

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

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42 **and dorsiflexion range of motion in people with chronic ankle rigidity: a randomized clinical**
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46 **ABSTRACT**

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

53
54 **Design:** a randomized clinical trial with two arms.

55
56 **Methods:** Patients were recruited by word of mouth and via social network as well as posters, and
57 analyzed in the neuro musculoskeletal laboratory of the “Université Catholique de Louvain-la-Neuve”,
58 Brussels, Belgium.

59
60 **Participants:** 67 men (aged 18-40 years) presenting with potential chronic non-specific and unilateral
61 ankle mobility deficit during WBDF were assessed for eligibility and finally 40 men were included and
62 randomly allocated to single session of either MWM or OM.

63
64 **Interventions:** Two modalities of manual therapy indicated for hypothetic immediate effects in chronic
65 ankle dorsiflexion stiffness, i.e. MWM and OM, were applied during a single session on included
66 patients.

67
68 **Main Outcome measures:** Comprised blinding measures of MAS with a specific electromechanical
69 device (namely: Lehmann’s device) producing passive oscillatory ankle joint dorsiflexion and with clinical
70 measures of WBADF-ROM as well.

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72 **Results:** A two-way ANOVA revealed a non-significant interaction between both techniques and time
73 for all outcome measures. For measures of MAS: elastic-stiffness ($p=.37$), viscous-stiffness ($p=.83$),
74 total-stiffness ($p=.58$). For WBADF-ROM: toe-wall distance ($p=.58$) and angular ROM ($p=.68$). Small
75 effect sizes between groups were determined with Cohen’s d ranging from .05 to .29. One-way ANOVA
76 demonstrated non-significant difference and small to moderate effects sizes ($d=.003-.58$) on all outcome
77 measures before and after interventions within both groups. A second two-way ANOVA analyzed the
78 effect of each intervention on the sample categorized according to injury history status, and
79 demonstrated a significant interaction between groups and time only for viscous stiffness ($p=.04$, $d=-$
80 $.55$).

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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

124 **Introduction**

125
126 Increased musculoarticular-stiffness (MAS) of the talocrural joint is a frequently encountered problem,
127 identified during evaluation of weight bearing ankle dorsiflexion (WBADF).(1) Such stiffness may follow
128 ankle injury such as ankle sprain.(2) In such a situation, MAS could be increased and might leads to a
129 lack of joint flexibility as well as decreased dorsiflexion range-of-motion (ROM),(1) however asymmetric
130 rigidity does not necessarily always follow ankle sprain. Nevertheless, MAS is an important and
131 necessary component of normal stability of the talocrural joint and could help to prevent abnormal ankle
132 joint movement and ankle sprains or tendinitis.(1)

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

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

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

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

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

165 **Method**

166 **Participants**

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

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

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182 **Measures**

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

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

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

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

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

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

213

214 **Procedure**

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

226 MWM was applied on the patient's symptomatic talocrural joint (Figure 3A), with the patient standing on
227 an examination table. The symptomatic foot was placed in front, flat on the table. The therapist looped
228 a non-elastic manual therapy belt around the patient's distal leg, immediately proximal to the talocrural
229 joint, and around the therapist's pelvis. A postero-anterior tibial glide was performed by the body-weight
230 of the therapist, via the belt. Synchronously, the therapist applied an antero-posterior force to the talus
231 with the web-space of both hands while performing the mobilization. At the same time, the patient was
232 asked to perform a slow active ankle dorsiflexion within pain-free limits. The belt remained perpendicular

233 to the tibia during the entire movement. Three series of ten repetitions were performed, with a one-
234 minute break between each series. (23,28-29)

235 The OM was applied on the patient's symptomatic talocrural joint with the subject lying prone with the
236 knee flexed to 90° to reduce tension on the gastrocnemius muscle to better target the joint (Figure
237 3B).(14-15,18-19) The therapist knee was used to block the patient's thigh on the examination table.
238 The therapist grasped the calcaneus with one hand and created a posterior glide of the talus while with
239 the other hand applied an anterior glide of the tibia according to concave-convex rule. Dorsiflexion of
240 the talocrural joint was performed simultaneous with the gliding motion.(14,18-19) Three sets of 10
241 mobilizations were performed with a rest period of one minute between each set.

242

243 **Statistical analysis**

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

254 **Results**

255

256 (i) A two-way ANOVA revealed non-significant differences in effect for primary and secondary outcome
257 measures for the two different interventions MWM and OM. There was no statistically significant
258 interaction between both techniques and time (pre and post-intervention). No significant interaction was
259 observed for elastic stiffness (ES; $p = 0.37$), viscous stiffness (VS; $p = 0.83$), reflex response to
260 movement (L-path; $p = 0.58$), distance from wall-toe ($p = 0.58$) and ankle joint angular measurement (p
261 $= 0.68$).

262

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

266

267 An explanatory analysis was conducted to determine the effect of history of ankle/foot injury on the
268 primary and secondary outcome measures. Participants were allocated to either a group with a history
269 of injury ($n=22$) or a group without any injury ($n=18$). In the injury group, 19 participants had a history of

270 one or several ankle sprains, 2 had a fracture and one a history of achilles tendinitis. 17 of these injuries
271 occurred within the previous 3 years, and 5 within 8 years.

272

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

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

281

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

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

286 **Discussion**

287

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

292 The results from our sample following MWM with respect to dorsiflexion ROM during the WBDF lunge
293 test are not consistent with previous reports (1-2), excepted with Vicenzino et al. (2006) (20) and
294 Gilbreath et al. (2014).(21) Marron-Gomez et al. (2015) used a similar study protocol, also comparing
295 two manual therapy techniques (MWM and high velocity thrust) for improving ankle dorsiflexion ROM in
296 a very restricted and specific population.(1) However in that study, MWM gave significantly superior
297 effects for improving ankle dorsiflexion ROM in patients with chronic ankle instability, improving the
298 WBADF lunge test by 1.7 cm, when compared to high velocity thrust procedure, our result for MWM are
299 from 1 cm. One goal of manual techniques is to improve ROM and this is probably not really indicated
300 in chronic instability where the ROM is by definition already excessive. So the patients in this study (1)
301 were likely to be very different from our sample; i.e.: chronic ankle instability versus chronic ankle
302 dorsiflexion stiffness. Moreover in that study (1) ankle MAS was not determined. Furthermore, the
303 clinical measures during WBADF lunge test also depend on the patient's tolerance of pain and
304 motivation, which can be influenced by the Hawthorn effect or bias due to lack of blinding. In addition,
305 the gain in range of 1.7 cm during this test is less than the required 1.9 cm minimal detectable change.
306 (26)

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

314 The OM used in the present investigation is an adapted version that has initially been described in
315 several textbooks.(13-14,18-19) However, to our knowledge the efficacy of this kind of technique has
316 not yet been compared to other forms of mobilization. This is in contrast to MWM for ankle dorsiflexion,
317 which has been compared to several other techniques, as described above. This technique, was
318 originally described with the patient lying in a supine position, knee straight gliding the talus posteriorly
319 during dorsiflexion. (14,17) In our study we performed a modified version from an osteopathic approach
320 (14,18-19) where the technique was applied in prone with the knee in 90° flexion, to reduce tension on
321 the gastrocnemius muscle and to improve gliding of the tibia relative to the talus.

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

329 In the secondary analysis, participants were categorized according to history of ankle/foot injury. In the
330 group with a history of injury, there was a significant increase in VS after both mobilization techniques.
331 According to a number of different studies (30-33) VS is due to changes in cytoskeletal proteins (desmin
332 intermediate filament), in the architecture of the muscle (viscosity of myoplasm), or the viscoelastic
333 properties of the muscle (titin filament system). (34) So we hypothesize that increased viscous stiffness
334 may be rather due in fact to increased muscle activity and/or h-reflex of the plantarflexor muscles, triceps
335 surae due to our single session of treatment. It is known that the musculotendinous structures account
336 for 75% of stiffness in movement at a joint, while the joint's articular structures account for the remaining
337 25%.(5) The reason for increased muscle activity remains unclear, but may be due to subconscious
338 neurophysiological protective behavior (aversive memory) and/or by a peripheral sensitization (medullar
339 reflex) from the subject having experienced previous injury. A previous study (35) has established a link
340 between increased muscle activity and increased stiffness to movement. Another recent study (36)
341 stated that increased viscosity leads to a rise in stretch resistance and so increased stiffness to
342 movement. The increased viscosity probably permits the tendon to transmit higher forces which can
343 raise the risk of injury at the tendon level.(36) Hence, increasing MAS, as demonstrated in our study,
344 could also prevent future ankle sprain particularly in those with a history of injury. Increases in VS could

345 be a preventive adaptation following mobilizations to guard the ankle in people with history of ankle
346 injury.

347

348 **Limitations and perspective for future studies**

349

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

364

365 **Conclusion**

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

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381 **References**

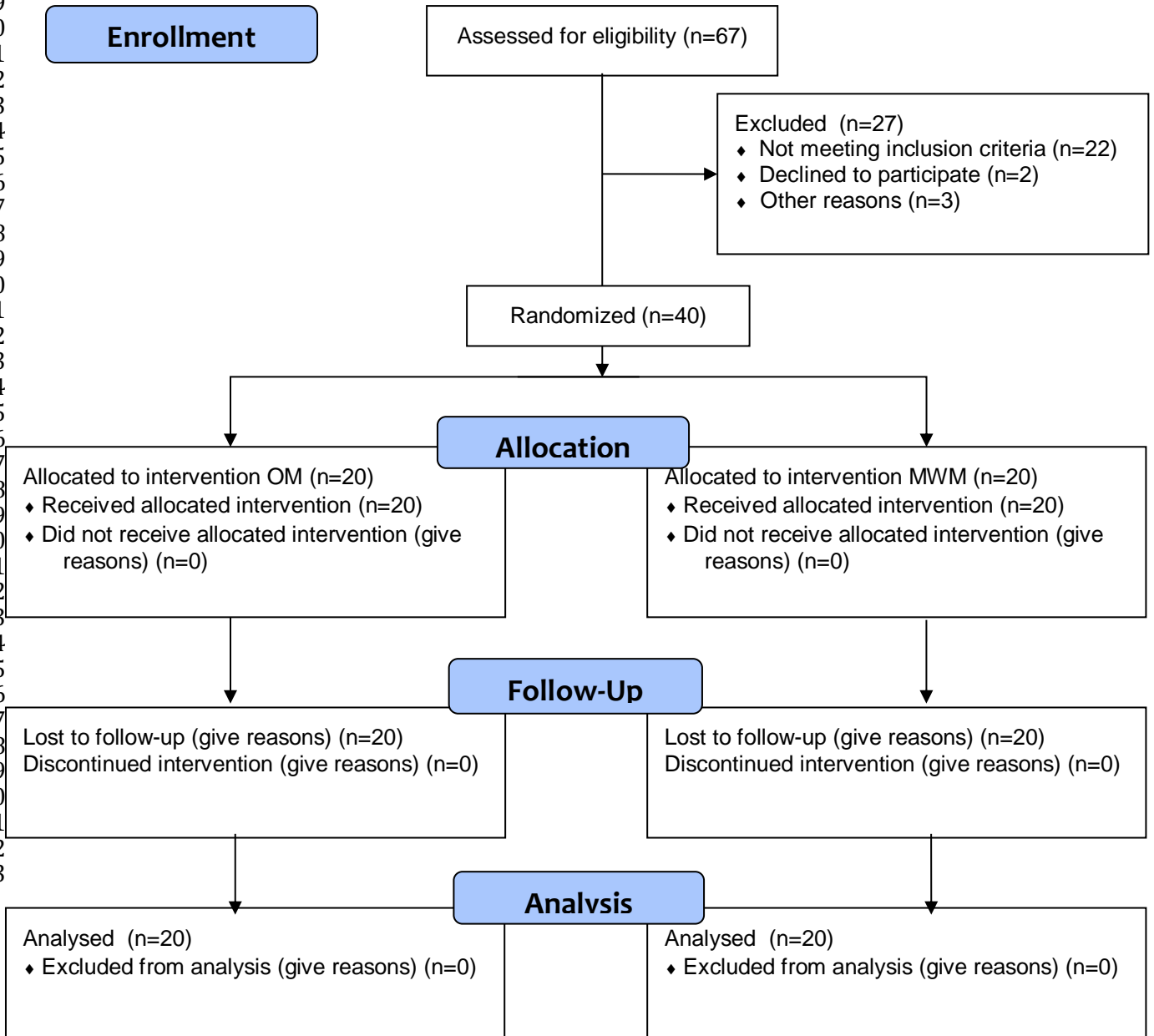
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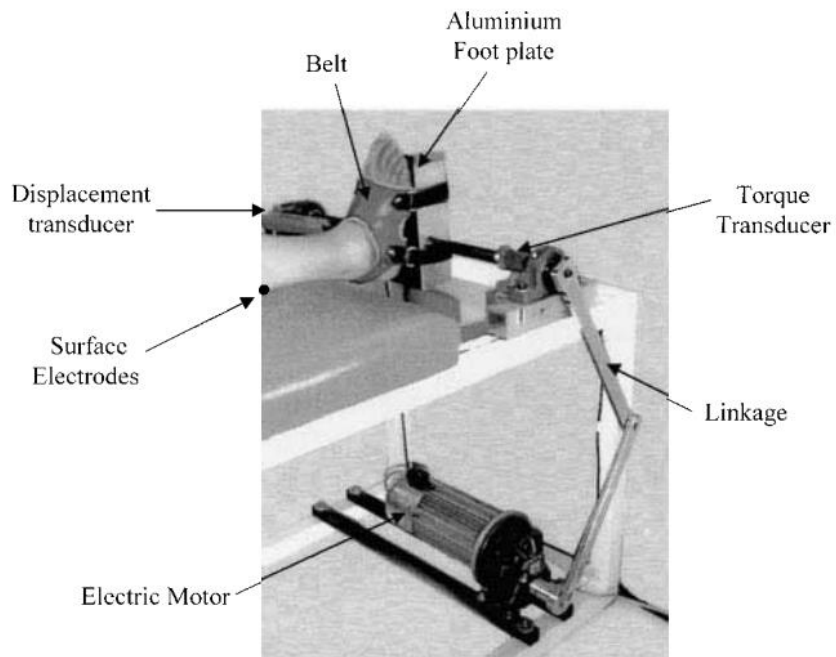
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Figure 1: CONSORT 2010 Flow Diagram





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

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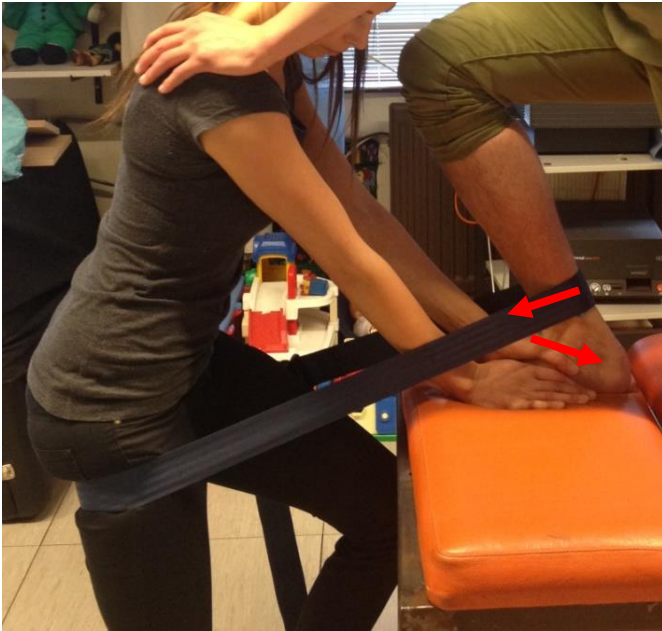


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Figure 2B. Weight-bearing ankle dorsiflexion lunge test measurements: wall-toe distance on the left and goniometer determined angular measurement on the right.

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Figure 3A. Weight bearing Mobilization With Movement

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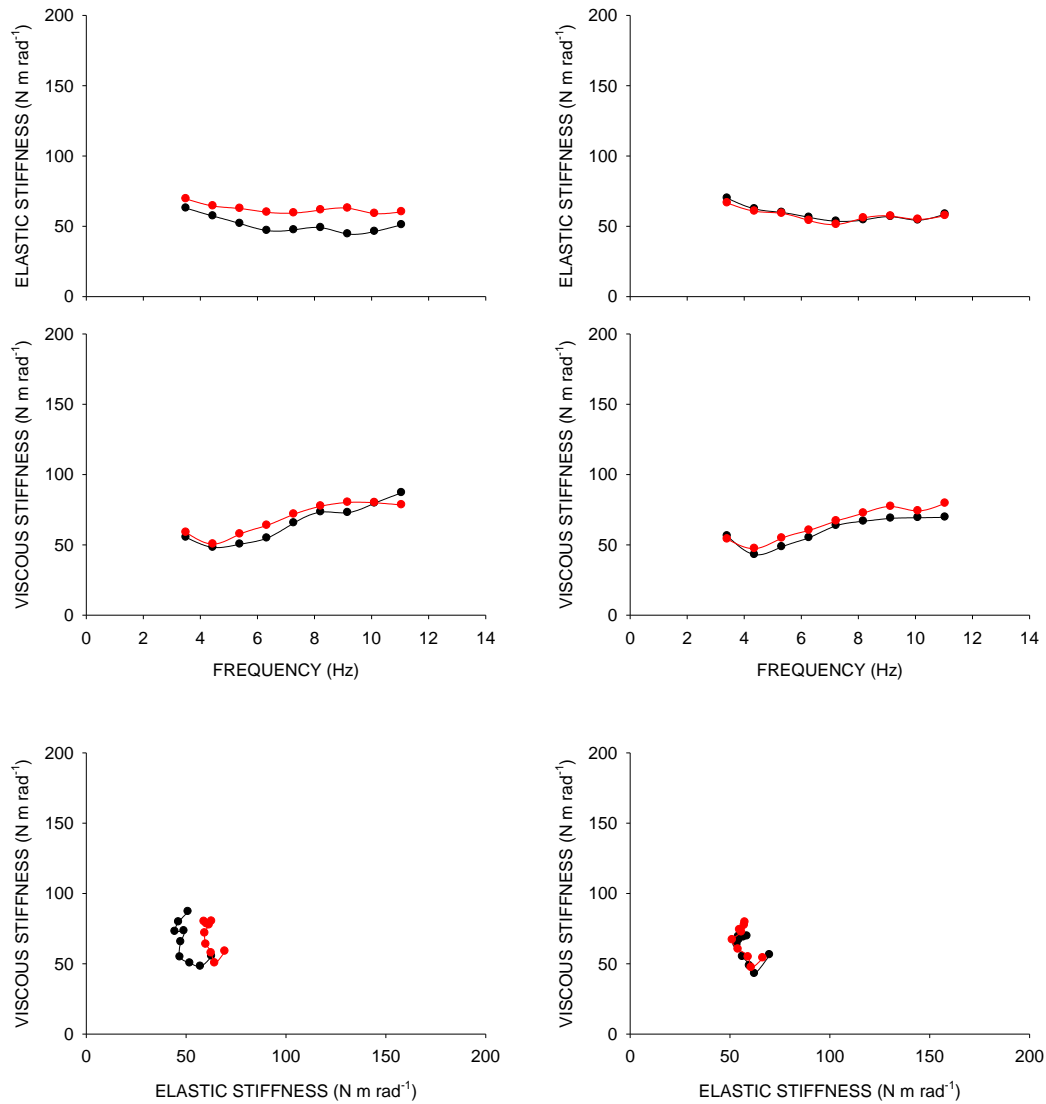


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Figure 3B. Osteopathic passive mobilization.

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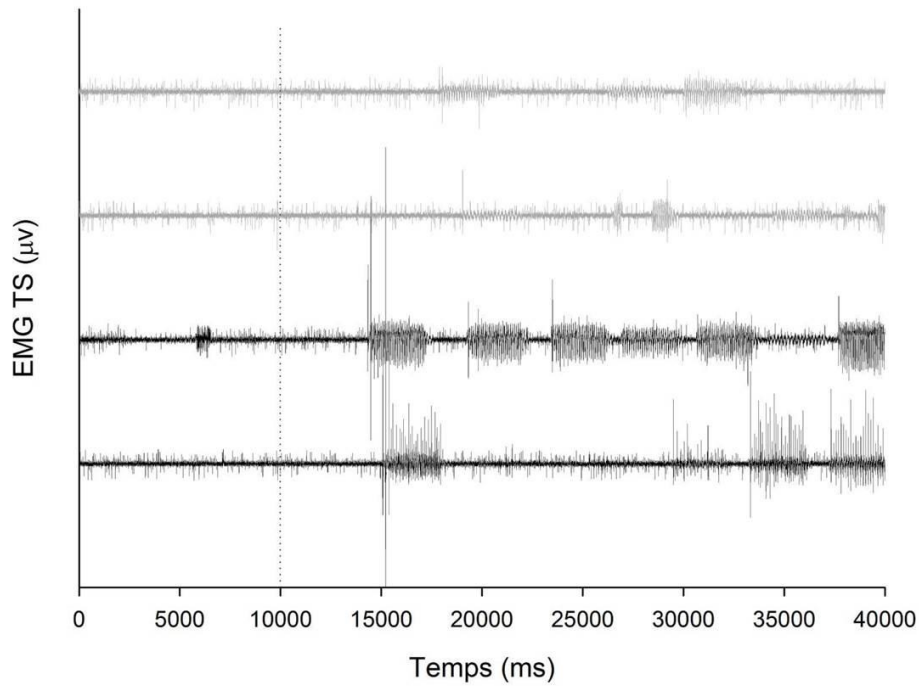
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567 **Figure 4A.** Means for elastic and viscous stiffness in the non-injury group (left) and injury group (right).
 568 Results for pre-intervention are presented in black while results for post-intervention are presented in red. The graphs on the left
 569 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
 570 the first set of diagrams two curves represent the means of the elastic stiffness in each group before (in black) and after (in red)
 571 the intervention. The second set of diagrams show the mean curves of the viscous stiffness before (black) and after (red) the
 572 intervention. The third set of diagrams present the phase diagram of viscous stiffness as a function of elastic stiffness. Graphs
 573 need to be observed and read by the slope of each curve. The inclination of the slope represents the mean of the curve.

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578 Figure 4B. EMG analyses of the triceps surae during MAS measurement on electromechanical device.

579 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
 580 the triceps surae for the injured ankle after (C) and before (D) MWM intervention.

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

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MWM						OM					
Number of subjects	Age (year s)	Weig ht (kg)	Heigh t (cm)	Practiced sport (h/week)	Previous injury (% yes-% no)	Number of subjects	Age (year s)	Weig ht (kg)	Heigh t (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

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

Non-injury						Injury					
Number of subjects	Age (year s)	Weig ht (kg)	Heig ht (cm)	Practiced sport (h/week)	Treatment type (% MWM - % OM)	Number of subjects	Age (year s)	Weig ht (kg)	Heig ht (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

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

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	MWM				OM				Two-way ANOVA (Between groups)	
			One-way ANOVA (Within group)				One-way ANOVA (Within group)		P-value	Cohen (d)
	Pre-intervention	Post-intervention	P-value	Cohen (d)	Pre-intervention	Post-intervention	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

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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

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

	Non-injury				Injury				Two-way ANOVA (Between groups)	
			One-way ANOVA (Within group)				One-way ANOVA (Within group)		P-value	Cohen (d)
	Pre-intervention	Post-intervention	P-value	Cohen (d)	Pre-intervention	Post-intervention	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

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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)

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