Acute Effects of Increased Joint Mobilization Treatment Duration on Ankle Function and Dynamic Postural Control in Female Athletes With Chronic Ankle Instability

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Background: Chronic ankle instability (CAI) is linked to mechanical and functional insufficiencies. Joint mobilization is purported to be effective at treating these deficits.

Purpose: To examine the effect of different treatment durations of a grade IV anterior-to-posterior ankle joint mobilization on weightbearing dorsiflexion range of motion (WB-DFROM), posterior talar glide (PG), and dynamic postural control in individuals with CAI.

Study Design: Controlled laboratory study.

Methods: A total of 48 female athletes (mean age, 22.8 ± 4.8 years) with unilateral CAI participated in this study. Participants were randomly assigned to 1 of 3 treatment conditions: 30 seconds, 60 seconds, and 120 seconds. Treatment was provided to the injured limb on 3 separate occasions 48 hours apart and consisted of a Maitland grade IV anterior-to-posterior talar joint mobilization based on the participant's initial group assignment. WB-DFROM; PG; and the anterior (ANT), posteromedial (PM), and posterolateral (PL) reach directions of the Star Excursion Balance Test were measured bilaterally before and after each treatment. The uninjured limb acted as a control. Data were analyzed using 2-way mixed-model analyses of variance, and effect sizes were calculated through use of Hedges *g*.

Results: Significant differences were detected after all treatment sessions for all outcome measures ($P \leq .001$) and between treatment groups after sessions 1, 2, and 3 for all outcome measures ($P \leq .001$). Effect sizes were very large or huge for all treatment groups for WB-DFROM, PG, and ANT reach direction. Substantial variation was found in effect sizes for PM and PL measures.

Conclusion: Accessory mobilization is an effective treatment to induce acute changes in ankle motion and dynamic postural control in patients with CAI, with longer treatment durations conferring greater improvements.

Clinical Relevance: This study adds clarity to the use of joint mobilization treatments and will add to the current clinical practice strategy for patients with CAI.

Keywords: chronic ankle instability; mobilization; Maitland; dorsiflexion; manual therapy

Ankle sprains are the most common musculoskeletal disorder, accounting for 22% of all sports injuries.[11,15] Despite the high prevalence and severity of ankle sprains,[4,11] they are often considered innocuous injuries and are treated with limited time and resources.[3] However, ankle sprains have the highest recurrence rate of any musculoskeletal injury.[1] Up to 70% of patients sustaining a single sprain report residual symptoms, including recurrent instability, additional ankle sprains, and reduced functional capacity.[45] These negative antecedents form the primary characteristics of chronic ankle instability (CAI).

CAI has been linked to several mechanical and functional insufficiencies.[19] The primary mechanical impairments include reduced dorsiflexion range of motion (DFROM),[10] reduced posterior talar glide (PG),[9] and

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increased anterior joint laxity.[7] After an inversion ankle sprain, the talus is subluxed, creating an anterior positional fault and resulting in anterior ligament laxity, restrictions in posterior noncontractile tissue, and observed decreases in DFROM.[22] The reduction in range of motion (ROM) may disrupt the transmission of afferent information to the sensorimotor system, contributing to the functional impairments associated with CAI.[21] Damage to ligamentous and capsular tissues causes partial deafferentation of mechanoreceptors, resulting in a loss of somatosensory information to the central nervous system.[20] Changes in arthrokinematic function frequently result in alterations to sensory input, suggesting a synergistic relationship between mechanical and functional impairments.[31]

Poor sensorimotor control and reductions in DFROM significantly increase the risk of lower extremity injury.[19] Interventions that address multiple aspects of impairment are necessary to alleviate the risks and limitations to activity experienced with CAI. Given that impairments are purported to be arthrogenic, interventions need to address the noncontractile tissue restrictions.[9]

Joint mobilizations restore arthrokinematic movements that occur between joint surfaces.[13] This is achieved through an increase in the extensibility of noncontractile tissues, increasing the extensibility of joint structures. Joint mobilizations also stimulate joint mechanoreceptors, which improves the transmission of afferent information to the central nervous system.[21,29] Mobilizations have consistently demonstrated acute improvements in DFROM and PG in those with a history of ankle sprains.[13,22,35] The use of joint mobilizations to increase afferent input and the effect of mobilizations on dynamic balance and postural control have also been identified.[8,23,24]

It is postulated that the acute magnitude of effect is influenced by treatment volume and duration. Treatment doses ranging from 30 to 120 seconds have been used by researchers to study the effects of mobilization of the talus. These studies have shown that significant improvements can be elicited from these treatment durations.[6,13,24,28] Because of methodological differences, the most efficacious treatment duration remains unclear. Given that injury treatment usually involves repeated therapy sessions, it is surprising that there is a paucity of research examining the acute effect of multiple treatments, particularly within the first week of management.

Therefore, we examined the effect of varying treatment durations within 3 treatment sessions on weightbearing DFROM (WB-DFROM), PG, and dynamic postural control in individuals with CAI. We hypothesized that longer treatment durations would lead to greater improvements in outcome measures than would shorter durations.

METHODS

Participants

Enrollment in the study was conducted between October 2016 and March 2017. A total of 56 female athletes from a variety of collegiate-level sports with self-reported CAI were screened for inclusion, with 48 participants (mean ± SD age, 22.8 ± 4.8 years; height, 171.1 ± 6.1 cm; mass, 70.8 ± 7.4 kg) going on to complete the study. A complete female cohort was selected due to the established sex differences in dynamic and functional measures relating to physical performance.[17] Inclusion and exclusion criteria followed the International Ankle Consortium's standards for enrolling patients with CAI in controlled research.[14] Criteria consisted of a history of at least 1 ankle sprain within the past 12 months, resulting in a combination of pain, swelling, and time lost or modification to normal function for 1 day or longer.[19] The Cumberland Ankle Instability Tool (CAIT) was used to determine the extent of injury, with a score of <24 out of 30 indicating the presence of the condition. Participants completed the CAIT bilaterally, allowing the uninjured extremity to be used as a control, as results were assessed to ensure participants had only unilateral symptoms. Participants were excluded if they reported a history of previous surgery, fracture, or acute musculoskeletal injury to either lower extremity within the previous 3 months.[14] The protocol adhered to the Helsinki declaration and was approved by the institutional research ethics committee. All participants provided written consent before participation. Participants were also screened for any contraindications to mobilization.[18]

Participants were randomly allocated to balanced treatment groups (n = 16) of 30 seconds, 60 seconds, or 120 seconds through use of a computer-generated simple random allocation sequence (Figure 1). Before testing and treatment intervention, baseline measures of limb length were obtained for all participants. Limb lengths were measured bilaterally by use of a limb measurement tape measure (Anatomical Tape Measure; Idass) from the anterior superior iliac spine to the distal tip of the medial malleolus. The limb lengths were used to calculate normalized reach distances on the Star Excursion Balance Test (SEBT). Participants and the research team were blinded as to the group allocation until after the first preintervention tests were completed. Pre- and posttest measures of PG, WB-DFROM, and dynamic postural control were collected for injured and uninjured limbs, in that order, with participants barefoot, according to previously described protocols.[9] Participants were blinded to all outcome measures, which were taken for both limbs (injured and uninjured). The intervention and testing took place over 5 days and consisted of 3 separate treatment sessions (sessions 1, 2, and 3), with each including pre- and posttesting immediately before and after the applied mobilization treatment. These were set 48 hours apart and scheduled for the same time of day to limit diurnal effects. All mobilization treatments and measurements were conducted by the same therapist (C.J.H.), who has more than 10 years of experience.

Dorsiflexion Range of Motion

The weightbearing lunge test was used to measure WB-DFROM, according to the knee-to-wall principle.[9] Participants stood facing a wall with the second toe and center of the heel perpendicular to the wall. Participants performed a lunge where the knee was flexed to contact the wall, while

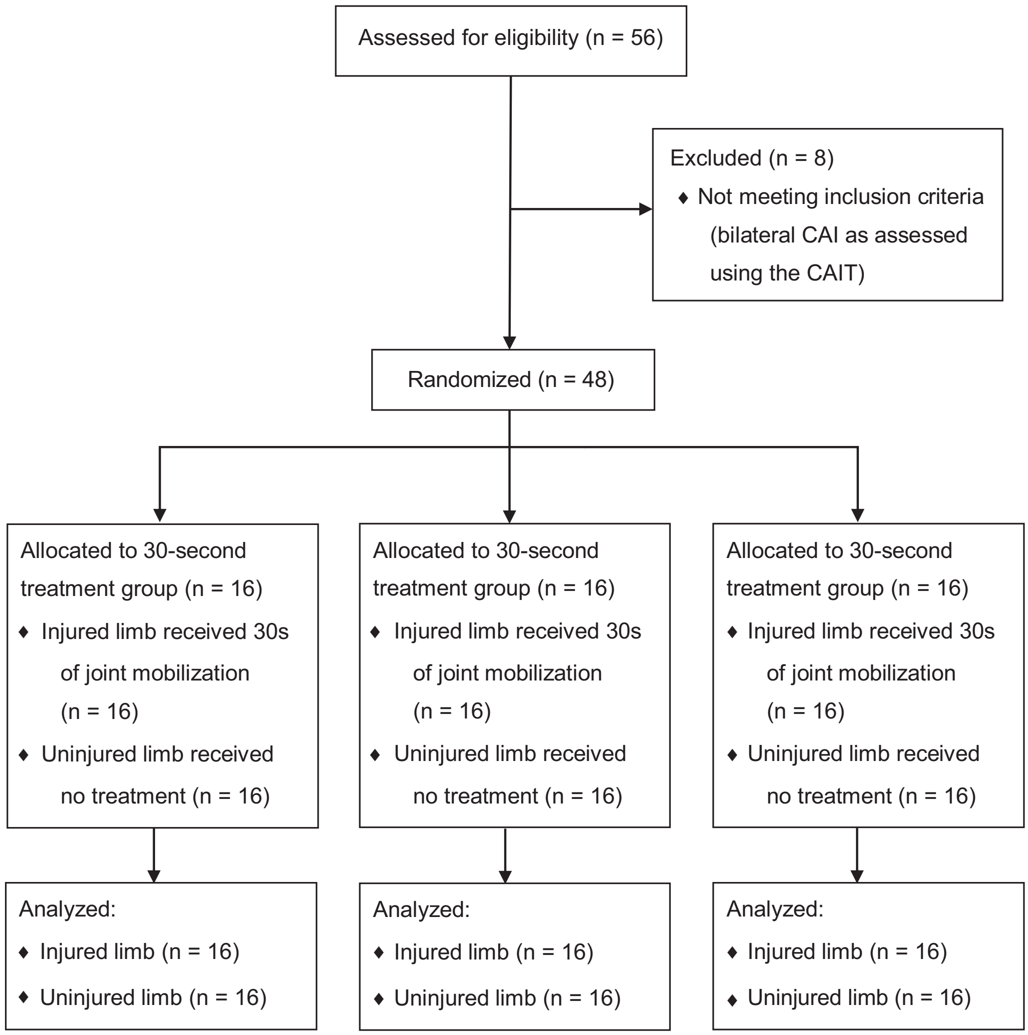

Figure 1. Flow diagram of participants. CAI, chronic ankle instability; CAIT, Cumberland Ankle Instability Tool.

the heel remained planted on the floor. Foot position was progressed away from the wall in 1-cm increments until knee and heel contact could not be maintained. Smaller increments were then used to achieve the maximum distance from the wall. Maximum distance was measured by use of a limb measurement tape from the base of the wall to the tip of the great toe. Foot pronation and supination were monitored to ensure that movements occurred solely in the sagittal plane. This method produces a greater DFROM measurement than any other position[27] and has demonstrated excellent reliability (intraclass correlation coefficient [ICC], 0.98-0.99).[32]

Posterior Talar Glide

PG was assessed by use of the PG test.[9] The test was performed with the participant seated on the plinth edge with knees bent at 90°. A digital inclinometer (Digi-PAS DWL80E) was secured just above the talocrural joint to measure knee flexion ROM. With the participant's foot in subtalar neutral, the talus was glided posteriorly. The first measurement was taken at initial soft tissue restriction, and knee flexion angle was recorded. The talus was then glided farther until a firm capsular end feel was encountered, and knee flexion angle again was recorded. The angle of knee flexion provides an estimate of PG because, when the talus can no longer be posteriorly displaced, the ankle can no longer be dorsiflexed and further knee flexion is limited.[9] Only a single measure for PG and WB-DFROM was taken to ensure there was no augmented effect from repeated assessment.

Star Excursion Balance Test

Dynamic postural control was assessed through use of the anterior, posterior, and posterolateral directions of the SEBT.[20] Equal halves of the length and width of the test foot were positioned in each quadrant of the SEBT and marked to ensure accurate repositioning between trials.[34] Participants performed maximal reaches with the uninvolved limb followed by a single, light toe-touch on the tape measure. A trial was discarded if the participant's hands did not remain on her hips, stance foot position or heel contact was not maintained, or balance was lost. Distances were measured in centimeters and normalized to leg length.[16] The average of 3 trials was used for analysis, with each direction independently examined. This method has been shown to be highly reliable (ICC, 0.84-0.92).[30]

Joint Mobilization Intervention

The joint mobilization was performed with the participant lying supine with the foot positioned over the end of the plinth. The ankle was placed at 20° to plantarflexion to achieve the talocrural loose-packed position, allowing greater pressure application, which is transmitted to the posterior tissues.[46] The stabilizing hand was placed proximal to the malleoli to stabilize the leg, while the mobilizing hand cupped the anterior talus using the first web space. The talus was then glided posteriorly with downward force.[2] The foundation of the Maitland technique is a grading system of I to IV. Grades I and II are primarily used to treat painful conditions and are performed before resistance is felt. This refers to the point at which a significant resistance to deformation is imposed by the tissue.[43] Grades III and IV are performed after resistance is felt and are designed to restore ROM, with grade 4 generally performed at the point of maximal resistance, which determines the end of range.[33] The joint mobilization selected for the current study was therefore defined as a grade IV, 1-second rhythmic oscillation with translation taken to tissue resistance.[28] Oscillation speed was kept constant by use of a metronome app (Metronome, ONYX Apps). This technique was chosen in order to load and unload the tissue in a way similar to that which would occur functionally.[2] The mobilization was applied for 30 seconds, 60 seconds, or 120 seconds according to each participant's initial group assignment.

Statistical Analysis

Statistical analysis was conducted using SPSS Version 26 (IBM). The percentage improvement for each dependent variable was calculated for each individual treatment session (sessions 1, 2, and 3) before data analysis because of its clinical relevance and immediate accessibility to clinicians. Two-way mixed-model analyses of variance ($P \leq .05$) were used to examine the differences in dependent variables. The independent variables were time (session 1, 2, 3), group (30 seconds, 60 seconds, 120 seconds), and limb (injured, uninjured). The Mauchly sphericity test was conducted with the Greenhouse-Geisser adjustment included for all significant outputs. Post hoc comparisons were completed via Tukey honestly significant difference test in the presence of a group effect. Effect sizes were calculated between the injured and control limbs and between groups for all statistically significant results using a bias-corrected Hedges *g* with 95% CIs. Effect size was interpreted as negligible (0-0.19), small (0.2-0.49), moderate (0.5-0.79), large (0.8-1.19), very large (1.2-1.99), and huge (≥2.0).[37]

TABLE 1
Demographics and Baseline Characteristics of the Study Participants[a]

Variables	Treatment Group		
	30s	60s	120s
Participants, n	16	16	16
Age, y	23.2 ± 4.7	22.6 ± 5.8	22.6 ± 3.9
Height, cm	169.8 ± 5.7	171.1 ± 6.5	171.6 ± 6.5
Mass, kg	69.9 ± 7.7	71.9 ± 6.6	70.6 ± 8.1
Body mass index, kg/m^2	24.5 ± 2.7	24.6 ± 1.9	23.9 ± 1.5
CAIT score, out of 30			
Injured (CAI)	13.3	13.4	14.3
Uninjured (control)	27.3	26.6	27.7
WBLT, cm			
Injured (CAI)	7.7 ± 1.9	8.8 ± 3.6	7.5 ± 2.1
Uninjured (control)	9.5 ± 1.5	11.9 ± 3.1	12.3 ± 4.6
PG, deg			
Injured (CAI)	5.9 ± 1.3	6.4 ± 1.4	5.4 ± 1.2
Uninjured (control)	9.4 ± 1.2	11.0 ± 2.4	10.2 ± 3.2
SEBT anterior, normalized %			
Injured (CAI)	51.7 ± 10.4	53.0 ± 6.5	58.6 ± 4.5
Uninjured (control)	60.9 ± 9.6	55.0 ± 1.5	63.2 ± 1.6
SEBT posteromedial, normalized %			
Injured (CAI)	70.8 ± 10.7	62.3 ± 12.7	75.6 ± 7.0
Uninjured (control)	71.4 ± 14.9	67.7 ± 6.9	78.2 ± 10.6
SEBT posterolateral, normalized %			
Injured (CAI)	78.4 ± 7.8	76.4 ± 8.9	80.6 ± 2.2
Uninjured (control)	79.7 ± 9.0	76.1 ± 3.6	85.9 ± 2.5

[a]Values are expressed as mean ± SD, except for number of participants. CAI, chronic ankle instability; CAIT, Cumberland Ankle Instability Tool; PG, posterior talar glide; SEBT, Star Excursion Balance Test; WBLT, weightbearing lunge test.

RESULTS

At baseline, the groups were similar for all dependent variables ($P \geq .05$) (Table 1). Treatment dose and mean ± SD percentage improvements for WB-DFROM, PG, and SEBT reach directions after each treatment session are presented in Table 2. Effect sizes and 95% CIs for injured limb versus control are shown in Figure 2, with effect sizes for treatment group differences shown in Figure 3. Significant differences were detected between groups after sessions 1, 2, and 3 for all outcome measures ($P \leq .001$).

For WB-DFROM, all treatment durations produced significant improvements compared with the control ($P \leq .001$), with the exception of the 30-second treatment group after session 2 ($P \geq .05$). Effect sizes were "huge" after all sessions for the 120-second group, after sessions 2 and 3 for the 60-second group, and after sessions 1 and 3 for the 30-second group. The effect size was "very large" after session 2 for the 30-second treatment group. Improvements were significantly greater in the 120-second treatment group than the 30-second group for all sessions ($P \leq .001$) and the 60-second group for sessions 2 and 3 ($P \leq .001$). The 60-second group showed

TABLE 2
Percentage Improvement for Weightbearing Dorsiflexion Range of Motion, Posterior Talar Glide, and Anterior, Posteromedial, and Posterolateral Directions of the Star Excursion Balance Test Within Each Session (S1, S2, and S3) Across the Study Timeline[a]

		Treatment Group					
		30s		60s		120s	
Variable	Session	Injured	Uninjured	Injured	Uninjured	Injured	Uninjured
WB-DFROM	S1	**6.53 ± 1.35**	–0.24 ± 0.90	**9.80 ± 10.19**	0.87 ± 0.47	**15.09 ± 6.78**[b]	0.69 ± 0.87
	S2	4.56 ± 3.20[c]	0.96 ± 1.07	**8.61 ± 4.53**[b]	0.14 ± 0.63	**14.53 ± 6.60**[b,c]	–0.74 ± 1.79
	S3	**4.68 ± 2.68**[c]	0.09 ± 1.36	**8.29 ± 4.04**[b]	–0.19 ± 1.41	**14.01 ± 4.96**[b,c]	–1.17 ± 0.71
PG	S1	**5.94 ± 1.50**	0.12 ± 1.21	**7.89 ± 6.33**	0.67 ± 0.59	**14.97 ± 6.17**[b,c]	0.25 ± 1.14
	S2	4.28 ± 3.39[c]	0.96 ± 1.20	**8.59 ± 4.20**[b]	0.22 ± 0.74	**13.28 ± 6.85**[b,c]	–0.36 ± 1.23
	S3	**4.55 ± 2.82**[c]	0.05 ± 1.39	**8.72 ± 4.02**[b]	–0.42 ± 1.34	**13.83 ± 4.72**[b,c]	–1.24 ± 0.82
SEBT ANT	S1	**1.13 ± 0.30**[c]	–0.11 ± 0.23	**2.13 ± 0.60**[b]	–0.14 ± 0.24	**3.02 ± 0.51**[b,c]	0.02 ± 0.18
	S2	**1.62 ± 0.40**[c]	0.08 ± 0.43	**2.11 ± 0.23**[b]	0.21 ± 0.18	**3.46 ± 0.42**[b,c]	0.02 ± 0.18
	S3	**1.83 ± 0.67**[c]	–0.40 ± 0.41	**2.48 ± 0.17**[b]	–0.12 ± 0.26	**3.77 ± 0.60**[b,c]	0.02 ± 0.18
SEBT PM	S1	0.90 ± 0.26[c]	0.84 ± 0.29	**2.10 ± 0.79**[b]	1.55 ± 0.38	2.21 ± 0.54[b]	1.89 ± 0.58
	S2	0.88 ± 0.45[c]	1.21 ± 0.38	2.60 ± 0.53[b]	2.00 ± 0.26	2.46 ± 0.62[b]	2.16 ± 0.57
	S3	0.94 ± 0.45[c]	1.15 ± 0.21	2.71 ± 0.75[b]	2.54 ± 0.69	2.78 ± 0.20[b]	2.42 ± 0.33
SEBT PL	S1	**1.58 ± 0.36**[c]	1.05 ± 0.29	2.33 ± 0.39[b]	2.01 ± 0.59	2.64 ± 0.15[b]	2.26 ± 0.48
	S2	1.60 ± 0.93[c]	1.60 ± 0.21	2.47 ± 0.18[b]	2.11 ± 0.27	2.86 ± 0.38[b]	2.94 ± 0.96
	S3	1.55 ± 0.46[c]	1.31 ± 0.36	2.54 ± 0.53[b]	2.38 ± 0.34	2.82 ± 0.22[b]	2.61 ± 0.40

[a]Values are expressed as mean ± SD. Boldface indicates significance when compared with control. ANT, anterior; PG, posterior talar glide; PL, posterolateral; PM, posteromedial; SEBT, Star Excursion Balance Test; WB-DFROM, weightbearing dorsiflexion range of motion.
[b]Significant when compared with the 30-second group.
[c]Significant when compared to the 60-second group.

improvement over the 30-second group for sessions 2 and 3 ($P \leq .001$).

PG for all treatment durations produced significant improvements compared with the control ($P \leq .001$), with the exception of the 30-second treatment group after session 2 ($P \geq .05$). Effect sizes were "huge" after all sessions for the 120-second group, after sessions 2 and 3 for the 60-second group, and after session 1 for the 30-second group. All other effect sizes were "very large." Improvements in PG were significantly greater in the 120-second group than the 60-second and 30-second group after all sessions ($P \leq .001$). The 60-second group showed improvement over the 30-second group for sessions 2 and 3 ($P \leq .001$).

For the anterior reach direction, each group showed a significant improvement ($P \leq .001$) compared with the control for all treatment sessions. Improvements were significantly greater for longer treatment durations compared with shorter ones for all sessions ($P \leq .001$), with all effect sizes being "huge."

The posteromedial direction showed improvements compared with the control only after session 1 for the 60-second group ($P \leq .05$). Improvements were significantly greater for both the 120-second and 60-second groups compared with the 30-second group for all sessions ($P \leq .005$). Effect sizes for session 1 were "small," "large," and "moderate" for the 30-, 60-, and 120-second treatment groups, respectively. For session 2, treatment group effect sizes were negatively "moderate" (30-second group), "very large" (60-second group), and "small" (120-second group). For session 3, these were negatively "moderate" (30-second group), "small" (60-second group), and "very large" (120-second group).

The posteromedial direction showed improvements compared with the control only after session 1 for the 30-second group ($P \leq .01$). Improvements were significantly greater for both the 120-second and 60-second groups compared with the 30-second group for all sessions ($P \leq .005$). Effect sizes for session 1 were "very large," "moderate," and "large" for the 30-, 60-, and 120-second treatment groups, respectively. For session 2, treatment group effect sizes were "negligible" (30-second group), "very large" (60-second group), and negatively "negligible" (120-second group). For session 3, these were "moderate" (30-second), "small" (60-second group), and "moderate" (120-second group).

DISCUSSION

Results showed that all treatment durations produced statistically significant improvements in WB-DFROM, PG, and reach directions of the SEBT ($P < .001$). Accessory mobilizations are therefore an effective treatment for inducing acute changes in ankle motion and dynamic postural control in patients with CAI and should be considered during their treatment regimen. Furthermore, our research suggests that the magnitude of change is influenced by treatment duration. The mechanical outcome measures demonstrated that longer treatment durations confer greater improvements compared with shorter durations. Grade IV mobilizations work at the end of the

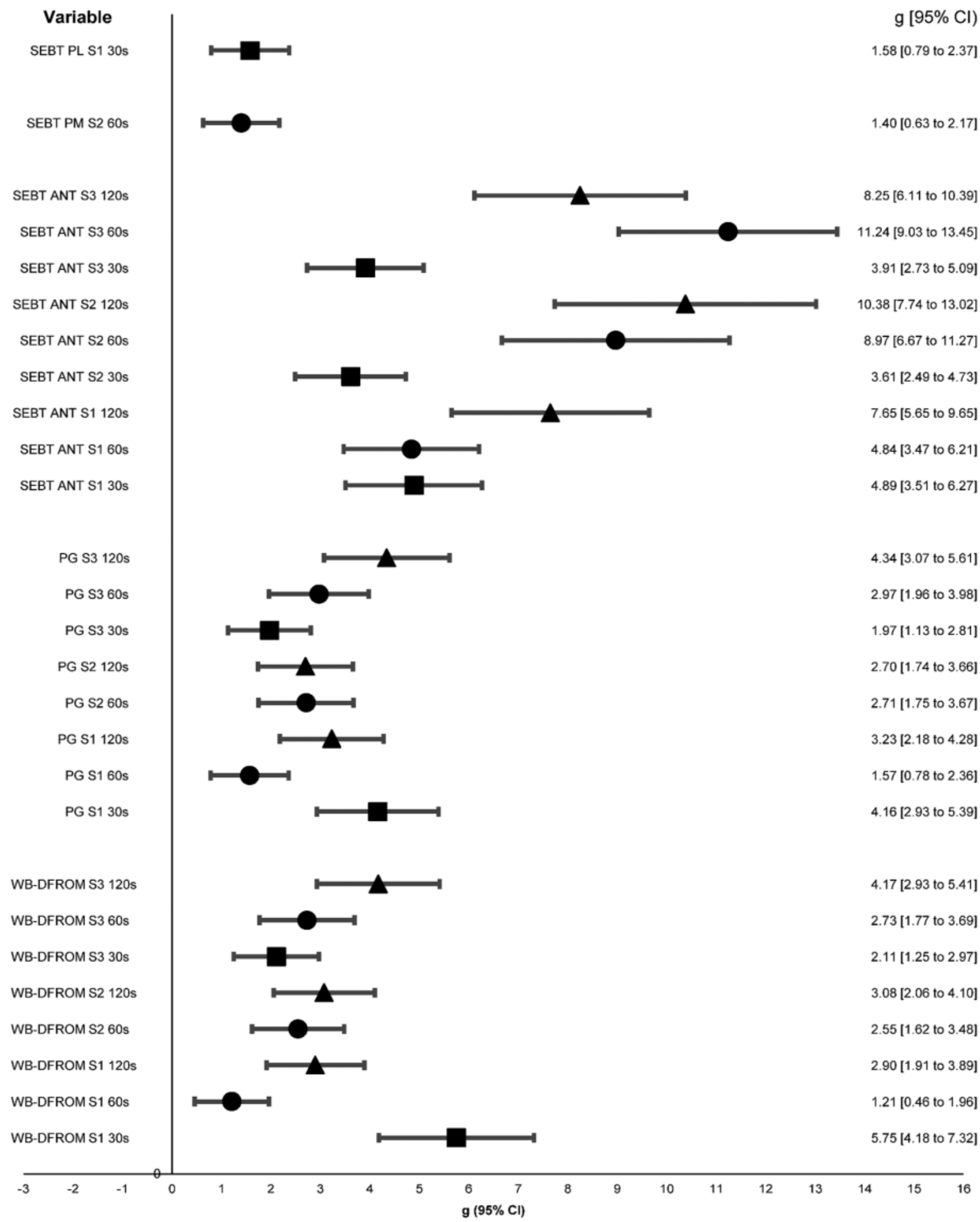

Figure 2. Forest plot (Hedges $g \pm$ 95% CI) of injured versus uninjured limb for weightbearing dorsiflexion range of motion (WB-DFROM); posterior talar glide (PG); and anterior (ANT), posteromedial (PM), and posterolateral (PL) directions of the Star Excursion Balance Test (SEBT) across 3 testing sessions (S1, S2, and S3) for all statistically significant results.

available range, producing a microfailure of the connective tissue and thus restricting motion.[40] Connective tissue accommodates stress in a manner described by the Hooke law and the stress-strain curve, where a proportional relationship exists between the deformation of an elastic structure and the stress applied to it. During a grade IV mobilization, the tissue moves beyond its elastic limit to the yield point and into the plastic range.[26] This results in a permanent elongation of the tissue due to a failure of the collagen's force-relaxation response when a load is applied or when the creep response causes deformation to occur too rapidly.[26] This deformation can occur from accumulated stress, potentially explaining the observed increase in ROM improvements as longer treatment durations were applied.

In a study by Green et al[13] on acute ankle sprains, improvements in DFROM were shown with effect sizes of 0.45, 0.19, and 0.11, respectively, for sessions 1, 2, and 3.[42] Within the present study, effect sizes for all treatment durations were of a "very large" or "huge" magnitude ($\geq$1.20). This may have been because of the chronic nature of the participants' symptoms in our study or differences in

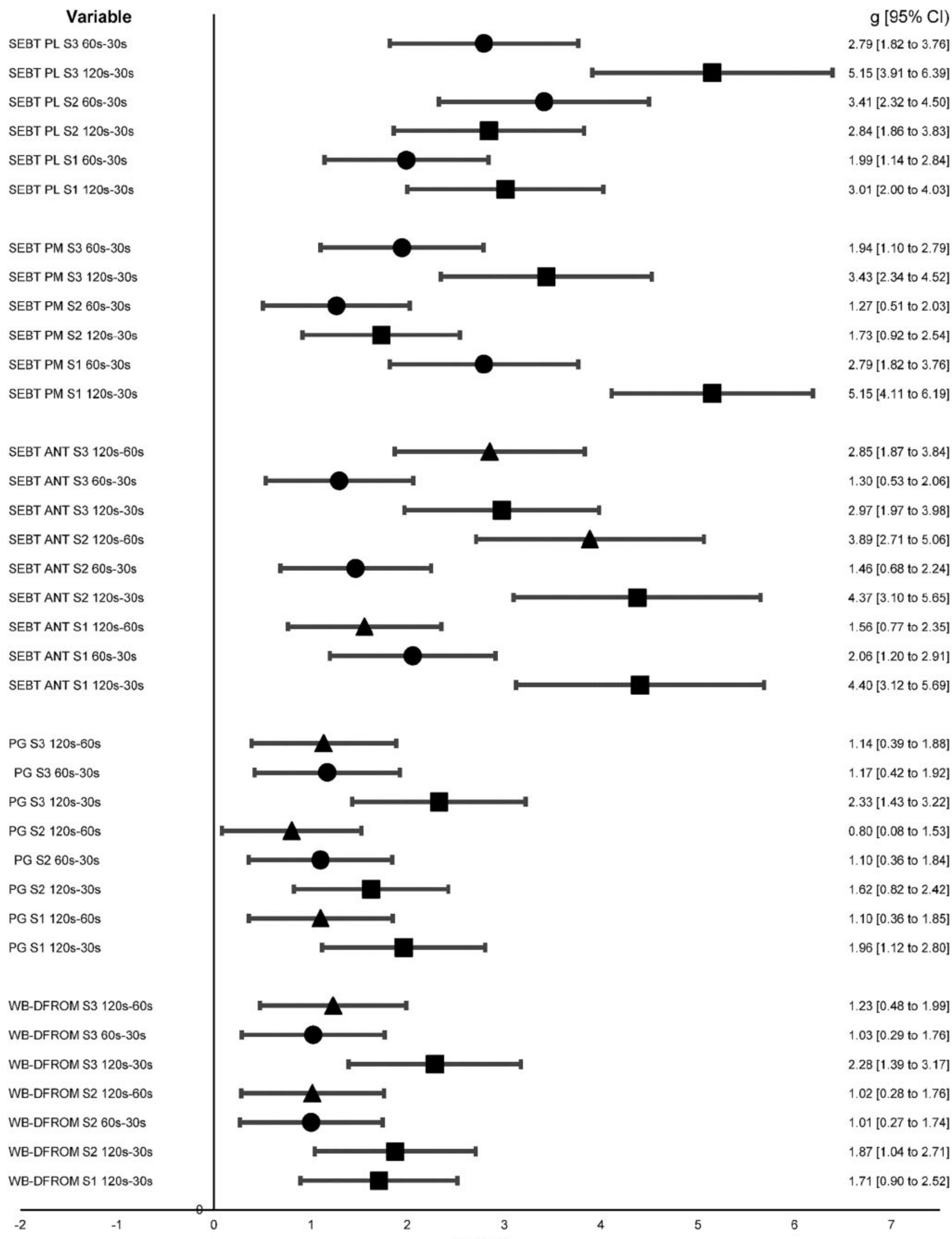

Figure 3. Forest plot (Hedges $g \pm 95\%$ CI) between treatment groups for weightbearing dorsiflexion range of motion (WB-DFROM); posterior talar glide (PG); and anterior (ANT), posteromedial (PM), and posterolateral (PL) directions of the Star Excursion Balance Test (SEBT) across 3 testing sessions for all statistically significant results.

the mobilization intervention. Green et al[13] did not provide a definitive identification of the grade used, but because of the presence of pain, the intervention was a small-amplitude oscillation applied at the beginning of range. This would be defined as a grade I mobilization, which is used to reduce pain and not influence ROM. Comparisons with studies by Hoch et al[22,24] highlight the benefit of using grade IV mobilizations over lower grades when improvements in arthrokinematic motion are being sought. In both studies, participants received four 2-minute sets of Maitland grade III mobilizations and two 2-minute sets of grade II joint tractions for 6 treatment session over 2 weeks. In the earlier study, Hoch et al[24] reported an improvement in WB-DFROM of 12.4%, with effect sizes greater than 3.0. Cumulatively over the 3 treatment sessions within the current study, all improvements were above this value (30 seconds, 15.8%; 60 seconds, 26.7%; 120 seconds, 43.6%), with the 120-second group showing superior increases after each session. Effect sizes also showed "very large" ($\geq$1.20) to "huge" ($\geq$2.0) improvements after each treatment session for each group. In their later study, Hoch et al[22] observed a nonsignificant decrease of 0.88% and an effect size of –0.51 for posterior talar displacement. Significant improvements in PG were seen in the current study, again with "very large" to "huge" effect sizes. Although grade III and IV mobilizations can work at the end of the available arthrokinematic range, grade IV mobilizations produce a far greater oscillatory frequency and mean force.[40] Greater loads are thus experienced by the connective tissue, resulting in greater plastic deformation of the restrictive structures, explaining the greater improvements within the current study.

Only 1 study has attempted to ascertain the effects of increased mobilization treatment durations on ankle range of motion. The methodologically similar study by Holland et al[25] identified that asymptomatic individuals elicited a greater improvement in WB-DFROM after a single treatment session as the duration of mobilization increased. This was of the magnitude of 10.9% (120-second group), 7.6% (60-second group), and 5.0% (30-second group), although the authors concluded that none of these was above the minimal detectable change score. The differences among treatment durations were slightly greater in the current study when mean scores were calculated across each of the 3 treatment sessions (14.5%, 8.9%, and 5.3%, respectively). The greater improvement identified can be attributed to the inclusion of patients with symptomatic CAI, many of whom demonstrated significant reductions in DFROM before the commencement of the intervention. At least 10° of DFROM is needed to walk, descend stairs, or kneel,[12] whereas running requires at least 20° of DFROM.[47] Patients with CAI often have DFROM $<0°$[41] because of the propensity of the talus toward anterior subluxation after a lateral ankle sprain, resulting in restrictions in posterior noncontractile tissue and anterior ligament laxity.[22] This allows for greater changes in ROM to be elicited through the application of anterior-to-posterior joint mobilizations within this population.

Development in the anterior reach direction of the SEBT was significant for all treatment durations, with longer treatments again conferring greater improvements. These improvements can be attributed to their relationship to WB-DFROM, with research indicating that an estimated 28% of the variance in anterior reach distance can be attributed to this measure.[23] After similar mobilization treatments, Hoch et al[24] identified a significant improvement of 2.8% in anterior reach distance on the SEBT after 6 treatment sessions. The current study identified cumulative improvements beyond this value for all treatment groups (30 seconds, 4.6%; 60 seconds, 6.7%; 120 seconds, 10.3%), with the 60-second treatment group demonstrating comparable values and the 120-second treatment group again showing superior values after each session individually. The effect sizes also identified these to be "huge" for all groups across the 3 sessions. It is again postulated that these enhanced scores are related to the use of grade IV mobilizations and their ability to provide greater deformation of the connective tissue. However, many of the kinematic predictors of performance on the SEBT can be attributed to proximal joint motion, with hip and knee flexion accounting for 78% of the variance in maximal reach distance.[36] As such, improvements in this measure will always be limited if only ankle joint mobility is being improved.

Although we found no notable improvements for posterolateral or posteromedial reach distances when treatment groups were compared against controls, statistically significant differences for all groups after all 3 sessions were revealed. Effect size calculations showed a full range of scores from negligible to very large, although no real pattern emerged. It is postulated that mobilizations may have a bilateral effect on dynamic balance. Motor activity intervention of 1 limb has been shown to enhance performance within the contralateral untrained limb.[38] This "cross-education" is thought to occur through neural mechanisms, and Carroll et al[5] suggested 2 plausible mechanisms. First, unilateral treatment could cause a spillover effect of neural drive from the active to the inactive hemisphere that induces adaptations in the control system of the contralateral limb. Second, treatment could cause "bilateral access" in which neuromuscular adaptations in the control system of the treated limb become accessible by the opposite limb. This requires further investigation and is beyond the scope of the current study. Contralateral effects could be biased by familiarization with the testing procedures, although this bias does appear small.[5]

The potential limitations of the current study are that only a female college-aged cohort was included. This may limit the ability to generalize the results of the current study to wider populations because connective tissue exhibits changes in biomechanical properties and cross-sectional area in response to exercise, disuse, and aging.[44] Studies have also shown that the tolerance of ankle ligaments in female patients is significantly less than that of males even in the absence of any previous ligamentous injury.[39] Another limitation of the study is that the long-term effects of the treatment were not assessed, such that conclusions cannot be made regarding maintenance of the observed improvements. In addition, treatment durations were limited to a maximum of 120 seconds, and we do not know whether improvements in outcome measures continue to increase through even longer durations or whether a ceiling effect once a given treatment duration is achieved.

CONCLUSION

The current study adds clarity to the use of joint mobilization treatment and will add to the current clinical practice and rehabilitative strategies for patients with CAI. These findings show that higher treatment durations confer greater improvements in arthrokinematic function and increased anterior reach distance in those with CAI, with 120-second treatment durations being optimal when single sets are being applied within the first week of treatment. Further research is required to ascertain the period for which the observed differences are maintained and to investigate the use of multiple sets.

REFERENCES

1. Anandacoomarasamy A. Long term outcomes of inversion ankle injuries: commentary. *Br J Sports Med*. 2005;39(3):e14.
2. Banks K, Hengeveld E. *Maitland's Clinical Companion: An Essential Guide for Students*. 1st ed. Churchill Livingstone/Elsevier; 2009.
3. Birrer RB, Fani-Salek MH, Totten VY, Herman LM, Politi V. Managing ankle injuries in the emergency department. *J Emerg Med*. 1999;17(4):651-660.
4. Braun BL. Effects of ankle sprain in a general clinic population 6 to 18 months after medical evaluation. *Arch Fam Med*. 1999;8(2):143-148.
5. Carroll TJ, Herbert RD, Munn J, Lee M, Gandevia SC. Contralateral effects of unilateral strength training: evidence and possible mechanisms. *J Appl Physiol*. 2006;101(5):1514-1522.
6. Cosby NL, Koroch M, Grindstaff TL, Parente W, Hertel J. Immediate effects of anterior to posterior talocrural joint mobilizations following acute lateral ankle sprain. *J Man Manip Ther*. 2011;19(2):76-83.
7. Croy T, Koppenhaver S, Saliba S, Hertel J. Anterior talocrural joint laxity: diagnostic accuracy of the anterior drawer test of the ankle. *J Orthop Sports Phys Ther*. 2013;43(12):911-919.
8. Cruz-Díaz D, Lomas Vega R, Osuna-Pérez MC, Hita-Contreras F, Martínez-Amat A. Effects of joint mobilization on chronic ankle instability: a randomized controlled trial. *Disabil Rehabil*. 2015;37(7):601-610.
9. Denegar CR, Hertel J, Fonseca J. The effect of lateral ankle sprain on dorsiflexion range of motion, posterior talar glide, and joint laxity. *J Orthop Sports Phys Ther*. 2002;32(4):166-173.
10. Drewes LK, McKeon PO, Kerrigan DC, Hertel J. Dorsiflexion deficit during jogging with chronic ankle instability. *J Sci Med Sport*. 2009;12(6):685-687.
11. Fong DT-P, Hong Y, Chan L-K, Yung PS-H, Chan K-M. A systematic review on ankle injury and ankle sprain in sports. *Sports Med*. 2007;37(1):73-94.
12. Green T, Refshauge K, Crosbie J. Effects of reduced ankle dorsiflexion following lateral ligament sprain on temporal and spatial gait parameters. *Gait Posture*. 1999;9(3):167-172.
13. Green T, Refshauge K, Crosbie J, Adams R. A randomized controlled trial of a passive accessory joint mobilization on acute ankle inversion sprains. *Phys Ther*. 2001;81(4):984-994.
14. Gribble PA, Delahunt E, Bleakley C, et al. Selection criteria for patients with chronic ankle instability in controlled research: a position statement of the International Ankle Consortium. *Br J Sports Med*. 2014;48(13):1014-1018.
15. Gribble PA, Bleakley CM, Caulfield BM, et al. 2016 consensus statement of the International Ankle Consortium: prevalence, impact and long-term consequences of lateral ankle sprains. *Br J Sports Med*. 2016;50(24):1493-1495.
16. Gribble PA, Hertel J. Considerations for normalizing measures of the Star Excursion Balance Test. *Meas Phys Educ Exerc Sci*. 2003;7(2):89-100.
17. Gribble PA, Hertel J, Plisky P. Using the Star Excursion Balance Test to assess dynamic postural-control deficits and outcomes in lower extremity injury: a literature and systematic review. *J Athl Train*. 2012;47(3):339-357.
18. Hengeveld E, Banks K. *Maitland's Peripheral Manipulation*. Butterworth-Heinemann; 2005.
19. Hertel J. Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. *J Athl Train*. 2002;37(4):364-375.
20. Hertel J. Sensorimotor deficits with ankle sprains and chronic ankle instability. *Clin Sports Med*. 2008;27(3):353-370.
21. Hoch MC, McKeon PO. Joint mobilization improves spatiotemporal postural control and range of motion in those with chronic ankle instability. *J Orthop Res*. 2011;29(3):326-332.
22. Hoch MC, Mullineaux DR, Andreatta RD, et al. Effect of a 2-week joint-mobilization intervention on single-limb balance and ankle arthrokinematics in those with chronic ankle instability. *J Sport Rehabil*. 2014;23(1):18-26.
23. Hoch MC, Staton GS, McKeon PO. Dorsiflexion range of motion significantly influences dynamic balance. *J Sci Med Sport*. 2011;14(1):90-92.
24. Hoch MC, Staton GS, Medina McKeon JM, Mattacola CG, McKeon PO. Dorsiflexion and dynamic postural control deficits are present in those with chronic ankle instability. *J Sci Med Sport*. 2012;15(6):574-579.
25. Holland CJ, Campbell K, Hutt K. Increased treatment durations lead to greater improvements in non-weight bearing dorsiflexion range of motion for asymptomatic individuals immediately following an anteroposterior grade IV mobilisation of the talus. *Man Ther*. 2015;20(4):598-602.
26. Houglum PA. *Therapeutic Exercise for Musculoskeletal Injuries*. 4th ed. Human Kinetics; 2016.
27. Krause DA, Cloud BA, Forster LA, Schrank JA, Hollman JH. Measurement of ankle dorsiflexion: a comparison of active and passive techniques in multiple positions. *J Sport Rehabil*. 2011;20:333-344.
28. Landrum E, Kelln BM, Parente WR, Ingersoll CD, Hertel J. Immediate effects of anterior-to-posterior talocrural joint mobilization after prolonged ankle immobilization: a preliminary study. *J Man Manip Ther*. 2008;16(2):100-105.
29. McKeon PO, Booi MJ, Branam B, Johnson DL, Mattacola CG. Lateral ankle ligament anesthesia significantly alters single limb postural control. *Gait Posture*. 2010;32(3):374-377.
30. Munro AG, Herrington LC. Physical therapy in sport between-session reliability of the Star Excursion Balance Test. *Phys Ther Sport*. 2010;11(4):128-132.
31. Myers JB, Riemann BL, Hwang J-H, Fu FH, Lephart SM. Effect of peripheral afferent alteration of the lateral ankle ligaments on dynamic stability. *Am J Sports Med*. 2003;31(4):498-506.
32. O'Shea S, Grafton K. The intra and inter-rater reliability of a modified weight-bearing lunge measure of ankle dorsiflexion. *Man Ther*. 2013;18(3):264-268.
33. Petty NJ, Maher C, Latimer J, Lee M. Manual examination of accessory movements—seeking R1. *Man Ther*. 2002;7(1):39-43.
34. Powden CJ, Dodds TK, Gabriel EH. The reliability of the Star Excursion Balance Test and lower quarter Y-balance test in healthy adults: a systematic review. *Int J Sports Phys Ther*. 2019;14(5):683-694.
35. Reid A, Birmingham TB, Alcock G. Efficacy of mobilization with movement for patients with limited dorsiflexion after ankle sprain: a crossover trial. *Physiother Can*. 2007;59(3):166-172.
36. Robinson R, Gribble P. Kinematic predictors of performance on the Star Excursion Balance Test. *J Sport Rehabil*. 2008;17(4):347-357.
37. Sawilowsky SS. New effect size rules of thumb. *J Mod Appl Stat Methods*. 2009;8(2):597-599.
38. Schlenstedt C, Arnold M, Mancini M, Deuschl G, Weisser B. The effect of unilateral balance training on postural control of the contralateral limb. *J Sports Sci*. 2017;35(22):2265-2271.
39. Silke K, Hertel J, Wunderlich R. The effects of fatigue and gender on ankle ligament laxity. *FASEB J*. 2011;25(1)(suppl):488.6.
40. Silvernail JL, Gill NW, Teyhen DS, Allison SC. Biomechanical measures of knee joint mobilization. *J Man Manip Ther*. 2011;19(3):162-171.

41. Soucie JM, Wang C, Forsyth A, et al. Range of motion measurements: reference values and a database for comparison studies. *Haemophilia*. 2011;17(3):500-507.
42. Terada M, Pietrosimone BG, Gribble PA. Therapeutic interventions for increasing ankle dorsiflexion after ankle sprain: a systematic review. *J Athl Train*. 2013;48(5):696-709.
43. Venturini C, Penedo MM, Peixoto GH, Chagas MH, Ferreira ML, de Resende MA. Study of the force applied during anteroposterior articular mobilization of the talus and its effect on the dorsiflexion range of motion. *J Manipulative Physiol Ther*. 2007;30(8):593-597.
44. Weppler CH, Magnusson SP. Increasing muscle extensibility: a matter of increasing length or modifying sensation? *Phys Ther*. 2010;90(3):438-449.
45. Wikstrom EA, Tillman MD, Chmielewski TL, Cauraugh JH, Borsa PA. Dynamic postural stability deficits in subjects with self-reported ankle instability. *Med Sci Sports Exerc*. 2007;39(3):397-402.
46. Wright IC, Neptune RR, Van Den Bogert AJ, Nigg BM. The influence of foot positioning on ankle sprains. *J Biomech*. 2000;33(5):513-519.
47. Yamaguchi S, Sasho T, Kato H, Kuroyanagi Y, Banks SA. Ankle and subtalar kinematics during dorsiflexion-plantarflexion activities. *Foot Ankle Int*. 2009;30(4):361-366.