FORCE STEADINESS DURING SUBMAXIMAL ISOMETRIC PLANTAR AND DORSIFLEXION IN RESISTANCE TRAINING: EXPERIENCED VS NON-EXPERIENCED INDIVIDUALS

Konstantinos Salonikidis,[1, A, B, C, D] Konstantinos Papageorgiou,[2, C, D]
Anastasios Meliadis,[3, A, B, C, D] Fotini Arabatzi[4, A, C, D]

[1] ORCID: 0000-0001-5769-5454. Laboratory of Neuromechanics, Department of Physical Education and Sport Science at Serres, Aristotle University of Thessaloniki, Greece
[2] ORCID: 0000-0002-9289-5627. Department of Informatics, Ionian University, Corfu, Greece
[3] Laboratory of Neuromechanics, Department of Physical Education and Sport Science at Serres, Aristotle University of Thessaloniki, Greece
[4] ORCID: 0000-0002-1706-9878. Laboratory of Neuromechanics, Department of Physical Education and Sport Science at Serres, Aristotle University of Thessaloniki, Greece

[A] Study Design; [B] Data Collection; [C] Statistical Analysis; [D] Manuscript Preparation

Address for correspondence:
Salonikidis Konstantinos
TEFAA SERRON, AUTh
AGIOS IOANNIS
62100 SERRES / GREECE
E-mail: saloniki@phed-sr.auth.gr

Abstract The purpose of this study was to determine differences in force steadiness during submaximal plantar flexion (PF) and dorsiflexion (DF) of the dominant leg between individuals experienced and not experienced in resistance training. Forty males aged 18–32 were divided in two groups based on their experience in resistance training (experienced – not experienced). Evaluation of maximal voluntary isometric force was carried out on a Humac-Norm isokinetic dynamometer. The measurement of the maximal voluntary contraction (MVC) was measured in 3 isometric attempts. Then, the stability measurement of 10, 30, 50 and 70% of the MVC was assessed. The duration of the isometric contraction was 10 seconds but only 6 seconds were analyzed. T-test for independent samples and ANOVA was applied for the statistical analysis. The results showed that the individuals with more experience in resistance training presented a significantly higher MVC and force steadiness of the plantar and dorsiflexors muscles, compared with the individuals with less experience ($p < 0.05$). In conclusion, the years of practice with resistance training appear to have a beneficial effect on force steadiness.

Key words stability, isometric torque, plantar flexor, dorsi flexor, ankle joint

Introduction

Steady voluntary muscle contractions affect the individual's quality of life, especially during aging, and also performance in sport at a younger age. The ankle muscles are very important for maintaining balance, especially while standing and walking, and a decrease in their strength due to age-induced sarcopenia is the most important factor responsible for falls in the elderly (Marzetti et al., 2017). Thus, maintaining strength in the ankle muscles in advanced age is critical for minimising falls. People with chronic ankle instability may need specific therapy to cope with recurrent sprains (Fuerst, Gollhofer, Lohrer, Gehring, 2018). In sport also, a reduction in ankle joint perturbation is important for a variety of athletic motions such as vertical and horizontal jumps, racing, sprinting, running with a change of direction, making these skills more accurate and effective (Bezodis, Kerwin, Salo, 2008).

Resistance training is an effective and beneficial mode of exercise to increase and maintain muscle strength, and also for rehabilitation and muscle health from childhood (Herzog, Longino, Clark, 2003). Beyond those strength gains, resistance exercise also could be associated with a reduced isometric force variability as a result of improved inter-muscular coordination and increased motor unit activation (Enoka, Amiridis, Duchateau, 2020; Salonikidis, Amiridis, Oxyzoglou, Giagazoglou, Akrivopoulou, 2011; Yao, Fuglevand, Enoka, 2000). The relationship between the levels of force and their variability remains unclear. Previous studies have reported that variability increases linearly as the level of force increases, up to 65% of maximum voluntary contraction (MVC), and then variability decreases with forces greater than 65% of MVC (Sherwood, Schmidt, 1980).

Variability in steady isometric force production has been assessed under different conditions in both upper and lower extremities. Salonikidis et al. (2011) evaluated the stability of the wrist muscle flexors in submaximal voluntary isometric contractions at different joint angles, in both young adult athletes and non-athletes. Although there were no significant differences in the maximum isometric strength between the trained and the untrained individuals, the former showed significantly less variation in force at all levels of submaximal voluntary contraction at all angles. The angle did not affect the power output variability. The authors concluded that workouts over a long-term can be linked to reduced variability in isometric force production, regardless of muscle length.

Bazzucchi, Felici, Macaluso, and De Vito (2004) examined whether there were differences between young and elderly women in MVC, in strength variability and in various EMG parameters at isometric elbow flexion and knee extension. They revealed that older women compared to the younger ones showed greater fluctuations in strength without significant differences in EMG parameters. There were also no differences between upper and lower extremities.

Brown, Edwards, and Jakobi (2010) examined the gender influence on the stability of elbow flexors in three positions of the forearm and at different submaximal isometric contractions of MVC. The results showed that men produced higher levels of strength and were more stable at all levels and at all positions of the joint, indicating that that power in absolute terms plays an important role in the stability of power generation between the two sexes.

Shinohara, Yoshitake, Kouzaki, and Fukunaga (2006) examined the lower limb plantar flexion variability at 3 low percentages of MVC at 2 different knee angles. They found 32% higher MVC in extended knee, and the variation in force production was lower than in the bent position. The stability also increased when gastrocnemius muscle activity also increased. In contrast, Oshita and Yano (2010) evaluated the asymmetry of force variation during isometric plantar flexion of the ankle joint at low intensities, and observed no significant differences in force variation between the right and left legs.

Christou, Grossman, and Carlton (2002) measured the stability of the knee extensors in two groups with different MVC performance. They did not find any significant difference in stability in force generation, while the relationship between strength and stability was not linear. According to Newell and Carlton (1988), force variability increases as the level of contraction intensity increases (*cf.* Sherwood, Smith, 1980).

The influence of visual feedback on stability was examined by Baweja, Patel, Martinkewiz, Vu, and Christou (2009), who compared the variability in isometric force output in the abduction of the index finger at different strength levels, with and without visual feedback. They found that visual feedback could significantly reduce the force variability during isometric contraction. Tracy, Dinenno, Jorgensen, and Welsh (2007) though, after investigating the elbow flexors and knee extensors in young and elderly patients, indicated that stability was worse with optical feedback, and this was attributed to the reduced ability to process visual information.

To sum up, fluctuations in muscle force production seem to depend on visual feedback, on the muscle group used, on the type of muscle contraction, the contraction intensity and on the general level of physical activity of the participant. However, there is a lack of clarity about the relationship between the level of the produced force and its variability.

The purpose of the present study was to determine whether there is a difference in the stability of submaximal isometric force production during plantar and dorsal flexion of the ankle joint of the dominant lower limb in individuals experienced in resistance training vs novices. We hypothesized that engaging in resistance training would positively affect stability. In particular, resistance training over a long term would increase stability at a) 10%, b) 30%, c) 50%, and d) 70% of MVC of the plantar and dorsal flexors of the dominant lower limb.

Material and Methods

Participants

Forty males aged 23.6 ±3.74 years old (body mass: 87.2 ±18.47 kg, height: 177.53 ±13.20 cm) with a dominant right lower limb were divided into two groups based on their experience in resistance training. Individuals who had been training for more than 3 years made up the advanced group (n = 20), and the rest made up the novice group. Participation in the survey was voluntary. None of the participants had experience with this type of measurement in the past. Individuals who had any neurological or musculoskeletal damage or disease were excluded from participating in the research. Participants signed a consent form for their participation in the survey after the experimental process was explained to them. Approval for the experiment was obtained from the institutional ethics committee on human research in accordance with the declaration of Helsinki.

Measures

The recording and evaluation of MVC and the stability of the dominant lower limb were performed on an isokinetic dynamometer (USA, Humac Norm CS MI.MA). The body weight and the size of the participants were measured by a Seca scale, while for measuring the angle of the ankle, a Lafayette goniometer was used.

Design and Procedures

The subject was in a supine position, the knee was fully extended at 180°, and the ankle was flexed at 110°. Finding the dominant lower limb had been done earlier using the “Waterloo footedness” questionnaire (Bini, Jacques, Sperb, Lanferdini, Vaz, 2016). Participants were asked to refrain from any physical activity for 48 hours before the measurements. All measurements were carried out over the same time period (13:00–16:00). All dynamometer adjustments were made according to the manufacturer’s manual. For the stability assessment, participants were asked to stably maintain the appropriate levels of power for 10 seconds. Optical feedback of the generated force during isometric contraction was provided both as a number and as a curve on a second screen, which was placed in front of them at eye level.

Measurement of MVC was performed after a 5-minute warm-up ("ballistic stretching"). For familiarization purposes, the individuals participated in 2 trial-attempts with a 20-second break. The supine position helped to achieve the best possible isolation of the muscles to be tested (Escamilla, Lewis, Pecson, Imamura, Andrews, 2016). Three main attempts were then performed with a 1-minute interval to minimize the effect of fatigue. The break between the trials and the measurements was 2 minutes. The break before changing the measurement direction was also 2 minutes. The duration of each trial was 5 seconds. The duration of each main effort was 10 seconds. Subjects could begin their maximum effort whenever they wanted, with the duration of each effort usually 2–3s.

After a minimum of 48 hours from the MVC measurements, the stability measurement was performed at 10, 30, 50 and 70% of the MVC in three attempts for each strength percentage (12 attempts × 2 movement directions = 24 in total). For their familiarization the participants performed two 10% attempts with a break of 15 seconds, which preceded the main efforts. The duration of each trial was 5 seconds. The duration of each main effort was 10 seconds. The break between the trial and main efforts was 30 seconds. In addition, the intermediate break for the 10% MVC was 15 seconds, for the 30 and 50% it was 30 seconds, while for the 70% the break was 1 minute. The break between the percentage changes was 1 minute. The same procedure and the same breaks were kept for both plantar and dorsal flexion.

Data acquisition

The maximum values recorded during the MVC measurement in the PF and DF were noted and used to determine the sub-maximal levels of force to measure stability. In the second part of the measurements for each subject, the first and last two seconds of each test were excluded from the analysis to avoid the transition phases in development of the required force in the stability phase. From the 2^{nd} to 8^{th} second, power fluctuations were quantified by calculating the coefficient of variation (CV = [SD / mean] × 100).

Statistical Analysis

For all statistical analyzes, SPSS 24 software was used. To compare the averages of demographic data (age, height, body mass), of the MVC and CV at the targeted percentages, during PF and DF, T-tests for independent samples were used. ANOVA was used to determine the effect of resistance training on the subjects. The factors "direction" (PF, DF), "level" (beginners, advanced) and "percentages" (10, 30, 50, and 70%) were examined. The significance level was set at $p < 0.05$.

Results

According to the answers given to the Waterloo Footedness questionnaire, all participants (n = 40) were dominant in the right lower limb. Analysis of the demographic data showed no statistically significant difference between the mean values of the two groups in height (beginners: 178.2 ±17.81 cm, advanced: 176.85 ±6.29 cm, $t_{(38)}$ = 0. 32, p > 0.05), body mass (beginners: 89.3 ±24.49 kg, advanced: 85.1 ±9.56 kg, $t_{(38)}$ = 0.71, p > 0.05) and age (beginners: 23.6 ±3.53 years, advanced: 23.59 ±4.03 years, $t_{(38)}$ = 0.01, p > 0.05).

In contrast, statistically significant differences were found in the means of peak force during both the PF (beginners: 75.35 ±9.85 Nm, advanced: 95.95 ±11.96 Nm, $t_{(38)} = -5.94$, $p < 0.01$) and DF (beginners: 37.6 ±3.89 Nm, advanced: 44.25 ±5.08 Nm, $t_{(38)} = -4.65$, $p < 0.01$).

Concerning the examination of the stability results during the PF, the beginners presented an average of CV at 10% of the MVC of 1.80 ±0.91 versus 1.03 ±0.53 of the advanced ($t_{(38)} = 3.27$, $p < 0.01$). At 30% of the MVC, the CV for beginners was 1.48 ±0.55 and for the advanced 0.80 ±0.38 ($t_{(38)} = 4.55$, $p < 0.01$). At 50% of the MVC, the CV for beginners was 1.48 ±0.42, while for advanced 0.71 ±0.17 ($t_{(38)} = 7.63$, $p < 0.001$). In 70% of the MVC, the CV for beginners was 1.35 ±0.36, while for advanced 0.89 ±0.21 ($t_{(38)} = 4.94$, $p < 0.001$).

Table 1. Coefficient of Variation in Stability Measurement during Production of Submaximal Voluntary Isometric Contraction in Plantar flexion (PF)

	Beginners		Advanced	
	mean	SD	mean	SD
PF 10%	1.80*	0.91	1.03	0.53
PF 30%	1.48*	0.55	0.80	0.38
PF 50%	1.48*	0.42	0.71	0.17
PF 70%	1.35*	0.36	0.89	0.21

Note: N = 40, p < 0.05. * = Average differs statistically significantly between the groups.

In DF at 10% of the MVC, the CV for beginners was 4.37 ±1.67, while for advanced 2.25 ±1.17 ($t_{(38)} = 4.66$, $p < 0.001$). At 30% of the MVC, the CV for beginners was 2.50 ±0.73 while for advanced 1.54 ±0.80 ($t_{(38)} = 3.97$, $p < 0.001$). At 50% of the MVC, the CV for novices was 2.68 ±0.58, while for advanced 1.67 ±0.87 (t (38) = 4.31, $p < 0.001$). In 70% of the MVC, the CV for beginners was 2.37 ±0.76 and for advanced 1.70 ±0.92 ($t_{(38)} = 2.52$, $p < 0.05$).

Table 2. Coefficient of Variation in Stability Measurement during Production of Submaximal Voluntary Isometric Contraction in Dorsi flexion (DF)

	Beginners		Advanced	
	mean	SD	mean	SD
PF 10%	4.37*	1.67	2.25	1.17
PF 30%	2.50*	0.73	1.54	0.80
PF 50%	2.68*	0.58	1.67	0.87
PF 70%	2.37*	0.76	1.70	0.92

Note: N = 40, p < 0.05. * = Average differs statistically significantly between the groups.

The results of the analysis of stability revealed that there was a statistically significant interaction of “direction” (PF and DF) and “percentages” in stability with the performance of the subgroups during PF and DF at the four intensity levels (10, 30, 50 and 70%) of the MVC ($F_{3, 114} = 14.42$, $p < 0.001$). In addition, the main effect of the factor “direction” was statistically significant ($F_{1, 38} = 164.04$, $p < 0.001$), while the main effect of the factor “percentages” was also statistically significant ($F_{3, 114} = 24.82$, $p < 0.001$).

In the same way we found a statistically significant interaction of “direction” (PF and DF) and “level” (beginner-advanced) with the subgroups during PF and DF ($F_{1, 38} = 7.71$, $p < 0.01$). Also, the main effect of the “level” factor was statistically significant ($F_{1, 38} = 37.92$, $p < 0.001$). Moreover, statistically significant interaction of “percentages” and “level” with the subgroups was found at all examined stability percentages of MVC ($F_{3, 114} = 5.76$, $p < 0.01$).

Finally, the results showed that there was a statistically significant interaction of “direction”, “percentages” and “level” in PF and DF at the four levels of MVC with the two groups of participants ($F_{3, 114} = 4.91$, $p < 0.01$). According to these results, the initial research hypothesis is confirmed.

Discussion

The research presented here focused on the possible effects of resistance training to stability on young trainees. The main findings showed that experience with resistance training had a positive effect on the stability of force production of the ankle joint, during PF and DF at 10, 30, 50, 70% of MVC. The greatest difference between the groups was observed at 110° ankle angle, with the knee fully stretched and the individual in supine position. DF was less stable compared to PF at all strength-levels with the experienced subjects being more stable in producing submaximal voluntary isometric contraction in relation to the beginners. The beginner group had an average experience of 1.75 years and the advanced group 6.71 average years of experience, which means that the 5-year difference in experience seems to be a very important factor influencing stability.

Among the number of factors affecting stability, a very important variable is the profile of physical activity of the individuals (Enoka et al., 2003). According to Arendt-Nielsen, Mills, and Forster (1989), in extended isometric contractions, the recruitment of new motor units occurs as the contraction time increases beyond the performance-duration the individual is used to. Therefore, the beginner participants in this research compared to the advanced ones had a higher CV, probably because the isometric contractions in their workouts are shorter. This results in the recruitment of new kinetic units and most likely, because the movement is novel for them, they exhibit a higher CV compared to the motor units which are conditioned to a particular motor pattern.

Already since 1985, Basmajian and De Luca have found that the failure of a muscle to maintain prolonged isometric contraction against an external resistance causes normal tremors and fatigue, resulting in the failure to maintain a certain level of strength. This is called the “muscle strength limit” and is apparently influenced by years of experience in a particular motor pattern. Muscle strength limit has been found to contribute to postural stability, at least in more aged individuals (Melzer, Benjuya, Kaplanski, Alexander, 2009). Therefore, the advanced individuals will have a lead over the beginner ones at the “muscle strength limit” in isometric contraction.

According to de Vries, Daffertshofer, Stegeman, and Boonstra (2016), muscle functional synchronization is important in motor coordination. Thus, when a simultaneous and coordinated activation of two muscles occurs, more force can be generated. Conversely, when the peak in the activation phase is not fully synchronized, then the maximum force output is reduced. This is another factor that is positively influenced by repeated training; therefore, advanced participants seem to have an edge compared to beginners.

In the present study, the order in which participants performed the stability measurement protocols at the different strength levels in both directions was predetermined (from 10 to 70% of the MVC, PF-DF). There was always a certain order, beginning with the PF and moving to the DF, from the lowest level of strength to the highest. In other studies (Kobayashi, Koyama, Enoka, Suzuki, 2014; Mugge, Abbink, Schouten, Dewald, Van Der Helm, 2010) the sequence of protocols is random to avoid a possible positive effect on the first test (in this case, the PF) due to a lack of fatigue. This way of ordering was chosen here because during the pilot measurements, both PF and DF during the execution, either randomly or in a predetermined order, did not show significant fluctuations in stability performance due to fatigue.

We also found that stability improves as the intensity of muscle contraction increases, and this happens regardless of the level of experience. More specifically, at 10% of the MVC, the stability is quite low, but at 30% it increases, remaining unaltered up to 70%. The present study did not consider stability in tensions above 70% of the MVC. Löscher and Gallasch (1993) reported that stability increased from 20 to 60% of the MVC but significantly decreased from 80% and on. Therefore, it seems that stability is maximized at 20–70% of the MVC. Lower or higher tensions than those reduce stability. In the present study, the highest CV was observed at 10% of the MVC, while from 30–70% CV was observed to decrease. These results are in line with the conclusions of Löscher and Gallasch (1993).

The maximum voluntary isometric force of the PF and DF of the ankle of the advanced participants was higher than that of the beginner group. Brown et al. (2010) reported that power in absolute terms increases stability, so they are in agreement with the findings of this research. In contrast, Christou et al. (2002) found that MVC did not affect stability during isometric contractions of the knee extensors.

Stability is influenced by the motor units studied in the test, the muscles, myo-typology and the profile of the physical activity of the individual (Huesler, Hepp-Reymond, Dietz, 1998; Sturm, Schmied, Vedel, Pagni, 1997). In the present study, the beginner group had a lower MVC compared to the advanced group, but it was not shown whether this was due to the smaller cross-section of the muscle or to other factors (e.g. nervous system).

The direction of movement plays an important role in stability. The results showed that PF is more stable in all participants compared to DF. According to Shinohara et al. (2006), the plantar flexors exhibit greater stability when the knee is at full extent at 180°, rather than when it is bent at 90°, although in the bending of the knee the involvement of the soleus is greater than that of gastrocnemius. Myo-typology plays an important role in stability, where type I muscle fibers are more stable than muscle fibers of type IIa and IIb in gastrocnemius (Enoka et al., 2003). Therefore, PF with extended knee should provide less stability than when the knee is bent, while in reality, the opposite is the case. Plantar flexors have more power than dorsal flexors, so according to Brown et al. (2010) it makes sense for the former to have even greater stability.

Regarding the profile of physical activity, Hortobágyi, Tunnel, Moody, Beam, and Devita (2001) reported that 10 weeks of strength training of the knee extensor muscles led to increased MVC and stability. Also, Tracy et al. (2007) found that resistance training increased the MVC and the stability of the knee extensors. However, Bellew (2002) observed that strength training increased the maximum force of the knee extensors, but the same was not observed with the stability at 30–90% of MVC. In general, it can safely be said that physical activity reduces variations in force generation. In the present study the beginner team had 5 years less experience (lower physical activity profile) compared to the advanced group. Therefore, this difference may be the reason for which the group of advanced subjects presents lower CV.

Conclusions

In conclusion, the factors that influenced the results of this research are the MVC, the direction of movement (PF-DF), experience in resistance training and the intensity of muscle contraction. The majority of researchers agree with the positive influence of these factors on force stability. Regarding physical education and sports training, the practical applications stemming from this research are that resistance training can benefit individuals in the long run by improving the balance of walking and posture control. It protects the muscular system and so new trainees, since they are involved in resistance training for life, may have better functionality in elderly life compared to age-peers who did not have similar exercise stimuli. Finally, the constraints of the present study are that the sample consisted of only men, the EMG was not recorded in the muscles that were activated and the joint angle was the same (110º) in both cases of the PF-DF. Also, there was neither a comparison between providing and not providing visual feedback, nor a comparison between completely new and advanced participants. Further research is needed in the future to clarify these research gaps.

What can be deduced from the above findings, especially in regard to future directions, is that long-term resistance training can increase stability in the plantar and dorsal flexors of the ankle joint in young healthy people. In day-to-day life, this improvement is for individuals who must constantly and consistently perform certain movements involving the legs and for which a certain amount of precision is required (e.g., driving, carrying a bucket of water, etc.). In recreational sports it can help trainees to perform movements that require stability, more effectively than trainees who do not train through resistance exercises. Finally, in competitive sports, the maximum strength of the plantar and dorsal flexors, which increases dramatically through resistance training, can increase stability in various athletic activities, and this, in turn, will hopefully lead to an improvement in the overall performance of athletes. Experimental designs for sports such as tennis would help us better understand how specific resistance training programs may affect coping with injury, injury prevention and competitive performance.

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Cite this article as: Salonikidis, K., Papageorgiou, K., Meliadis, A., Arabatzi, F. (2021). Force Steadiness during Submaximal Isometric Plantar and Dorsiflexion in Resistance Training: Experienced vs Non-experienced Individuals. *Central European Journal of Sport Sciences and Medicine*, *2* (34), 5–13. DOI: 10.18276/cej.2021.2-01.