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The effect of sensory-targeted ankle rehabilitation strategies on single-leg center of pressure elements in those with chronic ankle instability: A randomized clinical trial

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ABSTRACT

Objectives: To determine the effects of sensory-targeted ankle rehabilitation strategies on laboratory-oriented measures of single-leg balance in those with chronic ankle instability.
Design: Non-inferiority randomized controlled trial.
Methods: Seventy-seven participants with self-reported chronic ankle instability were randomized into 4 treatment groups: Ankle joint mobilization, plantar massage, triceps surae stretching, and a control group. All participants performed 3 trials of single-leg balance on a force plate with eyes open and closed at 3 time points (baseline, immediately after the first treatment, and following 6 treatments over 2 weeks). The spatial (standard deviation), temporal (velocity), and spatiotemporal (time-to-boundary) elements of center of pressure excursions in single-leg balance were evaluated with eyes open and eyes closed at each time point. Immediate and final change scores were calculated for each group from the baseline values on these variables.
Results: Joint mobilization produced immediate improvements in the temporal elements with eyes open and closed that exceeded the minimum detectable changes for these measures. Plantar massage and triceps surae stretching also enhanced the temporal element after a single treatment, but only with eyes closed. No substantial benefit of any of the interventions were found after 2-weeks of treatment, regardless of treatment group.
Conclusions: Sensory-targeted ankle rehabilitation strategies substantially improve single-leg postural control after one treatment, but these changes are short-lived. Future research is needed to determine whether combinations of sensory-targeted ankle rehabilitation strategies with other therapeutic interventions potentially improve single-leg balance stability in those with CAI compared to use in isolation.
Clinical trial registration number: NCT01541657.

1. Introduction

Ankle sprains are the most common musculoskeletal injury incurred by individuals who participate in physical activity.[1] It is well established that ankle sprains have highest recurrence rate of any musculoskeletal injury.[1] A conservative estimate based on prognostic evidence is that at least 1 out of 3 patients who suffer an ankle sprain will go on to will self-report long-term injury associated symptoms.[2] Reinjury coupled with episodes of giving way, decreased functional performance and health-related quality of life, and increased medical expenses signify that an ankle sprain is a gateway to a continuum of disability.[3] It is critical that we develop effective rehabilitation strategies to break this continuum and increase the likelihood of full restoration of health in ankle sprain patients.

It is well established that chronic ankle instability (CAI) is a complex phenomenon marked by changes in both sensory and motor function within the sensorimotor system.[3–5] Freeman et al.[6] initially proposed that the de-afferentation of the damaged sensory receptors was responsible for the functional deficits reported in those with functional instability. Evidence has emerged to suggest that the sensorimotor system dynamically reweights sensory

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information from multiple somatosensory sources (plantar, musculotendinous, and ligamentous receptors) to accomplish movement goals.[3,7] Those with CAI have demonstrated impaired motor control in single limb balance, landing, and during functional activities.[4] The decreased ability to effectively coordinate appropriate movement responses and patterns may place these patients at increased risk of injury. Rather than this risk being driven by motor impairments, perhaps CAI and the increased risk for recurrent ankle sprains are due to a diminished ability to effectively weigh and discriminate relevant sources of sensory information for developing effective movement strategies.

In a companion clinical trial,[7] the effect of systematically manipulating somatosensory information through manual therapy in individuals with self-reported CAI was investigated. Two weeks of Sensory-Targeted Ankle Rehabilitation Strategies (STARS) were shown to enhance patient- and clinician-oriented outcomes including self-reported function, single limb balance ability, and weight-bearing dorsiflexion.[7] It is apparent from this evidence that targeting and manipulating somatosensory sources around the ankle may have benefit for those with self-reported CAI. What remains unclear is whether these changes can be detected with laboratory-oriented measures of sensorimotor function.

Single limb balance assessment on a force plate is considered one of the major assessment tools for exploring sensorimotor function in CAI patients.[8–10] Center of pressure (COP) is a kinetic variable derived from a force plate that can be used to assess balance ability. Within COP, there are spatial elements based on the variability of COP excursions, temporal elements based on the velocity of COP excursions, and spatiotemporal elements that examine the spatial and temporal elements in the context of the size of the base of support. Time to boundary (TTB) is a COP measure that takes into account the magnitude and velocity of COP excursions in the context of the size of the foot (base of support). As a spatiotemporal measure, TTB provides an estimate of the amount of time a person has to make postural corrections while maintaining balance.

Patients with CAI have demonstrated larger spatial and temporal values in their COP excursions and decreased TTB compared to healthy individuals.[8,10,11] These deficits indicate that patients with CAI have a diminished ability to control COP excursions while maintaining single-leg balance and may be due to a more constrained sensorimotor system. COP spatial, temporal, and spatiotemporal elements have also been effective in detecting improvements in CAI patients after rehabilitation (lower spatial and temporal values and increased TTB).[12–14] By exploring the spatial, temporal, and spatiotemporal elements after STARS intervention, further insight may be gained into the sensorimotor responses to these interventions that may elucidate the patient- and clinician-oriented improvements already noted.[7] Therefore, the purpose of this study was to explore the effects of three different STARS interventions in comparison to a control condition over two-weeks on spatial, temporal, and spatiotemporal elements of COP in those with self-reported CAI. We hypothesized that each STARS treatment would substantially influence COP excursion elements (spatial, temporal, spatiotemporal) beyond the control treatment. Additionally, we also hypothesize that each STARS would not necessarily be inferior to each other based on the minimum detectable change for each COP element.

2. Methods

This study was a non-inferiority clinical trial that used a multi-center, multi-arm parallel randomized control study design with follow-up periods associated with the immediate effects of one treatment and cumulative effects of 2 weeks of treatment.[7] Based on the exploratory nature of this trial, patients and assessors were not blinded to treatment allocation. Three STARS were explored: ankle joint mobilization, plantar massage, and triceps surae stretching for improving laboratory-oriented outcome measures related to single-leg postural control. See Fig. 1 for the STARS descriptions.

Participants with CAI were recruited through advertisements and word of mouth between January 2012 and February 2014 from the general population (i.e. student, staff, and faculty) of three higher education institutions in the United States and tested in research laboratories on the respective campuses. CAI was defined as a history of a lateral ankle sprain; at least two episodes of "giving way" within the past 6 months; scoring ≥ 5 on the Ankle Instability Instrument (AII), scoring < 90% on the Foot and Ankle Ability Measure Activities of Daily Living scale (FAAM-ADL), and scoring < 80% on the FAAM Sport (FAAM-Sport).[7,15,16] Exclusion criteria consisted of failing to meet the above mentioned inclusion criteria and/or having 1) sustained an acute ankle sprain in the 6 weeks prior to screening, 2) a previous history of ankle surgeries, lower extremity surgeries associated with internal derangements or repairs, and/or (3) other conditions known to affect sensorimotor function.[7] The protocol was approved by the ethics committees for each institution and all individuals provided written informed consent prior to participation. Our power analysis (GPower: Version 2.0, University of Dusseldorf, Germany), indicated that the number of subjects necessary to detect significant changes on TTB variables was 16 per group, based on $\beta = 0.90$, $\alpha = 0.10$, and conservative effect sizes. Thus, we will recruit 20 participants per group and plan for a 20% dropout rate, which would leave 16 subjects in each group.[7]

Following baseline testing, participants were randomized into one of three treatment groups or the control group using sealed opaque envelopes created at each institution prior to the initiation of the investigation by individuals not involved with the investigation. Randomization procedures were conducted in blocks of 8 at each institution with each block containing two assignments to each group.

The STARS interventions have been previously described.[7] The respective treatment groups received six 5-min treatments of their assigned STARS with at least 24 h between treatments across two weeks. In order to determine the effectiveness of each STARS on COP excursion elements, all participants were assessed at 3 time points: baseline, immediately following the initial treatment, and within 72 h of completing 2-weeks of treatment. Participants performed single-leg postural control trials on a force plate (Accusway Plus, AMTI, Watertown MA) with their arms across their chests and the opposite foot held above the force plate for 10 s. Prior to the start of each trial, each participant's foot was meticulously placed in the center of the force plate to ensure that it was equally distributed across the anterior-posterior (AP) and medial-lateral (ML) axes of the force plate's center. Participants performed 3 trials of eyes open and eyes closed on both the treated and untreated limb. The treated limb was defined as the self-reported worse limb based on the AII and FAAM scores.

COP data from the single-leg postural control trials across the 3 testing sessions were separated into the AP and ML directions. In order to assess the COP spatial element, the standard deviation of COP excursions (COP-SD) was calculated for both directions. Lower COP-SD indicated lower variance within COP excursions and thus better postural control. The COP temporal element was captured by calculating the average velocity of COP excursions (COP-V) in both directions. Lower COP-V indicated better postural control. The mean of TTB minima (henceforth referred to as TTB) was calculated in both the ML and AP directions to capture the COP spatiotemporal element.[17] The TTB calculation was based on the previously described methods of Hertel et al.[17] and computed using a custom written MatLab code (Version R2015b, MathWorks Inc., Natick, MA, USA). TTB provided an estimate of the amount of time a participant had to make postural corrections to maintain single-limb

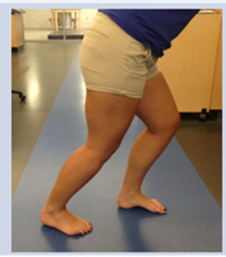
STARS	DESCRIPTION	
ANKLE JOINT MOBILIZATION	Two two-minute sets of joint mobilizations in which one-second large amplitude (grade III) oscillations are performed. Over the course of the five-minute treatment, patients receive approximately 60 oscillations.	
PLANTAR MASSAGE	Five minutes of foot massage that combines effleurage and petrissage on the plantar surface of the foot. Similar to joint mobilizations, use two two-minute sets of plantar massage with a one minute rest between each set.	
TRICEPS SURAE STRETCHING	Two sets of calf stretching with a slightly flexed knee to target the soleus. Each set will consist of three 30-second stretches with 10-second rests between stretches and one minute between sets.	

Fig. 1. The STARS interventions. Each of the STARS groups completed six sessions of the interventions described above over the course of 2 weeks. Reproduced with permission from McKeon PO, Wikstrom EA. Sensory-targeted ankle rehabilitation strategies for chronic ankle instability. *Med Sci Sports Exerc* 2016;**48**(5):776–784.

stance. Higher TTB values indicated more time to make postural corrections and greater stability.[17]

The amount of change due to the intervention was the outcome of interest for each variable. All COP elements were analyzed using change scores from baseline to post-test 1 (immediately following the first STARS treatment) and post-test 2 (upon completion of the 2-weeks of STARS treatment). In order to explore the effects each treatment had on COP elements, the control group change scores were used as the reference. The three STARS groups' change scores were compared to the control group change scores using independent sample t-tests with an alpha level set a priori at $p \leq 0.10$.[7] Based on the exploratory nature of this study, we chose to conduct only the statistical comparisons between each STARS change score and the control group in order to explore the ability for each STARS to influence postural control beyond that of no treatment. Bias corrected Hedge's g effect sizes (ES) with 90% confidence intervals [CI] were used to explore the magnitude of change due to the respective STARS treatments and make inferences about the likely change that might occur in the CAI population.[7] Within the Hedges' g calculation, a correction factor based on sample size is included that adjusts for the tendency for an upward overestimation bias of the standardized effect when using a pooled standard deviation.[18] Hedge's g ES were interpreted as less than 0.3 as small, 0.31–0.7 moderate, and greater than 0.71 as large.[7,9]

To evaluate the changes found in the context of each variable, the measurement error for all outcomes was assessed utilizing the non-treatment limb change from baseline to post-test 2. For spatial (COP-SD), temporal (COP-V) and spatiotemporal (TTB) variables in both the AP and ML directions, individual $ICC_{(2,3)}$ models were employed. From the reliability estimates, the minimum detectable change (MDC) was calculated from the standard error of the measurement ($SD_{\text{pre-test, post-test 2}} * \sqrt{1\text{-ICC}}$) and multiplied by $\sqrt{2}$ to determine the amount of change needed to go beyond the typical measurement error for the outcome.[9,12] This approach afforded the opportunity to control for type 1 error (finding statistical significance, but not exceeding the MDC) and type 2 error (not finding statistical significance due to sample size, but exceeding the MDC).

3. Results

Due to either data issues (5 participants) or adverse event unrelated to the study (1 participant), not all subjects were included in the analysis. The final analysis included 18 control participants, 18 joint mobilization participants, and 19 participants in the plantar massage and calf-stretching groups, respectively. The number of participants in each group exceeded the minimum participants required to maintain appropriate power and therefore no intention to treat analysis was employed. The means (±SD) for each of the COP variables, the respective change scores from post-tests 1 and 2, and MDCs can be found in Tables 1 (COP-SD), 2 (COP-V), and 3 (TTB).

Upon completion of the first treatment, none of the control group changes exceeded the MDC for any of the variables of interest, indicating that the control changes were attributed to measurement error. The joint mobilization group demonstrated significant reductions in COPML-V ($p = 0.03$, ES = 0.75 [0.19–1.32]) and an increase in the TTBML mean ($p = 0.08$, ES = 0.57 [0.01–1.13]) with eyes open. These changes also exceeded the respective MDCs. Neither plantar massage nor the stretching group demonstrated significant changes nor exceeded the MDC for eyes open trials immediately post-treatment.

Table 1
Spatial elements represented by the standard deviation of center of pressure (SD-COP) with eyes open and eyes closed captured during a single limb balance test on a force plate during 10-s trials at baseline, immediately after the first STARS treatment (post-test 1), and upon completion of the two week treatment (post-test 2). A negative change (Δ) score indicates improvement in performance.

	Baseline	Post-test 1	Single treatment Δ	p-value (Δ vs. control Δ)	Post-test 2	Six treatment Δ	p-value (Δ vs. Control Δ)
Mediolateral COP-SD eyes open (cm) MDC = 0.08 cm							
Control	0.51 ± 0.17	0.52 ± 0.18	0.02 ± 0.05	–	0.50 ± 0.15	−0.01 ± 0.08	–
Joint mobilizations	0.57 ± 0.10	0.55 ± 0.11	−0.02 ± 0.11	0.24	0.52 ± 0.10	−0.05 ± 0.10	0.15
Massage	0.53 ± 0.16	0.52 ± 0.14	−0.01 ± 0.10	0.41	0.48 ± 0.14	−0.05 ± 0.12	0.27
Calf stretching	0.52 ± 0.15	0.48 ± 0.13	−0.04 ± 0.10*	0.02	0.52 ± 0.14	0.00 ± 0.07	0.92
Anteroposterior COP-SD eyes open (cm) MDC = 0.15 cm							
Control	0.72 ± 0.32	0.72 ± 0.31	0.00 ± 0.16	–	0.67 ± 0.23	−0.05 ± 0.25	–
Joint mobilizations	0.76 ± 0.24	0.75 ± 0.19	−0.01 ± 0.23	0.88	0.68 ± .0.19	−0.08 ± 0.27	0.75
Massage	0.72 ± 0.27	0.67 ± 0.20	−0.05 ± 0.23	0.46	0.59 ± 0.19	−0.13 ± 0.21	0.31
Calf stretching	0.66 ± 0.25	0.61 ± 0.20	−0.05 ± 0.20	0.38	0.69 ± 0.25	0.03 ± 0.14	0.27
Mediolateral COP-SD eyes closed (cm) MDC = 0.12 cm							
Control	0.94 ± 0.25	0.94 ± 0.26	0.00 ± 0.17	–	0.93 ± 0.25	−0.01 ± 0.13	–
Joint mobilizations	1.09 ± 0.18	0.97 ± 0.17	−0.12 ± 0.17*,†	0.04	1.06 ± 0.16	−0.03 ± 0.16	0.59
Massage	1.04 ± 0.32	0.96 ± 0.24	−0.09 ± 0.18	0.14	0.93 ± 0.27	−0.11 ± 0.19	0.06*
Calf stretching	1.06 ± 0.35	0.95 ± 0.33	−0.11 ± 0.14*	0.04	0.99 ± 0.30	−0.07 ± 0.20	0.28
Anteroposterior COP-SD eyes closed (cm) MDC = 0.17 cm							
Control	1.17 ± 0.35	1.18 ± 0.35	0.02 ± 0.25	–	1.15 ± 0.36	−0.02 ± 0.22	–
Joint mobilizations	1.29 ± 0.31	1.16 ± 0.21	−0.12 ± 0.29	0.13	1.16 ± 0.29	−0.12 ± 0.17	0.11
Massage	1.22 ± 0.40	1.09 ± 0.33	−0.14 ± 0.24*	0.07	1.11 ± 0.37	−0.11 ± 0.24	0.21
Calf stretching	1.30 ± 0.48	1.09 ± 0.38	−0.21 ± 0.21*,†	<0.01	1.16 ± 0.35	−0.13 ± 0.30	0.20

* Indicates the STARS Δ was statistically significant compared to the control Δ.
† Indicates that the Δ exceeded the respective MDC.

Table 2
Temporal elements represented by the velocity of center of pressure (COP-V) with eyes open and eyes closed captured during a single limb balance test on a force plate during 10-s trials at baseline, immediately after the first STARS treatment (post-test 1), and upon completion of the two week treatment (post-test 2). A negative change (Δ) score indicates improvement in performance.

	Baseline	Post-test 1	Single treatment Δ	p-value (Δ vs. control Δ)	Post-test 2	Six treatment Δ	p-value (Δ vs. control Δ)
Mediolateral COP-V eyes open (cm) MDC = 0.28 cm/s							
Control	2.25 ± 0.79	2.16 ± 0.69	−0.08 ± 0.03	–	2.16 ± 0.63	−0.09 ± 0.46	–
Joint mobilizations	2.90 ± 0.63	2.44 ± 0.51	−0.46 ± 0.62*,†	0.03	2.55 ± 0.64	−0.36 ± 0.69†	0.19
Massage	2.51 ± 0.78	2.34 ± 0.72	−0.17 ± 0.51	0.57	2.26 ± 0.67	−0.25 ± 0.37	0.26
Calf stretching	2.28 ± 0.69	2.26 ± 0.60	−0.02 ± 0.30	0.48	2.27 ± 0.67	0.00 ± 0.41	0.54
Anteroposterior COP-V eyes open (cm) MDC = 0.27 cm/s							
Control	2.34 ± 1.06	2.21 ± 0.96	−0.13 ± 0.40	–	2.10 ± 0.72	−0.24 ± 0.86	–
Joint mobilizations	2.51 ± 0.70	2.26 ± 0.73	−0.24 ± 0.71	0.56	2.14 ± 0.70	−0.37 ± 0.47†	0.58
Massage	2.26 ± 0.76	2.05 ± 0.66	−0.20 ± 0.46	0.64	1.93 ± 0.64	−0.33 ± 0.44†	0.70
Calf stretching	2.08 ± 0.77	2.00±.066	−0.07 ± 0.41	0.69	2.00 ± 0.63	−0.08 ± 0.41	0.48
Mediolateral COP-V eyes closed (cm) MDC = 0.58 cm/s							
Control	4.40 ± 1.24	4.42 ± 1.44	0.02 ± 0.60	–	4.52 ± 1.38	0.12 ± 0.64	–
Joint mobilizations	5.48 ± 1.03	4.80 ± 1.09	−0.68 ± 0.83*,†	0.01	5.55 ± 0.99	0.07 ± 0.92	0.84
Massage	5.08 ± 1.77	4.46 ± 1.36	−0.62 ± 0.80*,†	0.01	4.70 ± 1.62	−0.38 ± 0.91*	0.06
Calf stretching	5.21 ± 2.03	4.76 ± 1.92	−0.46 ± 0.88*	0.06	4.94 ± 1.86	−0.27 ± 1.25	0.24
Anteroposterior COP-V eyes closed (cm) MDC = 0.64 cm/s							
Control	4.36 ± 1.47	4.21 ± 1.43	−0.15 ± 0.71	–	4.39 ± 1.40	0.02 ± 0.73	–
Joint mobilizations	5.21 ± 1.67	4.30 ± 1.25	−0.91 ± 1.03*,†	0.02	4.95 ± 1.72	−0.26 ± 0.94	0.33
Massage	4.87 ± 1.86	4.15 ± 1.42	−0.71 ± 1.10*,†	0.08	4.25 ± 1.56	−0.61 ± 1.13	0.05
Calf stretching	5.16 ± 2.13	4.37 ± 1.89	−0.79 ± 0.98*,†	0.03	4.66 ± 1.89	−0.50 ± 1.42	0.17

* Indicates the STARS Δ was statistically significant compared to the control Δ.
† Indicates that the Δ exceeded the respective MDC.

For eyes closed trials, all 3 STARS demonstrated the potential to alter COP elements, see Tables 1–3. Specifically, the joint mobilization group demonstrated significant reductions in COP-V in both the ML ($p < 0.01$, ES = 0.95 [0.37–1.52]) and AP ($p = 0.02$, ES = 0.84 [0.27–1.41]) directions that exceeded the respective MDCs. Additionally, the joint mobilization group demonstrated a significant reduction in the COPML-SD ($p = 0.04$, ES = 0.69 [0.13–1.25]) that also exceeded the MDC. The plantar massage group demonstrated substantial improvements in COPAP-SD ($p = 0.07$, ES = 0.98 [0.40–1.55]) as well as COP-V for both the ML ($p < 0.01$, ES = 0.88 [0.32–1.45]) and AP ($p = 0.08$, ES = 0.59 [0.04–1.14]) directions that exceeded the respective MDCs. The calf stretching group demonstrated a reduction in COPAP-SD ($p < 0.01$, ES = 0.98 [0.40–1.55]) and COPAP-V ($p = 0.03$, ES = 0.73 [0.17–1.29]) with changes that exceeded the respective MDCs. There were no concurrent changes in the ML direction in the stretching group. For all eyes closed testing, TTB was not altered beyond the MDCs for any of the STARS.

Upon completion of the final treatment, none of the control group changes exceeded the MDC for any of the variables of interest, indicating that control group changes were attributed to measurement error. Across all STARS treatments over the course of 2 weeks, no STARS substantially altered COP elements with eyes

Table 3
Spatiotemporal element represented by the mean of time-to-boundary minima (TTB) with eyes open and eyes closed captured during a single limb balance test on a force plate during 10-s trials at baseline, immediately after the first STARS treatment (post-test 1), and upon completion of the two week treatment (post-test 2). A positive change (Δ) score indicates improvement in performance.

	Baseline	Post-test 1	Single treatment Δ	p-value (Δ vs. control Δ)	Post-test 2	Six treatment Δ	p-value (Δ vs. control Δ)
Mediolateral TTB eyes open (cm) MDC = 0.33 s							
Control	2.03 ± 0.85	2.13 ± 0.87	0.10 ± 0.61	–	2.12 ± 0.87	0.09 ± 0.05	–
Joint mobilizations	1.40 ± 0.36	1.84 ± 0.50	0.43 ± 0.51*,†	0.08	1.60 ± 0.37	0.20 ± 0.42	0.50
Massage	1.83 ± 0.98	2.02 ± 1.17	0.19 ± 0.54	0.62	2.03 ± 1.33	0.20 ± 0.52	0.52
Calf stretching	1.93 ± 0.97	1.85 ± 0.61	−0.08 ± 0.47	0.33	1.85 ± 0.80	−0.08 ± 0.46	0.30
Anteroposterior TTB eyes open (cm) MDC = 0.91 s							
Control	5.32 ± 2.56	5.50 ± 2.35	0.17 ± 1.14	–	5.33 ± 2.13	0.01 ± 1.49	–
Joint mobilizations	4.37 ± 1.34	5.04 ± 1.79	0.67 ± 1.42	0.26	5.08 ± 1.60	0.72 ± 1.39	0.15
Massage	5.32 ± 2.89	5.74 ± 2.99	0.42 ± 0.96	0.49	6.21 ± 3.86	0.89 ± 1.43*	0.08
Calf stretching	5.61 ± 2.81	5.33 ± 1.91	−0.28 ± 1.33	0.27	5.33 ± 2.03	−0.28 ± 1.31	0.52
Mediolateral TTB eyes closed (cm) MDC = 0.15 s							
Control	1.02 ± 0.62	1.11 ± 0.99	0.08 ± 0.42	–	0.94 ± 0.42	−0.08 ± 0.40	–
Joint mobilizations	0.79 ± 0.29	0.84 ± 0.24	0.05 ± 0.25	0.77	0.70 ± 0.18	−0.09 ± 0.24	0.89
Massage	0.89 ± 0.48	1.01 ± 0.49	0.11 ± 0.13	0.79	0.96 ± 0.54	0.07 ± 0.18	0.16
Calf stretching	0.87 ± 0.52	0.94 ± 0.52	0.08 ± 0.18	0.95	0.85 ± 0.41	−0.02 ± 0.22	0.57
Anteroposterior TTB eyes closed (cm) MDC = 0.42 s							
Control	2.49 ± 1.13	2.62 ± 1.25	0.13 ± 0.57	–	2.47 ± 1.12	−0.02 ± 0.56	–
Joint mobilizations	2.11 ± 0.87	2.25 ± 0.82	0.41 ± 0.55	0.14	2.13 ± 0.65	0.02 ± 0.61	0.83
Massage	2.53 ± 1.80	2.91 ± 1.86	0.38 ± 0.44	0.15	2.80 ± 1.91	0.27 ± 0.60	0.13
Calf stretching	2.26 ± 1.30	2.63 ± 1.42	0.38 ± 0.56	0.20	2.40 ± 0.99	0.14 ± 0.63	0.42

* Indicates the STARS Δ was statistically significant compared to the control Δ.
† Indicates that the Δ exceeded the respective MDC.

open. The changes found resulted in small to moderate effect sizes favoring STARS compared to control with confidence intervals that crossed zero. Importantly, the upper limit of the confidence intervals crossed into the potentially large benefit and the lower limit maintained an effect close to 0. This indicated that no STARS treatment over the course of 2 weeks was detrimental on COP elements with eyes open.

For eyes closed trials, only the plantar massage intervention demonstrated significant reductions in the COPML-SD ($p = 0.06$, ES = 0.60 [0.04–1.15]) and COP-V in both the ML ($p = 0.06$, ES = 0.62 [0.07–1.17]) and AP ($p = 0.05$, ES = 0.64 [0.09–1.20]) directions with moderate effect sizes and confidence intervals that did not cross zero. However, these changes did not exceed the respective MDCs. TTB did not improve after two weeks of STARS. Again, an important note is that the upper limit of the confidence intervals crossed into the potentially large benefit and the lower limit maintained an effect close to 0 indicating that no STARS over the course of 2 weeks was detrimental on COP elements with eyes closed.

4. Discussion

The most important finding from this study was that immediately following a STARS treatment, each STARS influenced COP elements meaningfully with eyes open and eyes closed. However, no meaningful changes were retained within 72 h after completion of the two-week treatment. Joint mobilization and plantar massage appear to immediately enhance spatial and temporal elements of COP behavior in both the ML and AP directions whereas calf-stretching appears to influence only AP COP behavior.

After a single STARS treatment, joint mobilizations influenced COP elements in both vision conditions whereas plantar massage and calf stretching only influenced COP elements with eyes closed. This may indicate that each STARS (joint mobilization, plantar massage, or triceps surae stretching) makes a unique contribution of somatosensory information in the context other sensory input availability. In previous investigations,[12] a single treatment of joint mobilizations and plantar massage[13] substantially increased postural control in those with CAI in eyes open single limb postural control, but not eyes closed. The lack of change in TTB across any of the STARS with eyes closed in this study may indicate that the removal of vision masks any of the benefits of STARS in the context of single limb postural control tasks. The changes in the spatial and temporal elements found with the removal of vision suggest a potential for improving spatiotemporal behavior, but perhaps not at the critical points where the person is at greatest risk of losing balance.

While there were no substantial changes in COP elements after two weeks of STARS treatments, previous investigation clarified that individual STARS have substantial effects on patient- and clinician-oriented outcomes.[7,19] Specifically, six sessions of joint mobilizations have been shown to enhance self-reported function,[7,19] star excursion balance performance,[19] single limb balance test performance,[7] and weight-bearing dorsiflexion[7,19] in patients with CAI. Similarly, two weeks of plantar massage and calf stretching have increased postural control, self-reported function, and weight-bearing dorsiflexion as well.[7] In light of this evidence, the examination of COP behavior does not appear to lend clear insights into the global functional changes in CAI participants.

As identified in a companion study,[7] no STARS participants experienced gains in self-reported function above the cutoffs for CAI classification. In this study, we found no meaningful changes in TTB. Perhaps meaningful changes in spatiotemporal COP behavior, especially with eyes closed, serve as an indicator of meaningful self-reported functional improvements. When evaluating the balance training literature, the use of a progressive balance-training program over the course of 4 weeks resulted in substantial TTB improvements with eyes closed concomitantly with self-reported functional improvements that rose above the threshold for CAI classification.[14] Potentially STARS are not meant to be used in isolation, but may serve to augment the central processes influenced by balance and coordination training.[20] The immediate changes noted in COP behavior from the STARS supports the hypothesis that these interventions may create a window of opportunity in sensorimotor function that can be capitalized on through rehabilitation.[12] In this context, STARS may be beneficial for priming the sensory system rather than changing sensorimotor function.

There are several limitations associated with this study. Because there was no blinding of participants or investigators, expectation bias was not controlled for and may have influenced the findings. To control for this bias, we chose to use the 3-tiered approach to determining the meaningfulness of changes (statistical significance, magnitude of effect, and MDC).[7] Another limitation of this investigation is that clinicians would not typically use STARS in isolation in clinical practice. Future research is warranted to determine whether a combination of STARS or STARS in combination with other therapeutic interventions offer greater therapeutic benefit than individual STARS in isolation. The postural control assessment included in this investigation examined COP elements after successful 10-second single-leg standing attempts. In the previous investigation, STARS resulted in a substantial decrease in the number of errors on the single limb balance test. It may be that the COP behavior captured in this study is not truly representative of the diminished postural control experienced in these participants. Future research may be needed to examine COP behavior during unsuccessful attempts to maintain postural control rather than during successful attempts. Lastly, while group changes in postural control were noted in this study, certain participants may have had greater responses to their respective STARS compared to other participants. Key predictive factors for treatment success using STARS for improving the COP elements have not been established. Future research is needed to determine if there are critical screening factors[21] that may guide clinicians in the appropriate STARS selection for individual patients.

5. Conclusion

Based on the findings from this study, STARS impact the spatial, temporal, and spatiotemporal elements of postural control in those with CAI immediately after the first treatment. It appears that each STARS has the ability to influence these elements in a unique way, but the improvements are short-lived (within 10 min of treatment). Future research is needed to determine whether combinations of STARS or STARS in combination with other therapeutic interventions potentially improve instrumented postural control in those with CAI beyond STARS in isolation.

Practical implications

1. A single treatment of ankle joint mobilizations substantially improve single-leg balance with eyes open and eyes closed in those with CAI.
2. Plantar massage and triceps surae stretching appear to be effective in enhancing single-leg balance with eyes closed.
3. The immediate changes in single-leg balance found in this study suggest that STARS may open a window of opportunity for sensorimotor rehabilitation.
4. Future research is needed to explore the effects of combinations of STARS or STARS in combination with other rehabilitation techniques for enhancing outcomes in CAI patients.

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