle architecture

Table 3 shows the effects of the SS programme on muscle thickness, pennation angle, and fascicle length on both sides. The two-way repeated ANOVA indicated no significant interaction effects or main effects for muscle thickness at MG, LG, and soleus and for pennation angle and fascicle length at MG and LG.

Table 1 The effect of a static stretching (SS) programme on maximal voluntary isometric contraction torque of plantar flexors (MVC-ISO) at different positions and maximal voluntary concentric contraction torque (MVC-CON) at 30°/s and 120°/s

	Intervention side			Control side		
	PRE	POST	ES	PRE	POST	ES
MVC-ISO at 30° plantar flexion (Nm)	65.4 ± 15.9	66.8 ± 17.6	0.11	64.2 ± 17.8	59.4 ± 15.5	0.39
MVC-ISO at neutral position (Nm)	158.8 ± 31.7	167.9 ± 33.6*	0.31	151.6 ± 34.9	151.9 ± 34.1	0.05
MVC-CON at 30°/s (Nm)	134.7 ± 27.5	144.0 ± 25.4*	0.33	128.0 ± 27.0	131.1 ± 24.7	0.10
MVC-CON at 120°/sec (Nm)	82.9 ± 24.0	84.2 ± 22.5	0.30	77.5 ± 20.2	77.1 ± 17.6	0.09

Data presented as mean ± standard deviation

PRE before SS intervention programme, *POST* after SS intervention programme, *ES* effect size

*$p < 0.05$ vs. PRE

Table 2 The effect of a static stretching (SS) programme on the rate of force development (RFD) at different time periods in neutral positions

	Intervention side			Control side		
	PRE	POST	ES	PRE	POST	ES
RFD at 30 ms (Nm/ms)	0.36 ± 0.14	0.34 ± 0.18	0.17	0.41 ± 0.24	0.33 ± 0.18	0.38
RFD at 50 ms (Nm/ms)	0.42 ± 0.17	0.44 ± 0.20	0.11	0.49 ± 0.24	0.41 ± 0.23	0.34
RFD at 100 ms (Nm/ms)	0.55 ± 0.15	0.52 ± 0.18	0.15	0.54 ± 0.16	0.57 ± 0.34	0.12
RFD at 150 ms (Nm/ms)	0.54 ± 0.12	0.51 ± 0.14	0.02	0.52 ± 0.13	0.51 ± 0.18	0.08
RFD at 200 ms (Nm/ms)	0.47 ± 0.11	0.47 ± 0.11	0.01	0.48 ± 0.11	0.18 ± 0.16	0.02

Interaction effect for the comparison between the SS side and the control (CON) side based on a split-plot analysis of variance on the right columns

Data presented as mean ± standard deviation

PRE before SS intervention programme, *POST* after SS intervention programme, *ES* effect size

Table 3 The effect of a static stretching (SS) programme on muscle architecture (muscle thickness, pennation angle, and fascicle length)

	Intervention side			Control side		
	PRE	POST	ES	PRE	POST	ES
Muscle thickness at MG (mm)	20.2 ± 2.1	20.1 ± 2.0	0.02	19.2 ± 3.0	19.3 ± 2.8	0.02
Muscle thickness at LG (mm)	17.6 ± 2.4	17.6 ± 2.3	0.02	16.5 ± 1.7	16.8 ± 1.6	0.18
Muscle thickness at soleus (mm)	18.5 ± 3.7	19.0 ± 3.5	0.15	19.7 ± 3.5	19.7 ± 3.1	0.04
Pennation angle at MG (deg)	22.9 ± 3.3	22.3 ± 2.5	0.01	23.6 ± 3.5	23.0 ± 2.7	0.36
Pennation angle at LG (deg)	15.0 ± 2.8	15.2 ± 1.6	0.21	15.6 ± 2.8	15.7 ± 2.4	0.01
Fascicle length at MG (mm)	52.9 ± 10.1	54.1 ± 11.6	0.05	48.5 ± 6.3	49.8 ± 7.3	0.33
Fascicle length at LG (mm)	69.8 ± 14.8	68.2 ± 14.1	0.19	63.1 ± 11.6	63.1 ± 9.5	0.10

Interaction effect for the comparison between SS side and control (CON) side based on a split-plot analysis of variance on the right columns

Data presented as mean ± standard deviation

PRE before SS intervention programme, *POST* after SS intervention programme, *MG* medial gastrocnemius muscle, *LG* lateral gastrocnemius muscle, *ES* effect size

Discussion

This study investigated the effects of a high-volume SS programme (60 min/week for 5 weeks; a total of 300 min) on muscle strength and muscle architecture in healthy young males. The results of the present study showed that some measures of muscle strength were increased and there were no significant changes in muscle architecture after the high-volume SS programme. Although some previous studies were investigating the effects of an SS programme on muscle strength and muscle architecture, we tested a training volume much higher than those already done (Nunes et al. 2020a, b).

Regarding the effects of a high-volume SS intervention programme on muscle strength, there was a significant increase in MVC-ISO at a neutral position, although there were no significant changes in MVIC-ISO at plantar-flexion position and in MVC-CON. In MVC-ISO at a neutral position, the ES was small (0.31), which was thought to be a small training effect. The results of the present study were consistent with previous studies showing no significant increase in muscle strength (Akagi and Takahashi 2014; Blazevich et al. 2014; Konrad and Tilp 2014b; Nakao et al. 2019). However, because no adverse effects on muscle strength were found, SS intervention programmes may be not considered as detrimental to athletic performance. With resistance training, it has been observed that strength improvements follow the angle-specificity principle (Nunes et al. 2020a; Oranchuk et al. 2019). Specifically, for the isometric training, the greater gains are noticed near to angle trained (Oranchuk et al. 2019), and thus, we supposed that the same might occur with SS. That is, MVIC-ISO was improved at 0° position of plantar flexion (while MVC-ISO at 30° did not), because it is closer to the SS-training angle. Although possible, it remains speculative to whether strength gains would be greater if also we tested with ankle extended. Moreover, lack of improvement in strength at 30° of plantar flexion might be related to the force–length properties and muscular activation characteristics, which could impair the change in force production at very short muscle lengths.

Regarding the effects of the SS intervention programme on muscle architecture, some studies showed significant changes (Freitas and Mil-Homens 2015; Mizuno 2019; Simpson et al. 2017), and others did not (Akagi and Takahashi 2014; Blazevich et al. 2014; Konrad and Tilp 2014b; Nakamura et al. 2012; Sato et al. 2020). In the present study, we hypothesised the very high-volume SS programme would be able to induce some effect; however, we observed no significant change. In animal studies, passive stretching interventions activate insulin-like and myogenic growth factors, stretch-activated channels, and the AKT/mTOR pathway and protein synthesis, which are factors important for muscle hypertrophy (Mohamad et al. 2011; Riley and Van Dyke 2012; Tatsumi 2010). However, in a human study, Fowles et al. (2000) showed that an approximately 27 min passive stretch did not significantly elevate muscle protein synthesis rate in soleus muscle via biopsy samples. This suggests that low-intensity muscle stretch per se is not a sufficient stimulus for muscle hypertrophy (Fowles et al. 2000), and that even very high SS volumes may not substitute the low intensity of strain applied to the muscle (Nunes et al. 2020a, b).

Alternatively, in a previous study showing significant changes in fascicle length, Simpson et al. (2017) reported an SS intervention programme using an external load of 20% MVC torque, with participants also performing warm-ups including a calf-raise exercise. Therefore, these warm-up routines and/or external load could have caused changes in muscle architecture. Interestingly, recent studies have focused on stretching intensity, showing that a greater acute stretching effect on ROM and stiffness was achieved with a stronger stretching intensity (Takeuchi and Nakamura 2020a, b). In the present study, we defined stretching intensity as the point of discomfort without pain (tolerable level). Similarly, stretching intensity in a previous study by Akagi and Takahashi (2014) was also defined as the point of discomfort (Akagi and Takahashi 2014). Conversely, the previous study by Mizuno (2019) that showed a significant increase in muscle thickness of MG defined stretching intensity as the maximal level at which a participant could tolerate pain during stretching (Mizuno 2019). Freitas and Mil-Homens showed a significant increase in fascicle length of biceps femoris while defining stretching intensity as a point of discomfort (Freitas and Mil-Homens 2015), similar to our study. However, the stretching intensity was gradually increased during stretching intervention every 90 s in the present study. Therefore, a higher stretching intensity was possibly used in the previous study compared with that in the present study. This difference in stretching intensity could be related to a change in muscle architecture after an SS intervention programme. However, another previous study comparing the effects of SS intervention programmes of different intensities showed no significant changes in fascicle length and pennation angle of biceps femoris after both low- and high-intensity stretching intervention programmes (Beltrão et al. 2019). The effects of SS intervention programmes of different intensities have not yet been fully established, and further research is needed to clarify the effect of stretching intensity on change in muscle architecture.

The present work has some limitations to be mentioned. The participants in this study are healthy young males. It remains to be tested whether the high-volume SS intervention programme used in this study could provide sufficient stimulation for muscle strengthening and hypertrophy in other populations with existing muscle weakness or atrophy, like sarcopenic elderlies, or in prolonged disuse situations. Because the ankle position could affect the muscle architecture measurements, in the future study, it is needed to measure the muscle architecture in more positions with defined angles to avoid the effect of ankle position.

Conclusion

In conclusion, 5 weeks of high-volume SS induced positive changes on some measures of muscle strength but not on hypertrophy of plantar-flexor muscles in young male adults. Even with a volume much greater than already tested, the low strain offered by the SS per se seems not to be sufficient to induce architectural changes on skeletal muscle. In addition, this study also investigated the effects on MVC-ISO and MVC-CON, but it did not investigate sports performance-related tasks, such as jumping and sprinting. In the future, it will be necessary to consider changes in athletic performance that are closer to the sports field to further add pieces to this topic (Medeiros and Lima 2017).

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Author contribution KY contributed to study design and data collection, and drafted the manuscript; SS, RK, and YR contributed to data collection and made critical revisions to the manuscript; AK, TF, and JPN contributed to study design and data analysis, and make critical revisions to the manuscript; NM contributed to study design and data collection, and critical revision to the manuscript. All authors approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

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Data availability All data generated or analysed during this study are included in this published article.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Research involving human and/or animal participants All the procedures performed in the studies involving human participants were *European Journal of Applied Physiology* in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This study was approved by the Ethics Committee of Niigata University of Health and Welfare (#18305).

Informed consent Informed consent was obtained from all individual participants involved in the study.

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