TITLE

Acute effects of ankle plantar flexor force-matching exercises on postural strategy during single leg standing in healthy adults

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Highlights

- Force-matching exercises at three different target torque levels were performed.
- Postural strategy on an unstable platform was modulated by exercise at 5% of MVC.
- Postural strategy on a stable platform did not change after the exercises.

Abstract

Background: Ankle plantar flexor force steadiness, assessed by measuring the fluctuation of the force around the submaximal target torque, has been associated with postural stability.

Research question: To investigate whether a force-matching exercise, where submaximal steady torque is maintained at the target torque, can modulate postural strategy immediately.

Methods: Twenty-eight healthy young adults performed ankle plantar flexor force-matching exercises at target torques of 5%, 20%, and 50% of maximum voluntary contraction (MVC), in a randomized crossover trial. Participants with their ankle in a neutral position were instructed to maintain isometric contraction at each target torque, as measured by a dynamometer, for 20 seconds with 3 sets of 5 contractions. Before and after the force-matching exercises, the anterior-posterior velocities and standard deviation of the center of pressure (COP) on the stable platform and the tilt angle of the unstable platform during 20-seconds single-leg standing were measured. The velocities and standard deviations of the COP and tilt angle before and after the exercises were compared using paired t-tests.

Results: The tilt angle velocity of an unstable platform significantly decreased after the force-matching exercise at a target torque of 5% MVC ($p = 0.029$). , whereas it was unchanged after the exercises at target torques of 20% and 50% MVC. The standard deviations of the tilt angle of unstable platform test did not change significantly after any exercise. Furthermore, no significant differences were observed in the COP velocities or standard deviations on the stable platform test after any exercise.

Significance: Our findings suggest that repeated exertion training at low-intensity contractions can affect postural stability in an unstable condition. Particularly, force-matching exercise at very low-intensity torque, such as 5% of MVC, may be an effective method to improve postural control in the unstable condition, but not in a stable condition.

Keywords: Force steadiness; Postural control; Plantar flexor muscles; Single-leg standing; Force control

1. Introduction

Decreased postural control while standing leads to an increase in fall risks [1]. Postural control during quiet standing is often evaluated by measuring the center of pressure (COP) displacement [2, 3]. For example, the mean velocity of COP displacement is greater in older adults than in young adults [4]. Thus, a review article suggested that greater COP velocity and sway may be related to increased fall risk [5]. Postural stability is controlled by various factors, such as somatosensory, vestibular, and visual systems. As a result of these functions, integrated information from the central nervous system and sensorimotor system can control the exertion of accurate torque around the ankle joints, to control the standing posture [6, 7]. To stabilize COP sway, submaximal and controlled force exertion, modulated by afferent information such as the perception of feet soles, has been found to be more important than maximum force exertion [7, 8]. Postural stability control should often be performed with delicate and precise force control.

The ability to control submaximal forces is often assessed by measuring force steadiness when exerting a constant submaximal isometric contraction to match a target torque level [9, 10]. Force steadiness, which is influenced by motor unit discharge variability [11] and afferent stimulation from muscle spindle firing [12, 13], has been associated with physical functionality [14-16]. When performing accurate force exertion under visual feedback, ascending information, such as visual and somatosensory systems, is also required. Some studies have reported that older adults have impaired ability to exert a steady force compared with young adults at various joints [10], including the ankle plantar flexor [17] and knee extensor [18], and that older adults with a history of falls have even less force steadiness [19].

Ankle plantar flexor muscles play an important role in controlling postural stability [20, 21], and muscle activities of 10%–50% of maximum voluntary contraction (MVC) are required in these muscles during single-leg standing [22]. Regarding the relationship between ankle plantar flexor force steadiness and postural control, previous studies have shown that increased COP fluctuation on a stable platform is related to greater ankle plantar flexor force fluctuation at an intensity of 10% or 5% of MVC [23-25]. Furthermore, single-leg standing time with the eyes closed [26] and postural control on an unstable platform [24] were associated with ankle plantar flexor force steadiness at 20% of MVC, which indicated that those who performed stable standing could control force exertion steadily. These results suggest that the relationship between the postural control task and the target torque levels during the force steadiness test may depend on the postural control conditions, such as stable or unstable platforms. In addition, in older adults, force steadiness at 5% or 10% of MVC has been reported to not be associated with postural control in a stable condition [27-29], however force steadiness at 20% of MVC relates to postural sway in an unstable condition [29]. Considering these findings, the relationship between force steadiness and postural control may differ depending on age and the intensity of the target torque during force steadiness tasks.

It has been demonstrated that postural stability and force steadiness did not improve even when high-intensity resistance exercise, such as 70% or 80% of MVC of 1 repetition maximum (RM), was performed [30, 31]. Additionally, our previous study indicated that force steadiness at 50% of MVC was not correlated with postural control ability [24]. These studies suggested that moderate- to high-intensity training could not improve postural control sufficiently. On the other hand, a previous study showed that 4-week force-matching practice to control constant ankle plantar flexor force at 10% and 20% of MVC could stabilize force fluctuations and anteroposterior sway of the center of mass during quiet bipedal standing [32]. However, to the best of our knowledge, no study has examined the effects of each force-matching exercise at different target torque levels on postural control during single-leg standing under different conditions of stable and unstable support surfaces. Since single-leg standing is used in many situations, such as postural balancing, it is important to investigate the acute effects on postural control during single-leg standing.

Previous studies on the acute effects of force-matching exercises on postural control have been conducted only under stable conditions and low-intensity exercise. It is unclear how different intensities of force-matching exercises would influence postural control in different conditions, such as stable and unstable platforms. A good understanding of the effects of force-matching tasks on postural stability under different conditions can help develop an evidence-based approach for improving postural stability for each platform condition, such as stable or unstable platforms. This study aimed to investigate the acute effects of each force-matching exercise, with different intensities of target torque levels, on postural sway during single-leg standing on stable and unstable platforms. The hypotheses of the present study were that 1) force-matching exercise with a low-intensity target torque level of 5% of MVC contributes to modifying postural control in a stable condition, 2) force-matching exercise with a target torque of 20% of MVC contributes to modifying postural control in both stable and unstable conditions, and 3) force-matching exercise with a target torque of 50% of MVC does not modify any postural control tasks.

2. Methods

2.1. Participants

Twenty-eight healthy young adults (age, 24.1 ± 1.9 years; height, 165 ± 6 cm; body mass, 58 ± 10 kg; 14 females) participated in the present study. The participants had no history of neuromuscular disorders or surgery on their legs. Participants with physical problems such as vestibular disease, neurological dysfunctions, musculoskeletal lesions, and treatments that would affect the assessments were excluded. The purpose and procedures were explained to the participants before they provided informed written consent to participate in the present study. The present study was conducted in accordance with the Declaration of Helsinki and approved by the ethics committee of the Kyoto University Graduate School and Faculty of Medicine (R1918).

A priori analysis of sample size for the present study was conducted using G*Power software (version 3.1, Heinrich Hein University, Dusseldorf, Germany). Referring to a previous study [32], power analysis using an effect size of 0.8 (large effect size), with an α error of 0.0083 (= 0.05/6), and a power of 0.80, revealed that the required sample size was 23 subjects for a paired t-test analysis.

2.2. Procedure

The participants visited the laboratory for three times, with alternate days off, and performed force-matching exercises at three different target torque levels in a randomized crossover trial. Both postural control tasks which consisted of single-leg standing on a stable or unstable platform were performed before the force-matching exercise at each target torque level. Immediately after the exercise, the both postural control tasks were performed again (Fig. 1). The force-matching exercise, consisting of isometric contraction of the ankle plantar flexors at three target torque levels (5%, 20%, and 50% of MVC), was randomly performed on separate days. A rest interval was set between postural control tasks and the force-matching exercise. The interval was as long until the participants stopped feeling fatigued in their lower leg. This was done to prevent fatigue during the postural tasks. The interval was less than 5 minutes. Based on previous studies [17, 22-24, 26], we determined the three target torques at 5%, 20%, and 50% of MVC. Force steadiness at 5% of MVC was found to be related to postural sway during quiet standing [23], while force steadiness at 20% of MVC was observed to be related to postural sway in an unstable condition [24, 26]. In addition, postural control during single-leg standing in unstable conditions would require greater muscle activities of the ankle plantar flexor muscles [22], and a previous study has selected force steadiness at 50% of MVC as a high-intensity task [17]. In addition, all tasks including postural control tasks and ankle plantar flexor force-matching exercises were performed in the same unilateral leg (right leg) in all participants in order to confirm whether the acute effects occurred. A recent review article [33] reported that balance performance was not influenced by leg dominance; therefore, it would not be influenced in the present results even if the dominant leg of participants was left side.

2.3. Postural control task

The COP displacements during single-leg standing tasks on the right leg were measured using the Biodex Balance System SD (Biodex Medical Systems, Shirley, NY, USA). The Biodex Balance System SD has eight springs located around the perimeter of the balance platform, and the degree of tilt and COP can be measured via these springs. The system has a static mode, which locks the platform flat, and a dynamic mode, which can be inclined in any direction, varying between Level 1 (minimum stability) and Level 12 (maximum stability). In the present study, the static mode was used for the stable platform condition and dynamic mode with “Level 2” was used for the unstable platform condition [24, 34]. The participants put their bare right foot on the center of the platform and performed single-leg standing for 20 seconds, after they practiced once. Participants kept their arms in front of their chest, and both hips in a neutral position. Their right knee was kept at full extension, while their left knee was flexed slightly (less than 90 degree). The torque exerted by the plantar flexor depends on the knee joint angle [35]. In addition, if the participants perform postural control tasks with knee flexion, knee or hip muscles other than the plantar flexor may significantly contribute to postural control. Therefore, the postural control task was performed in the knee extension position under the same conditions as the force exertion tasks. The postural assessment device has a monitor for manipulation. The monitor was set at each participant’s eye level, and the participants were instructed to look at a point on the monitor 30 cm in front of them while maintaining a natural neck position. The feedback system was turned off, and the point where the participants looked was represented at the center of the monitor during the postural control task. The participants were instructed as follows: “Please keep your posture upright and look at a point straight ahead. When controlling your posture, try to use your ankle, with as little trunk flexion and extension as possible.” If a participant touched the platform with their left foot, the trial was repeated under the same condition with more than one minute rest interval to minimize the effects of fatigue; however, an incorrect attempt rarely arose.

2.4. Force-matching exercises

The participants sat on the dynamometer seat and performed force-matching exercises using the Biodex System 4 (Biodex Medical Systems, Shirley, NY, USA). Their right foot was securely fastened by an inelastic belt to the footplate of the dynamometer. Soft cloth was inserted between the inelastic belt and instep to prevent unwanted movement of the ankle joint. The trunk and pelvis were securely fixed by belts to keep the hip joint at 80 degrees of flexion and the knee at full extension. Since the present study focused on ankle control, force-matching exercises were also performed with full knee extension to limit the use of the knee joint to control the exerted force. The torque signals from the dynamometer were recorded in a personal computer using the software application MyoResearch XP Master Edition (Noraxon Inc., Scottsdale, Arizona, USA) with a sampling rate of 1500 Hz. Sampled data were processed with a moving root mean square time window (50 ms), in real time. For visual feedback, a monitor that showed the target torque level and exerted torque, was placed one meter ahead of the participant (Fig. 2).

Following a warm-up for 5 minutes, the maximum strength of ankle plantar flexion was measured. Maximum voluntary isometric contraction (MVC) was exerted for 3 seconds in two trials with a rest interval of more than one minute while checking the fatigue of the participants. The averaged peak torques for the two trials were calculated as maximum strength. There was no statistical difference in the MVC values between the two trials (1st MVC = 164.3 ± 33.3 Nm, 2nd MVC = 165.6 ± 34.2 Nm, $p = 0.102$), which indicated that there was no fatigue during MVC measurements with a rest interval of one minute. Based on the maximum strength of ankle plantar flexion, three force-matching exercises, consisting of the target torque levels of 5%, 20%, and 50% of MVC, were performed. Participants were instructed to maintain isometric contraction of the ankle plantar flexors for 20 seconds at each target torque. The force-matching exercise consisted of 3 sets of 5 contractions with inter-contraction interval of 5 seconds and an inter-set interval of 60 seconds; thus, isometric contractions were performed for a total of 15 times.

2.5. Data analyses

Referring to previous studies [23, 24, 32], we focused on anteroposterior postural sway because ankle plantar flexor force contributes mainly to the postural sway in the anteroposterior direction [20]. Postural control on the stable platform was determined by COP displacements obtained from the Biodex Balance System SD with a sampling rate of 20 Hz. Postural control on the unstable platform was determined by the tilt angle around the center of the platform obtained from the device with a sampling rate of 20 Hz. The COP and tilt angle data in the anteroposterior direction of the postural control tasks were collected for 20 seconds; the COP data for 10 seconds were analyzed, excluding the first and last 5 seconds to avoid the preparation period until the posture was steady and the effect of fatigue, respectively [23, 24]. The standard deviations of the sampled anteroposterior COP displacements and tilt angle (200 samples) were calculated, which represented the COP range of fluctuation within the base support and tilt range of fluctuation during postural standing tasks, respectively. Moreover, the mean velocities of the sampled anteroposterior COP and platform tilt were calculated by dividing the anteroposterior total movement distance (total trajectory length and total accumulation of tilt angle) by the time (10 seconds), which represented the movement of COP and tilt angle per unit time, respectively.

2.6. Statistical analyses

All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS version 22.0; IBM Japan, Inc., Tokyo, Japan). The Shapiro-Wilk test was used to check the normality of the data. To investigate the acute effects of force-matching exercises on postural control during single-leg standing on a stable and unstable platform, the velocities and standard deviations of COP and tilt angle were compared before and after force-matching exercises using a paired t-test or Wilcoxon signed-rank test. Since we conducted six t-tests (3 exercise × 2 postural sway index) in each condition, the p values were adjusted with Bonferroni correction if uncorrected p values were less than 0.05, to control the experiment-wise type I error. The level of significance was set at a corrected p-value < 0.05.

3. Results

Changes in velocities and standard deviations of COP on a stable platform

No significant differences were observed in the velocities or standard deviations of the COP during single-leg standing on a stable platform after any force-matching exercises (Table 1).

Changes in velocities and standard deviations of the tilt angle of an unstable platform

The velocity of the tilt angle during single-leg standing on an unstable platform significantly decreased after performing the force-matching exercise with a target level of 5% of MVC. However, the tilt angle velocities on an unstable platform did not change after force-matching exercise with target torque levels of 20% and 50% of MVC. No significant differences were observed in the standard deviations of the tilt angle during single-leg standing on an unstable platform after any force-matching exercises (Table 2).

4. Discussion

The present study investigated the acute effects of force-matching exercises of ankle plantar flexion at three different target torque levels on postural strategy during single-leg standing on stable and unstable platforms. The standing posture is controlled by a feedback system in which corrective torque is generated by the central nervous system and sensorimotor system [6, 36], and force control is also regulated by the central nervous system and sensorimotor feedback [11, 37-39]; therefore, force control tasks can modulate the postural strategy. Indeed, the results showed a significant decrease in the velocity of the tilt angle on an unstable platform immediately after the force-matching exercise at a target torque level of 5% of MVC. However, none of the force-matching exercises changed the velocities or standard deviations of the COP of a stable platform. To the best of our knowledge, this study is the first to verify the effects of force-matching exercises on postural control under different conditions, such as stable and unstable environments. Our results suggest that very low-intensity exercise, such as 5% of MVC, was efficient in modulating postural strategy in an unstable condition, but it was challenging to modulate postural strategy in a stable condition regardless of the exercise intensity.

In terms of the effect of force-matching exercise at a target torque level of 5% of MVC, our results showed that force-matching exercise decreased the velocity of the tilt angle on an unstable platform. In contrast, the standard deviation of the tilt angle did not change after any exercise. The standard deviation of the tilt angle represents the range of fluctuation of tilting during single-leg standing, while the velocity of the tilt angle represents the total accumulation of tilt angle variation per unit time. In the present study, a significant decrease was found in the velocity of the tilt angle but not in the standard deviation of the tilt angle, suggesting that the range of fluctuation of tilt angle did not change, but the total accumulation of tilt angle variation decreased. These results indicate that force-matching exercise at a low-intensity target level of 5% of MVC could change the postural control strategy only in the unstable condition but not in the stable condition. When controlling the posture to be stabilized, humans require afferent feedback from ankle proprioceptive sensibility [40]. The standard deviation in both conditions did not change because a certain range of COP and tilting sway may be needed for correction and modulation of the posture using ankle proprioception. It has been reported that the H-reflex amplitude decreases when the postural condition becomes more challenging [41], suggesting that it prevents the overdrive of autogenic excitation of motoneurons and alters the saturation of motoneuron excitability in response to central descending commands [42]. When controlling postural sway in a difficult task, such as in an unstable condition, reflexive mechanisms with a large and fast reaction are inhibited to avoid oversaturation of the spinal motoneurons, and adapted to improve postural balance control at the supraspinal level, with small and slow reactions [1, 42]. In an unstable condition, these adjustments might result in a decreased tilt angular velocity. The

COP sways while standing on a stable platform could not change immediately after any exercise, although some cross-sectional design studies reported that force steadiness at 5% of MVC was related to postural sway on a stable surface [23, 24]. One reason that force-matching exercise at 5% of MVC did not change postural sway may be that the participants were healthy young adults with good physical functioning. Since standing on a stable platform may have been less complicated for our participants, the exercise may have had a more negligible effect on postural sway in the stable condition. Controlling posture in an unstable condition requires more information from afferents and the central nervous system than in a stable environment [43, 44]. The difference in strategy between standing conditions may have induced these results. Regarding exercise intensity, a previous study reported that resistance training at high-intensity (80% of 1 RM) did not modulate the nervous system to regulate motor unit recruitment and firing rate [31]. Our findings also suggest that force control exercise at low-intensity levels (such as 5% of MVC), rather than high-intensity levels, which would require a precise force control mechanism, might induce precise postural control with adaptation at supraspinal levels.

Contrary to our hypothesis, force-matching exercise at 20% MVC did not change postural control on an unstable platform. Our previous cross-sectional study revealed that postural sway on an unstable platform was correlated with force steadiness at 20% of MVC [24] and a recent study has reported that postural sway in an unstable condition was also correlated with force steadiness at 20% of MVC in community-dwelling older women [29]. Considering these findings, we hypothesized that force-matching exercise at a target torque level of 20% of MVC would effectively improve postural control on an unstable platform. Nevertheless, this hypothesis was inconsistent with the present results that only force-matching exercise at 5% of MVC could improve postural control on the unstable platform. A previous study investigating force-sharing within the triceps surae revealed that soleus activity could contribute to greater plantarflexion during low-intensity contraction than gastrocnemius [45]. In addition, the soleus works continuously during postural control [46]. Considering these facts, the soleus may be facilitated following force-matching exercise at 5% of MVC and can maintain a constant discharge rate during the postural control task, which may cause less tilting of the platform during the postural control task, and the velocity was reduced. However, the activation strategy among the triceps surae was not clear because we did not evaluate the neuromuscular system of the triceps surae. If these mechanisms facilitate postural control, the strategy on a stable platform would be changed in this study. However, as mentioned above, the participants were healthy and young. If older adults or patients who are impaired in the postural control system, a postural control strategy on a stable platform may change after low-intensity force-matching exercise. Future studies should evaluate the distribution and strategy of triceps surae during force-matching exercise and postural control tasks, and older adults or patients who are impaired in the postural control system should be investigated.

With regard to control of force exertion, motor unit discharge variability affecting force fluctuation can be influenced by low-intensity force exertion [38]. Previous studies showed that force steadiness of the upper limb at low-intensity, such as 5% of MVC, was less steady in older adults [47] and patients [48] than in young adults and healthy adults, respectively. Force control at low-intensity may be one of the abilities impaired by aging or disease, therefore improvement of force control at low-intensity, such as 5% of MVC, should be important for older adults and patients. Low-intensity force-matching exercise may be useful training in clinical situations for older adults and patients because low-intensity exercise can cause less joint stress and soreness. However, a recent study suggested that low-intensity force-matching practice for 4 weeks could not reduce postural sway in older adults [27]. A previous cross-sectional study also reported that force steadiness at 5% or 10% of MVC was not related to postural sway in stable conditions in older adults [28]. Age-related decline in motor behavior such as motor unit discharge [49] or sensorimotor function [50] can affect the force and postural controls. Postural sway in older adults cannot only be caused by voluntary force control, but by the age-related decline in neurophysiology. Therefore, it may not be possible to modulate postural control simply by improving voluntary force control in older adults. When considering the applications for older adults, the results of the present study may need to be interpreted with caution. In addition, methodological differences between our study (as well as that of Oshita and Yano [32]) and the aforementioned studies, such as in subjects, postural control tasks (with eyes open or closed), or force-matching exercises, may have influenced the apparent contradiction. It is suggested that postural control was modulated by modified voluntary force control in young adults who did not have impaired sensorimotor functions in the present study or in the study by Oshita and Yano [32]; therefore, future studies are needed to determine whether performing low-intensity force-matching exercise would result in improving postural control in older adults and patients.

Focusing on the effects of plantarflexion exercise on postural sway, Oshita and Yano [32] reported that force steadiness practice in ankle plantar flexion at 10% or 20% of MVC for 4 weeks could decrease the anteroposterior velocity of the center of mass during quiet bipedal standing in young healthy men. In the present study, force-matching exercise at 20% of MVC did not change the COP sway during single-leg standing immediately. The difference between these results might be caused by differences in measuring methods and intervention duration. One of the differences between the present study and the previous study by Oshita and Yano [32] is the postural control task. The previous study used bipedal standing, but the present study used single-leg standing as the postural control task. In addition, in their study, the anteroposterior velocity of the center of mass was measured by a laser displacement sensor at the third lumbar vertebra during bipedal standing, which differs from the measurement of postural sway in our study. Regarding the effect of intervention duration on neuroplasticity, Kornatz, et al. [11] reported that low-intensity force-matching training at 10% of maximum load in abduction of the index finger for 2 weeks could reduce the discharge rate variability of motor units in the first dorsal interosseus muscle. On the other hand, acute effects are caused by various factors because muscle fatigue and corticospinal excitability coexist immediately after exercise sessions [51]. One limitations of this study is that we did not investigate neurophysiological factors such as muscle fatigue or corticospinal excitability. Neuroplasticity can be affected by various factors, such as target muscles, exercise intensity, and intervention duration; future studies are needed to investigate the effects of these factors.

The results of the force-matching exercise at 50% of MVC showed no significant changes in either stable or unstable conditions. One plausible explanation for our findings is that strenuous activities of the lower leg muscles are required during the force-matching task at 50% of MVC than during postural control. It is considered that such excessive activities of the lower leg muscles cannot contribute to modulating delicate force control during postural control. A previous study [24] showed that force steadiness at 50% of MVC was not related to postural control in either stable or unstable conditions. Therefore, force-matching exercise at 50% of MVC may not regulate postural control, including the range of controlling COP and tilt angle, trajectory length of COP, and accumulation of tilt angle. These results suggest that force-matching exercise with high-intensity exercise, such as 50% of MVC, may be inadequate to improve postural stability.

The present study has some limitations. The force-matching exercise was targeted only on ankle plantar flexion, although ankle dorsiflexor and hip muscles also have important roles in postural control. In a previous study, Davis, et al. [51] reported that greater postural sway was related to hip abductor and ankle dorsiflexor force steadiness. Further studies are required to clarify the modulation of postural control due to force-matching exercise in the hip muscles. The present study only investigated the effects of exercise intensities of 5%, 20%, and 50% of MVC. Future studies will need to investigate the effects of low-intensity exercises, especially in more detail, such as in 10% of MVC. Another limitation of this study is that we did not investigate neuroplasticity. Investigation of the effects of neuroplasticity on postural control would be interesting because the discharge rate variability of motor units could be modulated by repeated force-matching exercises [11], and the greater intensity of force steadiness tasks could induce the greater blood oxygenation dependent responses in the ipsilateral parietal lobule, putamen, insula, and contralateral superior frontal gyrus [39]. Furthermore, the present study investigated only three different target torque intensities (5%, 20%, and 50% of MVC). Since Oshita and Yano [25, 32] revealed the relationship between postural sway and force steadiness at 10% of MVC, future studies should investigate the effects of a force-matching task at another intensity such as 10% of MVC on postural control.

5. Conclusion

In conclusion, the velocity of the tilt angle during single-leg standing on an unstable platform decreased immediately after one session consisting of force-matching exercise at a target torque level of 5% of MVC, whereas postural control on a stable platform was unchanged immediately after force-matching exercises. The findings suggest that force-matching exercise at low-intensity target torque levels, such as 5% of MVC, would effectively improve postural control on an unstable platform. These important findings would contribute to the understanding of the effects of voluntary force control on postural control.

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Declarations of interest

None.

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Figure legend

Fig. 1

Experimental procedure

After performing single-leg standing tasks (Pre), with both a stable and unstable platform, maximum strength is measured to determine maximum voluntary contraction (MVC). Each force-matching exercise at target torque level of 5%, 20%, or 50% of MVC was performed. Thereafter, both single-leg standing tasks is performed again (Post).

Fig. 2

This shows a monitor for visual feedback during force-matching tasks with force signals. The horizontal line in the center of the monitor represents the target torque level and the solid line represents the exerted torque. The participant is instructed to match the exerted torque to the target torque level.

Postural tasks (Pre) →

- stable platform
- unstable platform

Force-matching exercises →

- target at 5% of MVC
- target at 20% of MVC
- target at 50% of MVC

Postural tasks (Post)

- stable platform
- unstable platform

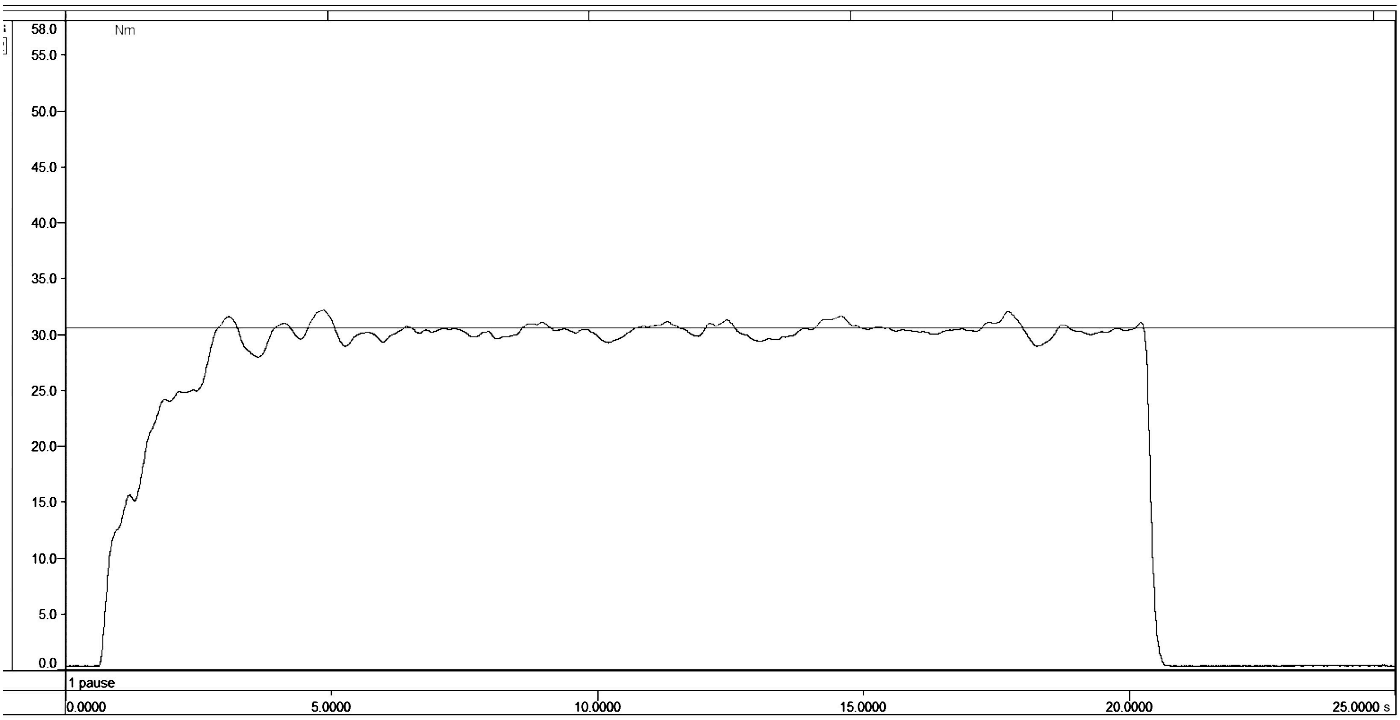
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Table 1 The anteroposterior COP velocity and standard deviation on the stable platform before and after the force-matching exercise

	PRE	POST	Uncorrected p value	Corrected p value
Velocity [mm/s]				
A target torque level at 5% MVC	16.4 ± 4.8	14.9 ± 3.5	.034 †	.205
A target torque level at 20% MVC	16.5 ± 5.2	14.7 ± 3.5	.084 †	
A target torque level at 50% MVC	16.9 ± 5.2	15.8 ± 4.2	.025 ‡	.152
Standard deviation [mm]				
A target torque level at 5% MVC	5.2 ± 1.3	5.7 ± 2.0	.109 ‡	
A target torque level at 20% MVC	5.6 ± 1.9	5.2 ± 1.5	.335 ‡	
A target torque level at 50% MVC	5.8 ± 1.4	5.3 ± 2.1	.101 †	

COP, center of pressure; MVC, maximum voluntary contraction; PRE, task before the force-matching exercise; POST, task immediately after the force-matching exercise. †, *p* value from Wilcoxon Signed Rank Test. ‡, *p* value from paired t-test.

b

Table 2 The anteroposterior platform tilt angular velocity and standard deviation on the unstable platform before and after the force-matching exercise

	PRE	POST	Uncorrected p value	Corrected p value
Velocity [degree/s]				
A target torque level at 5% MVC	2.65 ± 1.12	2.15 ± 1.05	.008†	.046[a]
A target torque level at 20% MVC	2.33 ± 1.12	2.38 ± 1.19	.873†	
A target torque level at 50% MVC	2.50 ± 1.12	2.13 ± 1.02	.018†	.107
Standard deviation [degree]				
A target torque level at 5% MVC	0.93 ± 0.46	0.86 ± 0.39	.539†	
A target torque level at 20% MVC	0.82 ± 0.37	0.86 ± 0.41	.909†	
A target torque level at 50% MVC	0.74 ± 0.38	0.75 ± 0.31	.982†	

MVC, maximum voluntary contraction; PRE, task before the force-matching exercise; POST, task immediately after the force-matching exercise. †, *p* value from Wilcoxon Signed Rank Test.

[a] significant difference between PRE and POST.