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Selective effect of static stretching, concentric contractions, and a one-leg balance task on ankle motion sense in young and older adults

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ABSTRACT

Background: Being aware of ankle movement and motor control has a critical role in maintaining balance during functional activities such as standing, walking, and running. Since the somatosensory system declines with aging, this is even more important for older adults.

Research question: How do different exercise modalities (static stretching, one-leg balance task, concentric contractions, and control) acutely influence ankle motion sense in young and older adults?

Methods: Seventeen young and fifteen older participants performed four different intervention protocols (static stretching, one-leg balance task, concentric contractions, and control) in random order. Each session comprised measurements of ankle motion sense in plantar flexion (PF) and dorsal flexion (DF) directions prior to and after an intervention protocol. Average threshold levels (in degrees) of motion sense detection were calculated from three trials in each direction (PF/DF).

Results: A lower threshold of motion ankle sense was observed for young adults compared to older adults regardless of the exercise modality and the direction of the movement ($p < 0.001$). However, the changes in PF and DF ankle motion senses followed a similar trend in both groups during the three exercise modalities: static stretching increased ankle motion sense threshold (PF: 14% and 5%; DF: 19% and 11% in young and older adults, respectively), concentric contractions decreased ankle motion sense threshold (PF: -24% and -14%; DF: -19% and -21% in young and older adults, respectively), and the one-leg balance task did not significantly influence the ankle motion sense threshold (PF: -1% and -2%; DF: 6% and 1% in young and older adults, respectively).

Significance: Based on these results, static stretching should not be performed before ankle activities that require a good balance, precision, and coordination. Concentric contractions could be recommended before activities that challenge our postural stability.

1. Introduction

Good postural stability is a fundamental skill that is often compromised in the older adult population due to a progressive decline of the somatosensory system function [1,2]. One of the important fields of postural control is proprioception, which has an important role in joint stability, balance, and automatic control of movement [3]. It is known that physical performance can be acutely altered by different exercise modalities. For instance, it has been suggested that static stretching may impair physical performance (e.g., vertical jump height, sprint running time, decrease in force and power) [4–7], although, the acute effects of different exercise modalities on proprioception have not been investigated extensively. As impaired proprioception can lead to less

accurate detection of body position changes, and so increase the risk of a fall [8]. Knowing the acute influence of different exercise modalities on proprioception may be important for programming appropriate exercise sequences within the same training session.

Proprioception refers to the sensation of limb movement (i.e., motion sense), limb position and perception of force produced by the muscles [9]. The muscle spindle is known as a prime proprioceptive receptor, detecting changes in muscle length and velocity of moving body parts [10], while receptors in the skin, joint and ligaments provide additional information about joint position and motion [9]. The structural and functional declines of somatosensory system which typically occur with aging [11] may lead to a decline in proprioception [12,13]. This age-related decline in proprioception has been called

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Table 1
Characteristics of the participants.

| Group | Gender | Number | Age (years) | Body height (cm) | Body mass (kg) |
|--------------|--------|--------|-------------|------------------|----------------|
| Young adults | Female | 8 | 23.5 ± 1,3 | 169.6 ± 4.5 | 56.4 ± 3.9 |
| | Male | 9 | 23.1 ± 1,8 | 178.7 ± 5.1 | 76.9 ± 7.9 |
| Older adults | Female | 7 | 67.3 ± 1.6 | 167.5 ± 4.2 | 62.7 ± 13.2 |
| | Male | 8 | 66.8 ± 1.9 | 178.6 ± 7.1 | 79.8 ± 12.6 |

presbypropria, which describes the inability of the proprioceptive system to accurately interpret actual limb position or movement due to physiological aging [14]. Proprioception is even more important in the older population who have limited visual or vestibular function [15]. Proprioceptive training is a necessary element to prevent falls in older adults [16] and to restore proprioceptive senses after an injury [17,18]. It has been shown that older adults with very poor ankle proprioception have significantly worse balance than peers with good proprioception [19], while proprioceptive impairment can also contribute to balance difficulties in older adults resulting in falls [20]. Although it has been shown that the posture of participants with higher levels of physical activity is more stable than in less active participants [21–24], no previous study has examined whether applying different exercise modalities might induce different acute effects on ankle motion sense in young and older adults.

The functional state of the neuro-muscular system can be acutely altered by different exercise modalities including static stretching [25], concentric contractions [9] and one-leg balance tasks [26]. This can lead to acute changes in muscle-tendon length, stiffness, muscle activation [25], force output [9,25] and spinal excitability [9,25,27], which could have a divergent influence on muscle mechanoreceptors and, consequently, on proprioception. To date, the acute effect of exercise on proprioception has been mainly explored in young adults. Some studies have demonstrated that static muscle stretching has no significant effect on proprioceptive senses [5,28,29], while significant acute decreases in proprioceptive acuity were observed following proprioceptive neuromuscular facilitation (PNF) stretching [30]. Concentric contractions are among the most widely used fatiguing protocols for exploring the acute changes in proprioception [31–33]. While some studies have reported disturbed proprioception [31,32,34], others studies did not find a significant effect on proprioception by of fatigue induced by concentric contractions [33,35]. To our knowledge, no previous study has examined the acute effect of balance tasks on proprioception despite it being known that balance training induces adaptation in all sensory systems that assist postural control, such as the vestibular, the visual, and the somatosensory system as well as in the motor systems controlling muscular output [27]. Precise ankle motion sense detection is crucial in non-weight bearing stages of gait for safe ground clearance and to avoid tripping over [15] and consequently for good postural stability. Since there are structural and functional declines of the somatosensory system that take place with aging [2], we would expect different responses in older adults compared to younger. Due to conflicting results for young adults and little information on the older age group, more research is needed to clarify how the aforementioned exercise modalities influence ankle motion sense.

To address these research gaps, the aim of the present study was to test the acute effect of different exercise modalities (static stretching, concentric contractions, and one-leg balance task) on ankle motion sense in young and older adults. We hypothesized that (I) young adults will have a lower threshold of motion ankle sense (i.e., improved proprioception) than older adults regardless of the exercise modality [12,13,15]. Based on the mechanisms behind static stretching [25], concentric contractions [36] and one-leg balance task [26] we also hypothesized that (for both groups) (II) static stretching will increase ankle motion sense threshold; (III) concentric contractions will increase ankle motion sense threshold; (IV) ankle motion sense threshold will

not change significantly after a one-leg balance task. Knowing that the acute changes in ankle motion detection could provide practical information for proper sequence planning during the same exercise unit, especially for older adults.

2. Methods

2.1. Participants

In total, 17 students of the Faculty of Sports and 15 older adults volunteered to participate in this study (Table 1). They had no history of ankle injury or neuromuscular deficits that could compromise ankle motion sense. Participants were excluded if they presented any dysfunction of the central nervous system, any acute symptom of lower extremity pathology or balance difficulties. All participants were physically active people. Inclusion criteria for this study were regular physical activity at least 2 times per week. The study avoided recruiting competitive athletes to ensure similar physical activity levels in both groups. Participants were asked to refrain from physical activities and alcohol for at least 48 h prior to testing, and to avoid consuming caffeine on the day of measurement. All participants were informed about testing procedures and provided a written informed consent prior to commencing the study. The experiment was approved by the local Ethics Committee of the Faculty of Sports Ljubljana according to the Declaration of Helsinki.

2.2. Procedures

A repeated-measures design was used to evaluate the acute influence of different exercise modalities (static stretching, concentric contractions, one-leg balance task, and control) on ankle motion sense in young and older adults (Fig. 1). Each participant attended to the laboratory on five occasions. The first session was used for familiarization with the test and exercise modalities. The exercise modalities were randomly used during the remaining testing sessions (one per session). Ankle motion sense test was performed before and 30 s after applying each exercise modality. Only the ankle of the dominant leg was tested. Leg dominance was determined by the question: “Which foot would you use to kick a ball at a target?” [37].

2.3. Materials and testing

Passive joint movement sensation was measured on a custom-built device driven by an electromotor (Bechoff, Verl, Germany). Participants were seated in a custom-built chair with hips and knees flexed to 90°. The dominant leg was positioned in a footplate, while the other leg was placed on a wooden platform at the same level. The foot made a 90° angle with the leg in the starting position. The rotational axis of the footplate was aligned with the rotational axis of the ankle (i.e., medial ankle malleolus). Participants were barefoot and straps were not used so as to minimize influence from the cutaneous skin receptors. Visual cues were reduced by using a blindfold, while headphones were worn to eliminate possible sound cues from the motor. Prior to the beginning of the test, the participants actively moved their ankle through a full range of motion to avoid thixotropy [38]. The electromotor passively rotated the ankle joint at a velocity of 0.5°/s [39]. Participants were instructed

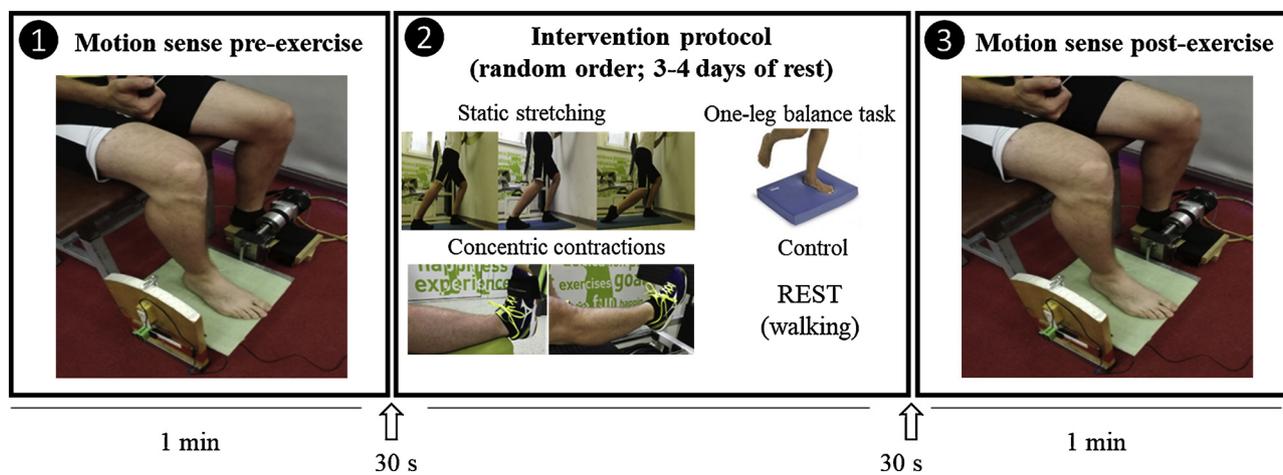


Fig. 1. Time-framed overview of the experimental protocol.

to press a hand switch when they felt ankle movement and were then asked to state the direction of the movement (plantar flexion [PF] or dorsal flexion [DF]). The test was performed 3 times for each direction (PF/DF) in a random order. Resting periods of different interval durations (between 5 and 10 s) were given between each repetition to avoid any anticipation on the part of the participant. The ankle joint was returned to the starting position (0°) before each trial. The stop position (in degrees) was the dependent variable for each trial. The mean value of the three trials performed in each direction (PF/DF) was used for statistical analyses.

Participants performed a single control session and three different intervention protocols in randomized order. Intervention protocols were designed to target muscles around the ankle joint (PF and DF) of the dominant (measured) leg.

- Static stretching. Participants performed three different static stretching exercises. Each exercise targeted a specific muscle (tibialis anterior, soleus, gastrocnemius). Each muscle was stretched 6 times for 40 s, with a 20 s resting period between each stretch. Participants were instructed to stretch the muscle to their discomfort zone, but not pain, as acknowledged by the participant [28].
- Concentric contractions. Two different exercises were used. In the first exercise, participants were asked to perform dorsal flexion of the ankle with foot strap cable equipment. In the second exercise, they performed toe-lifts in a leg press machine. They were asked to follow the beat of a metronome (60 beats/min, 1 s for concentric phase, 2 s for eccentric phase). The loads for both exercises represented 30% of the one-repetition maximum (1RM) and they performed 30 repetitions per exercise. The 1RM was estimated during the familiarization session from a test of repetitions to failure using the Brzycki equation [40]. During the 1RM test, participants were verbally encouraged to perform as many repetitions as possible though they always performed less than 10 repetitions.
- One-leg stand on compliant surface. A one-legged stance on Airex soft mat was performed barefoot, with open eyes, arms crossed over the chest and slightly bent knees. The balance protocol consisted of 4 sets of 4 repetitions that lasted 20 s. 40 s of rest were introduced between repetitions of the same set with 1 min between repetitions of different sets [27].
- Control. The motion sense test was applied twice separated by 15 min. During the control sessions, participants were only allowed to walk around the laboratory. The control session was used to determine the reliability of the motion sense test (PF: coefficient of variation [CV] = 8.01%, intraclass correlation coefficient [ICC] = 0.95; DF: CV = 11.08%, ICC = 0.90).

2.4. Statistical analysis

Normal data distribution (Shapiro-Wilk test) and homogeneity of variances (Mauchly's sphericity test) were confirmed ($p > 0.05$). The Greenhouse-Geisser correction was used for one of the interactions (exercise \times time \times muscle) because the assumption of the homogeneity of variances had been violated ($p < 0.001$). A mixed model analysis of variance (ANOVA) with Bonferroni post hoc corrections was applied with "time" (pre-exercise and post-exercise), "exercise modality" (stretching, concentric contractions, one-leg balance task, and control), and muscle group (PF and DF) as between- and "group" (young and older adults) as within-participants factors. Cohen's *d* effect size (ES) and percent differences were also used to quantify the magnitude of the differences. The following scale was used to interpret the magnitude of the ES: negligible (< 0.2), small (0.2–0.5), moderate (0.5–0.8), and large (≥ 0.8) [30]. All statistical analyses were performed using the SPSS (IBM SPSS version 25.0, Chicago, IL, USA) software package with statistical significances set at an alpha level of 0.05 (two-tailed).

3. Results

The ANOVA revealed a significant main effect of exercise ($F = 8.15$, $p < 0.001$) and group ($F = 31.13$, $p < 0.001$), but the main effect of time ($F = 4.12$, $p = 0.051$) and muscle ($F = 2.72$, $p = 0.110$) did not reach statistical significance. Bonferroni post hoc comparisons revealed a lower threshold of motion ankle sense for concentric contractions compared to the control ($p = 0.001$, ES = 0.35) and stretching ($p = 0.001$, ES = 0.34) protocols, while young adults showed a lower threshold of motion ankle sense than older adults ($p < 0.001$, ES = 1.57). The exercise \times time was the only significant interaction ($F = 29.9$, $p < 0.001$) having been caused by the reduction and increment in the motion ankle sense threshold after the stretching and concentric protocols, respectively. The comparison of pre- and post-exercise ankle motion sense values for each exercise modality are depicted separately for both groups for PF (Fig. 2) and DF (Fig. 3) muscles. The interaction exercise \times group ($F = 1.63$, $p = 0.189$), time \times group ($F = 1.67$, $p = 0.206$), time \times muscle ($F = 0.72$, $p = 0.402$), muscle \times group ($F = 3.02$, $p = 0.092$), exercise \times muscle ($F = 0.55$, $p = 0.649$), exercise \times time \times group ($F = 0.06$, $p = 0.983$), exercise \times muscle \times group ($F = 1.34$, $p = 0.265$), time \times muscle \times group ($F < 0.01$, $p = 0.981$), exercise \times time \times muscle ($F = 0.73$, $p = 0.479$), and exercise \times time \times muscle \times group ($F = 1.75$, $p = 0.163$) did not reach statistical significance.

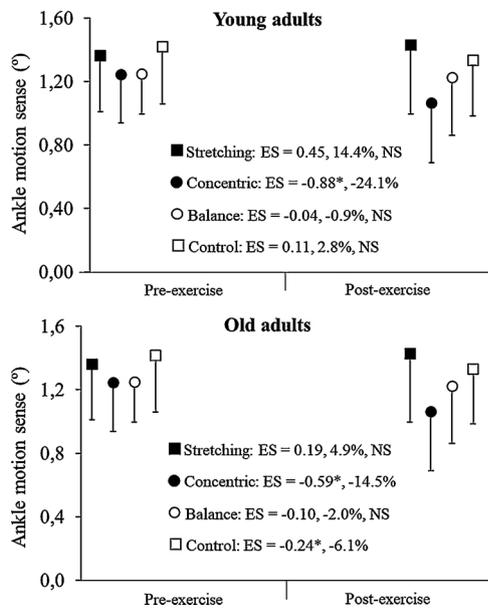


Fig. 2. Comparison of the plantar flexor ankle motion sense values obtained at pre- and post-exercise for each exercise modality. ES, Cohen's *d* effect size ([post-exercise mean – pre-exercise mean] / pre-exercise SD). The mean value and standard deviations (error bars) are depicted. *, significant changes ($p < 0.05$). NS, no significant differences.

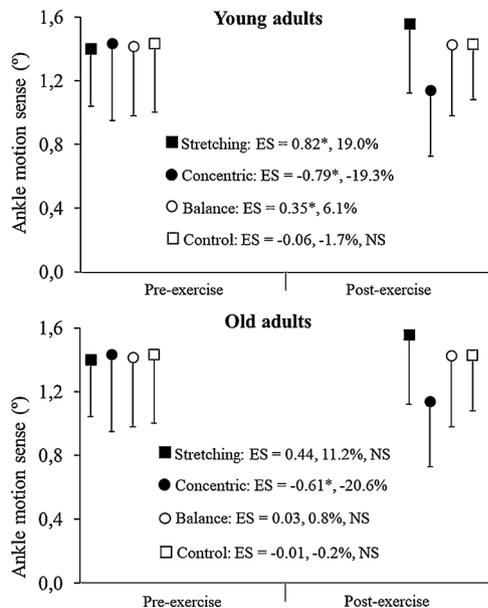


Fig. 3. Comparison of the dorsal flexor ankle motion sense values obtained at pre- and post-exercise for each exercise modality. ES, Cohen's *d* effect size ([post-exercise mean – pre-exercise mean] / pre-exercise SD). The mean value and standard deviations (error bars) are depicted. *, significant changes ($p < 0.05$). NS, no significant differences.

4. Discussion

The present study examined the acute effects of static stretching, concentric contractions and a one-leg balance task on ankle motion sense in young and older adults. A lower threshold of motion ankle sense was observed for young adults compared to older adults regardless of the exercise modality or the direction of the movement (PF or DF). However, the changes in PF and DF ankle motion senses followed a similar trend in both groups during the three exercise modalities: with static stretching increased ankle motion sense threshold, concentric

contractions decreasing ankle motion sense threshold, and the one-leg balance task having no significant influence on ankle motion sense threshold.

The first hypothesis of the study was confirmed since the older adults presented higher motion sense thresholds in the ankle joint than young adults. This finding was expected because it is known that proprioception is progressively impaired with aging [12,15,41]. However, the main novelty of the present study is that we simultaneously explored the effects of different exercise modalities thus minimizing bias for different experimental groups in other studies. No significant differences were observed between young and older adults for changes in PF and DF ankle motion sense following the different exercise modalities. This is important because even though motion sense detection in older adults was at a lower level, they still followed the same adaptation pattern in single exercise modalities.

Different exercise modalities may induce selective changes in the functional state of the muscles [4,5,31,32]. Therefore, the primary goal of this study was to reveal the influence of three commonly used exercise modalities (static stretching, muscle fatigue, and one-leg balance task) on ankle motion sense. It is known that static stretching is effective in increasing joint range of motion [42] and injury prevention [43–46], but it can also have a negative effect on some physical performance (e.g., jumping, sprinting, or running) [47]. The obtained results confirmed the second hypothesis since static stretching had a negative effect on ankle motion sense. The thresholds levels for ankle motion detection were significantly greater after static stretching for both young and older adults. No previous study has examined the acute effects of static stretching on motion sense detection, however we can compare our results with other similar studies. Static stretching of ankle muscles has been shown to decrease postural control [5,48,49] which could also be related to the deteriorated ankle motion sense detection seen in our study. With static stretching, mechanical adaptations of the muscle-tendon unit (MTU) and subsequent adjustments to the neural system were observed [25]. It is also known that muscle spindle receptors and Golgi tendon organs can be affected due to increased MTU length and reduced passive MTU stiffness following static stretching [48]. These changes might then be associated with decreased afferent input into the motor neuron pool that reduce tonic reflex activity [25]. The above mentioned mechanisms relating to static stretching could explain why a deterioration of ankle motion sense was observed in the present study.

Contrary to our third hypothesis, the muscle fatigue induced with concentric contractions caused an improvement of ankle motion sense in both groups. Although this was the first study to explore the effect of fatigue with concentric contractions on motion sense detection there have been several reports on aspects of proprioception after different fatigue protocols based on concentric contractions. It has been noted that force matching performance was less accurate and less consistent after concentric contractions of ankle PF [34] when they were performed until maximal exhaustion. Other studies have suggested that joint position sense may be impaired after dynamic contractions of PF [50] and isometric contractions of DF muscles [51], however some studies have revealed that ankle joint proprioception is not impaired after different fatiguing protocols [33,35]. Concentric contractions performed at 30% of the 1RM caused better ankle motion detection in young and older adults. It seems that this kind of activity may have positive effects on motion detection as long as they are not performed until muscular failure. This exercise modality probably caused increased muscle spindle discharge [36] resulting in a higher resting discharge rate after concentric contractions [52]. This may be one of explanations for improved ankle motion detection after concentric contractions. The discrepancy between the current results and previous findings may also be caused by the passive nature of the task used in the present study because previous studies have shown that the effect of muscle fatigue on proprioception is affected by the nature of the task (active vs. passive) [53].

Motion sense detection did not significantly change after performing the one-legged balance task. Other studies that looked at balance on unstable surfaces have shown that vestibular [26] and visual [54] information is upweighted while information derived from somatosensory system becomes ambiguous [55]. This is caused by changes in the length of muscles in the lower extremity that are not coherent with changes in body orientation relative to gravity [56]. Even though different studies have reported reduced gains in proprioceptive reflexes after balancing exercise [57,58], we assume that changes in the use of afferent information disappeared after this period of one-legged balancing. The one-legged balancing exercise might impose different difficulty on the participant that could lead to contrasting adaptations. Additionally, the participant's previous experience with balance tasks could also have an influence on one-leg balance task execution [26]. All to all, it seems that the one-leg balance task did not induce greater neural and mechanical adaptations to influence ankle motion sense.

It should be noted that the group of older adults in the present study consisted of physically active individuals. Physical activity can have positive influence on proprioception [59] and lessen the differences between young and older adults. One of possible limitations could be measuring motion sense in non-weight bearing conditions. However, this should not be underestimated, because good ankle control is also crucial in non-weight bearing stages of the gait [15]. Another limitation of our study could be that the duration of intervention protocols were not matched. However, exercise modalities performed also have different duration in practice, so the results should have ecological validity. Our exercise modalities are specific and cannot be generalized to other variants. For example, the length of the stretch and familiarization with the stretching exercise may have impacted our results, which could be responsible of the conflicting results reported in the literature regarding the effects of stretching [60]. Also, multi-joint functional exercises could have had a more positive effect on ankle motion sense than single-joints concentric contractions, while the surface could also have been an important factor to consider for the one-leg balance task. It is therefore plausible that other types of stretching, concentric contractions or balance tasks could promote different changes on ankle motion sense.

In summary, we confirmed that older participants are less capable of sensing joint motion but it seems that different exercise modalities have very similar effects on both groups. Our findings showed that static stretching has a negative effect on ankle movement sense. Note that a reduction in ankle movement sense could impair customary walking, safe stepping and foot ground clearance during swing phase [15]. This could be even more important for older adults who have impaired balance control. Motion sense detection improved after concentric contractions in both groups, so it is possible to recommend this intervention before activities that challenge postural stability. This information can be useful for appropriate sequence planning during the same exercise unit, especially for older adults.

Author contributions

Darjan Smajla: Conceptualization, Data Curation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing.

Amador García-Ramos: Methodology, Writing – review & editing.

Katja Tomazin: Conceptualization, Supervision.

Vojko Strojnik: Conceptualization, Supervision. Writing – review & editing.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.gaitpost.2019.04.006>.

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