The immediate effects of two manual therapy techniques on ankle musculoarticular stiffness and dorsiflexion range of motion in people with chronic ankle rigidity: a randomized clinical trial

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ABSTRACT

Objective: Ankle rigidity is a common musculoskeletal disorder affecting the talocrural joint, which can impair weight-bearing ankle dorsiflexion (WBADF) and daily-life in people with or without history of ankle injuries. Our objective was to compare the immediate effects of efficacy of Mulligan Mobilization with Movement (MWM) and Osteopathic Mobilization (OM) for improving ankle dorsiflexion range of motion (ROM) and musculoarticular stiffness (MAS) in people with chronic ankle dorsiflexion rigidity.

Design: a randomized clinical trial with two arms.

Methods: Patients were recruited by word of mouth and via social network as well as posters, and analyzed in the neuro musculoskeletal laboratory of the "Université Catholique de Louvain-la-Neuve", Brussels, Belgium.

Participants: 67 men (aged 18-40 years) presenting with potential chronic non-specific and unilateral ankle mobility deficit during WBDF were assessed for eligibility and finally 40 men were included and randomly allocated to single session of either MWM or OM.

Interventions: Two modalities of manual therapy indicated for hypothetic immediate effects in chronic ankle dorsiflexion stiffness, i.e. MWM and OM, were applied during a single session on included patients.

Main Outcome measures: Comprised blinding measures of MAS with a specific electromechanical device (namely: Lehmann's device) producing passive oscillatory ankle joint dorsiflexion and with clinical measures of WBADF-ROM as well.

Results: A two-way ANOVA revealed a non-significant interaction between both techniques and time for all outcome measures. For measures of MAS: elastic-stiffness (p=.37), viscous-stiffness (p=.83), total-stiffness (p=.58). For WBADF-ROM: toe-wall distance (p=.58) and angular ROM (p=.68). Small effect sizes between groups were determined with Cohen's d ranging from .05 to .29. One-way ANOVA demonstrated non-significant difference and small to moderate effects sizes (d=.003-.58) on all outcome measures before and after interventions within both groups. A second two-way ANOVA analyzed the effect of each intervention on the sample categorized according to injury history status, and demonstrated a significant interaction between groups and time only for viscous stiffness (p=.04, d=-.55).

Conclusion: A single session of MWM and OM targeting the talocrural joint failed to immediately improve all measures in subjects with chronic ankle dorsiflexion stiffness. Despite this, there was an increase in viscous stiffness in people with history of ankle injury following both manual techniques, the value of which remains unclear even if it might help to prevent future abnormal ankle joint movements.

Keywords:
Ankle stiffness, talocrural joint, Mulligan mobilization with movement, osteopathic medicine, orthopaedic manual therapy

List of abbreviations:

WBADF	weight-bearing ankle dorsiflexion
MWM	Mulligan Mobilization with Movement
OM	Osteopathic Mobilization
ROM	range of motion
MAS	musculoarticular stiffness
ES	Elastic stiffness/Intercept in Newton.meter.radian^{-1}
VS	Viscous stiffness/Slope in Newton.meter.sec -1 radian^{-1}
L-path	Path length in Newton.meter.radian^{-1}

Introduction

Increased musculoarticular-stiffness (MAS) of the talocrural joint is a frequently encountered problem, identified during evaluation of weight bearing ankle dorsiflexion (WBADF).(1) Such stiffness may follow ankle injury such as ankle sprain.(2) In such a situation, MAS could be increased and might leads to a lack of joint flexibility as well as decreased dorsiflexion range-of-motion (ROM),(1) however asymmetric rigidity does not necessarily always follow ankle sprain. Nevertheless, MAS is an important and necessary component of normal stability of the talocrural joint and could help to prevent abnormal ankle joint movement and ankle sprains or tendinitis.(1)

Measurement of MAS can be determined by a technique known as free-oscillation, which is a comprehensive measure of joint stiffness comprising the stiffness of the muscle-tendon unit, skin, ligaments and joint capsule, along with a number of other mechanical and neuromuscular factors. The assessment of MAS is important when evaluating muscular performance, injury prevention and gender differences in flexibility.(3-4)

MAS of the talocrural joint can be objectively measured using an electromechanical device (5) that imparts a passive oscillatory dorsiflexion movement (4), but also by means of clinical tests (1,6) such as toe-wall distance and angular goniometric measurement during the weight bearing lunge test.(6-7) Electromechanical measurement of ankle MAS has been used in several previous studies of asymptomatic participants and in patients with fibromyalgia syndrome, spasticity after a stroke, or after plyometric training of gastrocnemii.(4-5,8-12)

In orthopaedic manual therapy, different methods have been proposed to treat MAS associated with loss of dorsiflexion ROM at the talocrural joint.(13-21) These include single session of Mulligan's Mobilization with Movement (MWM) (16), anteroposterior mobilization of the talus (14,17), high velocity thrust (19), and Osteopathic Mobilization (OM), these both methods claimed to obtain immediate effects.(15-21) They have been described in clinical practice manuals, with greater proportion of studies reporting on the effects of MWM in comparison to high velocity thrust for improving ankle dorsiflexion ROM in chronic ankle instability (1) or to study MWM efficacy in isolation for subacute (2) or recurrent ankle sprains (20) and for chronic ankle instability.(21) With the exception of one study (20) the results are generally in favor of MWM.

Generally MWM is an increasingly popular form of manual therapy for musculoskeletal disorders (22), concerning the ankle MWM try to improve talocrural ROM. MWM is a combination of accessory joint glide of the talus combined with physiological active ankle dorsiflexion movement.(23) OM is a purely passive anteroposterior accessory mobilization of the talus with respect to tibia during a passive physiological dorsiflexion in our study, performed in a non weight-bearing position.(14,18-19) To date, there have been no studies comparing the effectiveness of each technique with respect to electromechanically determined ankle MAS or ankle joint ROM determined by the WBADF lunge test in people with chronic ankle dorsiflexion stiffness.

Therefore, the aim of the study was to investigate immediate effects of the relative efficacy of MWM and OM on MAS as the primary outcome measurement and joint ROM during the WBADF lunge test as the secondary outcome measurement. The hypothesis was that MWM would produce significantly greater reduction in MAS and increased ankle joint ROM when compared to OM.

Method

Participants

Volunteers with asymmetric ankle stiffness were sought for participation in this study from advertisements placed in physiotherapy clinics and word of mouth among University students. The inclusion criteria for participation were male gender, aged between 18 to 40 years, with a chronic unilateral mobility deficit of the talocrural joint; i.e. subjective blocking sensation and/or feeling of ankle stiffness together with the presence of ankle region pain/tenderness, during active WBADF while squatting. Subjects were recruited with chronic unilateral mobility deficit of the talocrural joint, which could be following a previous history of ankle injury or without previous history of ankle injury and were enrolled between October 2015 and February 2016. See figure 1 for the flow diagram.

Exclusion criteria were a history of ankle joint surgery or injury to the foot, ankle, knee or hip in the previous one-year. The subjects provide signed informed consent, and ethical approval for this study was provided by the “Commission d’Ethique Biomédicale Hospitalo-facultaire” (CEBFH) of the “Université Catholique de Louvain” (Registration number of the trial: B 403 201421483) and was registered in ClinicalTrials.gov NCT02653807.

Measures

Demographic details including weight, height, days currently playing sport, and history of foot or ankle injury (e.g. ligament sprain, muscle tear, or fracture) were collected (Table 1-2).

Five outcome measures were blindly evaluated by one of the author (MB) in this study: Three electromechanically determined measures of MAS during oscillatory ankle dorsiflexion as the primary outcome measures and two ankle joint dorsiflexion ROM measures during the WBADF lunge test as the secondary outcome measures. All measures were recorded immediately before and after a single session of the intervention. All the outcome measurements were blindly assessed with minimal interaction (standardized procedure) between assessor and subjects, and no interaction between the assessor and the practitioner.

The electromechanical device used to quantify MAS is shown in Figure 2A. This apparatus had been used in previous research studies (4,10-12) and has been shown to have high precision, reliability and accuracy.(5) See Detrembleur and Plaghki (2000) for more details of the process.(4)

Three variables were recorded by the electromechanical device.(4) First the path length namely L-path representing the reflex response to movement quantified by the L-path of the phase diagram between elastic and viscous stiffness. The L-path represents a measure of the variation in total viscoelastic stiffness ($N \cdot m \cdot rad^{-1}$) over the 10 different ankle oscillation frequencies. Second the slope representing the KV frequency regression line. This is used as a summary value of the viscous stiffness component (VS). Third the intercept (elastic) represents the KE frequency regression line. This is used as the summary value of the elastic stiffness component (ES). These three variables represent MAS, which together evaluate articular and muscle effects, although muscles have been shown to provide the major contributor to passive ankle torque.(24)

For the second measurement, we used the WBADF Lunge Test a common clinical test used to evaluate ankle dorsiflexion ROM (7,25-26) which has been shown to have moderate to excellent intra-rater reliability (ICC = 0,65-0,99) with a minimal detectable change of 1,9 cm and 4,7° (Figure 2B).(26-27)

Explanatory electromyographic (EMG) measurement of the triceps surae was conducted to analyze EMG responses to MWM in one additional subject for both ankles (healthy and injured ankle) with one exception: we placed EMG leads on the motor end plate of the triceps surae during the MAS measurement with the electromechanical device. We were able to record the EMG before and after intervention, and observe any change in electrical activity.

Procedure

Patients were allocated to either treatment group (MWM or OM) by a lottery. Allocation was blindly achieved by concealed lottery from one of the author (MB), with pieces of paper in an opaque and closed envelope (n=40) drawn from a bag indicating either MWM or OM (ratio:0,50) (Figure 1). The mobilization was performed by the same physical therapist (PT), one of the author (EB) during the whole study, this last-one opened each closed envelope taken by the patient just before to start mobilization. The PT was a novice (PT student) trained in each technique for around 6 hours by face-to-face interaction with an expert manual therapist, the first author (BH). Before starting acquisition the expert ensured that the novice applied both techniques correctly. All the protocol of this study was conducted at our laboratory: Institute of Experimental and Clinical Research in the Neuro Musculo Skeletal Lab, Université Catholique de Louvain-La-Neuve, Brussels, Belgium.

MWM was applied on the patient’s symptomatic talocrural joint (Figure 3A), with the patient standing on an examination table. The symptomatic foot was placed in front, flat on the table. The therapist looped a non-elastic manual therapy belt around the patient’s distal leg, immediately proximal to the talocrural joint, and around the therapist’s pelvis. A postero-anterior tibial glide was performed by the body-weight of the therapist, via the belt. Synchronously, the therapist applied an antero-posterior force to the talus with the web-space of both hands while performing the mobilization. At the same time, the patient was asked to perform a slow active ankle dorsiflexion within pain-free limits. The belt remained perpendicular to the tibia during the entire movement. Three series of ten repetitions were performed, with a one-minute break between each series. (23,28-29)

The OM was applied on the patient’s symptomatic talocrural joint with the subject lying prone with the knee flexed to 90° to reduce tension on the gastrocnemius muscle to better target the joint (Figure 3B).(14-15,18-19) The therapist knee was used to block the patient’s thigh on the examination table. The therapist grasped the calcaneus with one hand and created a posterior glide of the talus while with the other hand applied an anterior glide of the tibia according to concave-convex rule. Dorsiflexion of the talocrural joint was performed simultaneous with the gliding motion.(14,18-19) Three sets of 10 mobilizations were performed with a rest period of one minute between each set.

Statistical analysis

Sigmastat 3.5 Software (SPSS Inc, Chicago, IL, USA) was used for all statistical analyses. The hypothesis of homoscedasticity (equal variances) and normality (normal distributions) were also tested. Two-way ANOVA assessed the significance of differences in MAS and dorsiflexion ROM measurements between (i) the different groups (MWM and OM as factor groups, and pre and post-intervention as factor time); (ii) following this, a one-way ANOVA was used to assess the significance of differences in MAS and dorsiflexion ROM measurements within each group; (iii) finally an explanatory two-way ANOVA was used to assess the difference between groups but this time, history of injury and non-injury as factor groups, and pre and post-intervention as factor time was performed; and (iv) one way ANOVA to assess the differences within each group.

Results

(i) A two-way ANOVA revealed non-significant differences in effect for primary and secondary outcome measures for the two different interventions MWM and OM. There was no statistically significant interaction between both techniques and time (pre and post-intervention). No significant interaction was observed for elastic stiffness (ES; $p = 0.37$), viscous stiffness (VS; $p = 0.83$), reflex response to movement (L-path; $p = 0.58$), distance from wall-toe ($p = 0.58$) and ankle joint angular measurement ($p = 0.68$).

(ii) One-way ANOVA revealed no significant difference between pre and post intervention in MWM group. Similar results were observed in OM group. The means ± SD and data for each intervention as factor groups are presented in Table 3.

An explanatory analysis was conducted to determine the effect of history of ankle/foot injury on the primary and secondary outcome measures. Participants were allocated to either a group with a history of injury (n=22) or a group without any injury (n=18). In the injury group, 19 participants had a history of one or several ankle sprains, 2 had a fracture and one a history of achilles tendinitis. 17 of these injuries occurred within the previous 3 years, and 5 within 8 years.

(iii) Two-way ANOVA was applied with factors groups (injury vs. non-injury) and time (pre and post intervention). No significant changes were found for all outcome measures, except a significant interaction for VS, which was elevated after the intervention (VS; p = 0.04; Cohen's *d*=-0.55).

(iv) One-way ANOVA revealed no significant difference between pre and post intervention on all outcome measures in the injury group. Similar results were observed in the non-injury group. The means ± SD and data for injury as factor groups are presented in Table 4. The mean curves for ES and VS by frequency and L-path are presented in Figure 4A.

EMG recordings in one additional patient on his healthy ankle showed no increase in electrical activity of the triceps surae before or after the intervention. However, on his injured ankle abnormal EMG activities after intervention were observed (Figure 4B).

No adverse events were reported in either group in the week following the experiment protocol.

Discussion

To our knowledge, the present study is the first to compare the effects of two different manual therapy techniques on instrumentally determined ankle joint MAS and ROM measures in people with chronic ankle dorsiflexion ROM impairment. The results revealed no clinical relevance as well as no significant improvement between and within techniques applied to the talocrural joint on all outcome measures.

The results from our sample following MWM with respect to dorsiflexion ROM during the WBDF lunge test are not consistent with previous reports (1-2), excepted with Vicenzino et al. (2006) (20) and Gilbreath et al. (2014).(21) Marron-Gomez et al. (2015) used a similar study protocol, also comparing two manual therapy techniques (MWM and high velocity thrust) for improving ankle dorsiflexion ROM in a very restricted and specific population.(1) However in that study, MWM gave significantly superior effects for improving ankle dorsiflexion ROM in patients with chronic ankle instability, improving the WBADF lunge test by 1.7 cm, when compared to high velocity thrust procedure, our result for MWM are from 1 cm. One goal of manual techniques is to improve ROM and this is probably not really indicated in chronic instability where the ROM is by definition already excessive. So the patients in this study (1) were likely to be very different from our sample; i.e.: chronic ankle instability versus chronic ankle dorsiflexion stiffness. Moreover in that study (1) ankle MAS was not determined. Furthermore, the clinical measures during WBADF lunge test also depend on the patient's tolerance of pain and motivation, which can be influenced by the Hawthorn effect or bias due to lack of blinding. In addition, the gain in range of 1.7 cm during this test is less than the required 1.9 cm minimal detectable change. (26)

In a study (2) conducted with only 14 subjects with subacute grade II ankle sprain, the authors performed MWM in a similar fashion and with the same numbers of repetitions as in the present study. Improvement in ankle dorsiflexion was about 1.6 cm on the WBADF lunge test, and was again below the minimal detectable change of 1.9 cm. Vicenzino et al. (2006) also demonstrated improvement in dorsiflexion ROM after 4 sets of 4 repetitions of weight-bearing MWM. (20) This study included a sample of subjects with recurrent ankle sprains but the results were not significantly different from changes seen in control subjects. Gain in dorsiflexion ROM was 0.6 cm.

The OM used in the present investigation is an adapted version that has initially been described in several textbooks.(13-14,18-19) However, to our knowledge the efficacy of this kind of technique has not yet been compared to other forms of mobilization. This is in contrast to MWM for ankle dorsiflexion, which has been compared to several other techniques, as described above. This technique, was originally described with the patient lying in a supine position, knee straight gliding the talus posteriorly during dorsiflexion. (14,17) In our study we performed a modified version from an osteopathic approach (14,18-19) where the technique was applied in prone with the knee in 90˚ flexion, to reduce tension on the gastrocnemius muscle and to improve gliding of the tibia relative to the talus.

It has been suggested that limitation of ankle dorsiflexion during the WBDF lunge test may be managed by MWM applied to the talocrural joint or inferior tibiofibular joint.(29) Within the Mulligan concept, in the absence of improved ROM following a talocrural MWM, it is recommended to try an anteroposterior MWM of the fibular relative to the tibia at the inferior tibiofibular joint. This is particularly recommended when the patient presents with a history of ankle sprain.(29) Future studies should investigate the pragmatic application of MWM on the fibula based on treatment responsiveness to determine the efficacy of this approach in specific patients with history of ankle sprain.

In the secondary analysis, participants were categorized according to history of ankle/foot injury. In the group with a history of injury, there was a significant increase in VS after both mobilization techniques. According to a number of different studies (30-33) VS is due to changes in cytoskeletal proteins (desmin intermediate filament), in the architecture of the muscle (viscosity of myoplasm), or the viscoelastic properties of the muscle (titin filament system). (34) So we hypothesize that increased viscous stiffness may be rather due in fact to increased muscle activity and/or h-reflex of the plantarflexor muscles, triceps surae due to our single session of treatment. It is known that the musculotendinous structures account for 75% of stiffness in movement at a joint, while the joint's articular structures account for the remaining 25%.(5) The reason for increased muscle activity remains unclear, but may be due to subconscious neurophysiological protective behavior (aversive memory) and/or by a peripheral sensitization (medullar reflex) from the subject having experienced previous injury. A previous study (35) has established a link between increased muscle activity and increased stiffness to movement. Another recent study (36) stated that increased viscosity leads to a rise in stretch resistance and so increased stiffness to movement. The increased viscosity probably permits the tendon to transmit higher forces which can raise the risk of injury at the tendon level.(36) Hence, increasing MAS, as demonstrated in our study, could also prevent future ankle sprain particularly in those with a history of injury. Increases in VS could be a preventive adaptation following mobilizations to guard the ankle in people with history of ankle injury.

Limitations and perspective for future studies

The present study has several limitations. Despite a standardized protocol, and rigorous supervision and training of investigators from an experienced manual therapist, the researchers applying both techniques had limited clinical experience. Moderate or long lasting effects were not studied because these both concepts claimed to have immediate effects after a single session of treatment, then this protocol try to taste this common hypothetic statement. After a sample size calculation concerning the main easy clinical outcome measurable in everyday practice, i.e. the WBADF, a power analysis revealed that a total of 62 subjects for each group was necessary to highlight a difference with a power of 90% with a α-threshold of 0.05. We were not able to achieve the goal of 124 subjects in the 6 months time-frame for this project due to a number of reasons: difficulties in patient recruitment, laboratory availability, as well as the patient and therapist availability for data collection, among other reasons. Future studies should also consider different outcome measures including pain during weight bearing ankle dorsiflexion, electromyographic activity, ankle ROM during functional activity such as walking and jump landing or using specific functional scales of the lower limb, as well as the participant's subjective rating of ankle stiffness as well as the application of MWM on the fibula.

Conclusion

This study demonstrated that there is no superiority of efficacy in evaluated outcome measures between weight-bearing MWM and OM applied at the talocrural joint, in people with chronic ankle dorsiflexion stiffness during a single session of treatment. Both techniques, targeting immediate effects, failed to show significant improvement and clinical relevance in ROM during the WBADF lunge test or instrumented measures of ankle MAS. Conversely, both techniques induced significant increased viscous stiffness at the ankle joint only in subjects with a previous history of ankle injury. However, this might be potentially helpful to prevent or protect future ankle sprain in people with history of ankle injury.

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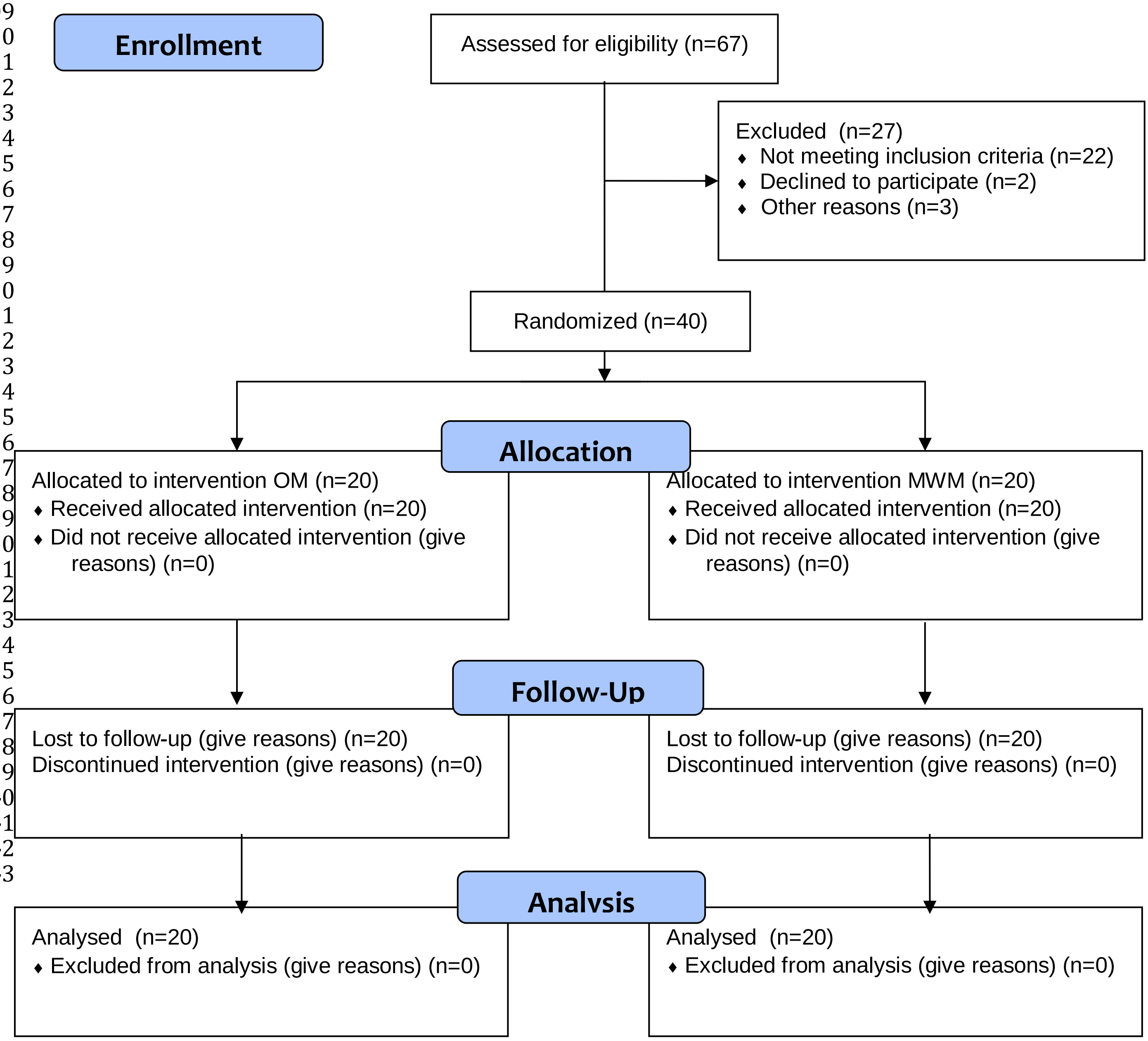
Figure 1: CONSORT 2010 Flow Diagram



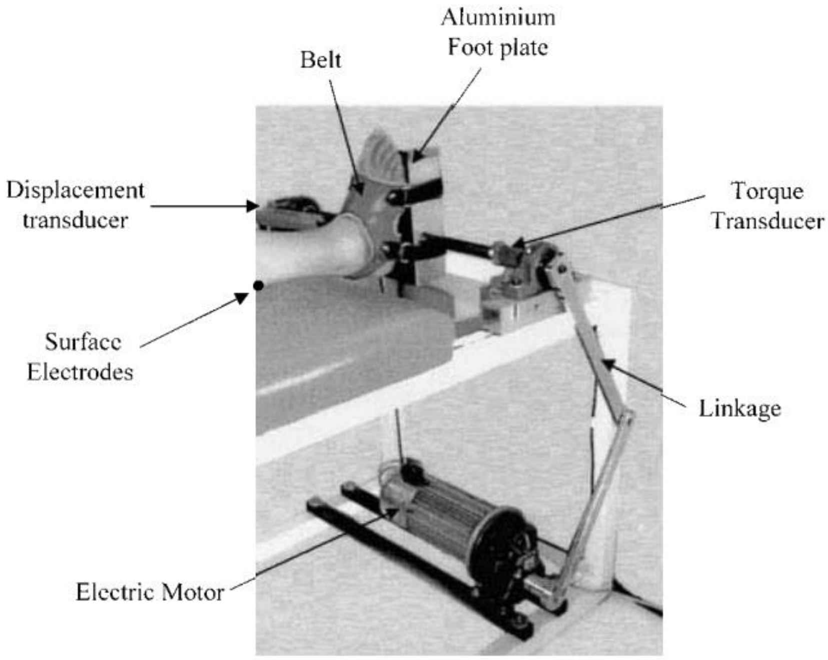


Figure 2A. Electromechanical device used to measure ankle musculoarticular stiffness (Detrembleur and Plaghki (2000).

Figure 2B. Weight-bearing ankle dorsiflexion lunge test measurements: wall-toe distance on the left and goniometer determined angular measurement on the right.

Figure 3A. Weight bearing Mobilization With Movement

Figure 3B. Osteopathic passive mobilization.

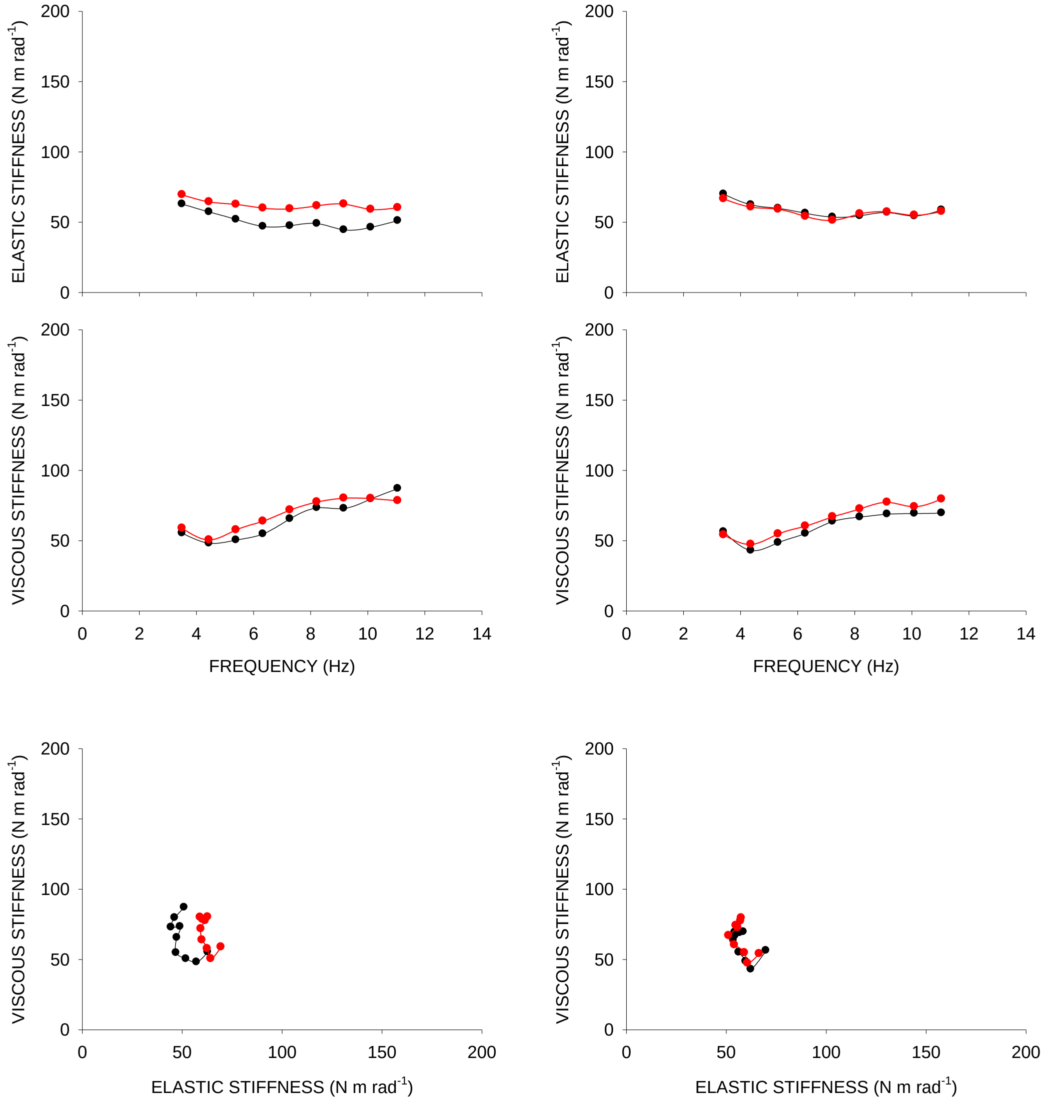


Figure 4A. Means for elastic and viscous stiffness in the non-injury group (left) and injury group (right). Results for pre-intervention are presented in black while results for post-intervention are presented in red. The graphs on the left show the data of the means in the non-injury group and the graphs on the right show the data of the means in the injury group. In the first set of diagrams two curves represent the means of the elastic stiffness in each group before (in black) and after (in red) the intervention. The second set of diagrams show the mean curves of the viscous stiffness before (black) and after (red) the intervention. The third set of diagrams present the phase diagram of viscous stiffness as a function of elastic stiffness. Graphs need to be observed and read by the slope of each curve. The inclination of the slope represents the mean of the curve.

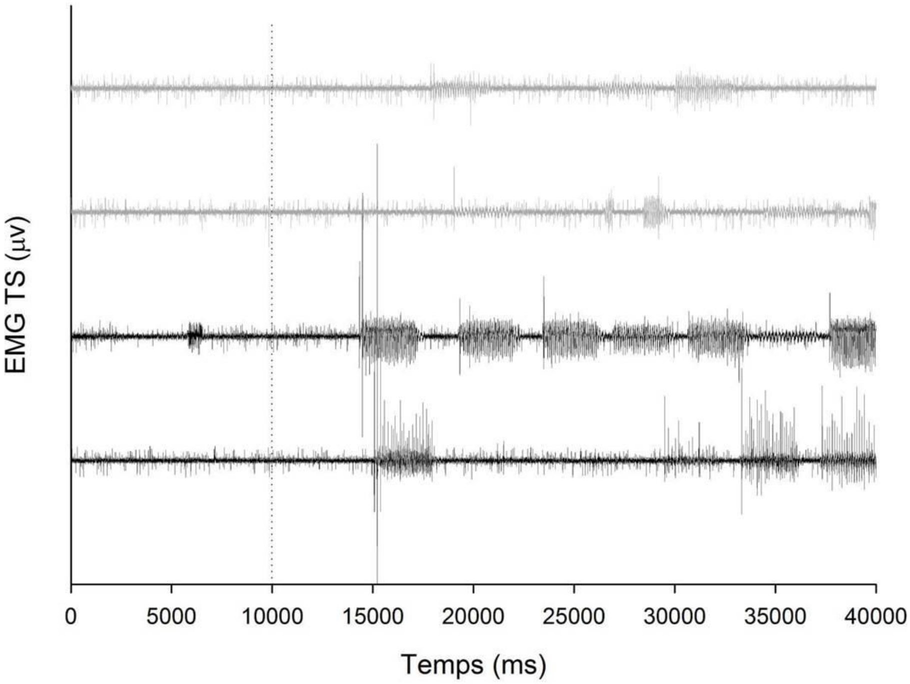


Figure 4B. EMG analyses of the triceps surae during MAS measurement on electromechanical device. In grey is the EMG of the triceps surae for the healthy ankle after (A) and before (B) MWM intervention. In black is the EMG of the triceps surae for the injured ankle after (C) and before (D) MWM intervention.

Table 1 Mean values for anthropometric measurement in the MWM and OM group

MWM						***OM***					
Number of subjects	*Age (years)*	*Weight (kg)*	*Height (cm)*	*Practiced sport (h/week)*	*Previous injury (% yes-% no)*	*Number of subjects*	*Age (years)*	*Weight (kg)*	*Height (cm)*	*Practiced sport (h/week)*	*Previous injury (% yes-% no)*
20	21.7	76.2	183.6	5.7	55 - 45	20	22.2	75	181.1	3.7	55 - 45

Table 2 Mean values for anthropometric measurement in each group categorized by injury

Non-injury						***Injury***					
Number of subjects	*Age (years)*	*Weight (kg)*	*Height (cm)*	*Practiced sport (h/week)*	*Treatment type (% MWM - % OM)*	*Number of subjects*	*Age (years)*	*Weight (kg)*	*Height (cm)*	*Practiced sport (h/week)*	*Treatment type (% MWM -% OM)*
18	20.3	76.1	183.5	4.1	50 - 50	22	22.2	75.2	181.4	4.9	50 - 50

Table 3 Means ± SD and data for all outcome measurements for MWM and OM pre and post-intervention

	MWM				*OM*					
			One-way ANOVA (Within group)				*One-way ANOVA (Within group)*		*Two-way ANOVA (Between groups)*	
	Pre-intervention	***Post-intervention***	***P-value***	***Cohen (d)***	***Pre-intervention***	***Post-intervention***	***P-value***	***Cohen (d)***	***P-value***	***Cohen (d)***
ES (N.m.rad^{-1})	55.6 ± 24.9	62.2 ± 25.1	0.41	-0.27	66.6 ± 30.9	66.1 ± 25.7	0.96	0.02	0.37	0.29
VS (N.m.s-1 rad^{-1})	5.1 ± 4.2	4.7 ± 3.7	0.80	0.08	4.1 ± 3.1	4.1 ± 2.7	0.92	0.03	0.83	-0.05
L path (N.m.rad^{-1})	131.9 ± 40.3	132.1 ± 45.7	0.99	-0.003	123.7 ± 35.1	117.5 ± 39.2	0.60	0.17	0.58	0.17
Distance (cm)	12.1 ± 4.3	13.2 ± 4.4	0.46	-0.24	11.6 ± 3.6	12.3 ± 3.7	0.58	-0.18	0.58	0.06
Angular ROM (°)	31.6 ± 6.9	33.5 ± 6.5	0.37	-0.29	31.5 ± 4.7	34.2 ± 4.5	0.08	-0.58	0.68	-0.29

ES: Elastic stiffness/Intercept in Newton.meter.radian^{-1}
VS: Viscous stiffness/Slope in Newton.meter.sec -1 radian^{-1}
L-path: Path length in Newton.meter.radian^{-1}
Between Cohen (d) effect size = within Cohen (d) effect size OM – within Cohen (d) effect size MWM

Table 4 Means ± SD and data for all outcome measurements for non-injury and injury groups pre and post-intervention

	Non-injury				*Injury*					
			One-way ANOVA (Within group)				*One-way ANOVA (Within group)*		*Two-way ANOVA (Between groups)*	
	Pre-intervention	***Post-intervention***	***P-value***	***Cohen (d)***	***Pre-intervention***	***Post-intervention***	***P-value***	***Cohen (d)***	***P-value***	***Cohen (d)***
ES (N.m.rad^{-1})	55.9 ± 33.3	64.9 ± 28.7	0.39	-0.29	65.4 ± 23.4	63.5 ± 22.4	0.80	0.08	0.16	0.37
VS (N.m s-1.rad^{-1})	5.7 ± 4.2	4.5 ± 3.5	0.33	0.33	3.7 ± 2.9	4.3 ± 2.9	0.46	-0.22	0.04*	-0.55
L path (N.m.rad^{-1})	131.6 ± 46.9	130.1 ± 53.8	0.30	0.03	124.7 ± 28.5	120.4 ± 31.5	0.64	0.14	0.80	0.11
Distance (cm)	12.9 ± 4.1	13.7 ± 4.3	0.55	-0.20	11.1 ± 3.7	11.8 ± 3.7	0.46	-0.23	0.95	-0.03
Angular ROM (°)	33.2 ± 5.5	35.6 ± 5.8	0.22	-0.42	30.2 ± 5.9	32.4 ± 4.9	0.18	-0.41	0.77	-0.01

ES: Elastic stiffness/Intercept in Newton.meter.radian^{-1}
VS: Viscous stiffness/Slope in Newton.meter.second-1 radian^{-1}
L path: Path length in Newton.meter.radian^{-1}
Between Cohen (d) effect size = within Cohen (d) effect size injury – within Cohen (d) effect size non-injury
* Indicates significant differences between injury and non-injury groups (p<0.05)