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Effects of ankle joint mobilization on dynamic balance muscle activity and dynamic balance in persons with chronic ankle instability - Feasibility of a cross-over study

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ABSTRACT

Introduction: Studies with focus on effects of manual therapy techniques on postural control and muscle activity in patients with chronic ankle instability (are lacking. The purpose of this study was to evaluate the feasibility of a planned cross-over study to assess efficacy of manual therapy techniques applications in patients with chronic ankle instability.

Methods: This feasibility study used a randomized controlled, blinded assessor cross-over design. Criteria of success under evaluation were adherence and attrition rates and adverse events. while preliminary treatment effects of manual therapy techniques on muscular activity (measured by surface electromyography) and on dynamic balance (measured by time to stabilization test) were secondary aims.

Results: Thirteen participants (mean age: 24.4 ± 3.8 years) with chronic ankle instability volunteered in this feasibility study. Success criteria showed a high adherence (98.7%) and low attrition (0%). No missing data were reported but four out of 26 data sets could not be used for statistical analysis because of non-readability of the recorded data. Preliminary treatment effect showed divergent results for surface electromyography and time to stabilization. One significant result ($p = 0.03$, $ES = 1.48$) in peroneus longus muscle activity after jump landing between 30 and 60 ms could be determined.

Conclusions: This study showed that the study protocol is feasible but should be modified by offering participants the opportunity to familiarize to the jumps and to the test repetitions. This study generates better understanding of manual therapy techniques for patients with chronic ankle instability.

1. Introduction

Ankle injuries are one of the most common sports-injuries worldwide. One study showed for an acute ankle sprain incidence rate of 0.93 per 1000 athlete-exposures (athlete-exposure is defined as one athlete participating in one competition or practice) (Doherty et al., 2014). About 42% of acute ankle sprains that occurred in American football, 28% in basketball, 19% in soccer and 46% in volleyball were recurrent injuries (Attenborough et al. (2014)) while. Acute ankle sprain may lead in 20–40% of the injured individuals to a chronic ankle instability (CAI) (Hintermann et al., 2004). The prevalence of CAI one year after a first-time lateral ankle sprain was estimated to be at 40% (Doherty et al., 2016). The number of days of immobility ranged from 36.2 to 73.4 per patient while healthcare costs ranged from 318 USD to 941 USD per person suffering from acute ankle sprain.

Clinical phenotypes in patients with CAI can vary broadly, making the decision regarding treatment complex and the prediction of treatment outcomes difficult. Researchers, therefore, shifted to a personalised or precision approach where the focus is on building subgroups of population who would benefit from a given treatment (Geifmann et al., 2018). For example, the Hertel (2002a) model described a mechanical and functional ankle instability. Based on this model, Hiller et al. (2011a) developed a CAI model that distinguished three subgroups of symptoms: mechanical instability (MI), functional instability (FI) and recurrent sprains (RS).

This current feasibility study deals with the FI as the most common

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CAI form. Main criteria of the clinical diagnostic definition of FI are a subjective feeling of instability and “giving away” of the ankle joint (Delahunt et al., 2010; Hiller et al., 2011a). FI in patients with CAI is associated with restricted dorsiflexion range of motion and restriction of posterior fibular glide (Hertel, 2002b), reduced sensorimotor system impairments and poor sensory integration of afferent and efferent signals which may hamper the neuro-reflective loop (Hertel and Olmsted-Kramer, 2007).

Manual therapy techniques (MTT) are usually applied in practice to rectify joint restrictions such as reduced dorsiflexion in the ankle joint. However, MTT acts via two types of pathways (Eichelberger et al., 2018; Rogan et al., 2019; Tal et al., 2018). A biomechanical pathway focusing on arthro-kinematics surface joint motion (e.g. roll, spin, slide) and a multidimensional pathway. The latter involves mechano-transduction mechanisms on the cellular level (Rogan et al., 2019) and stimulates different reflex modifications via the peripheral nervous system and autonomous nervous system.

Ankle joint mobilisation activates receptors of the joint capsule and the periarticular structures (Baeske, 2016). Stimulating these receptors (depending on their modality), increases the afferent sensory input from the ankle joint to the central motor cortex. The efferent pathway will be modulated (Schmid et al., 2008) which leads to an improved muscle activation rate of the joint encompassing muscles (Rogan et al., 2021), an improved dynamic postural control (Cruz-Díaz et al., 2015; Hoch and McKeon, 2011).

This involves the feedforward mechanism due to altered proprioception, altered activity of the gamma – motoneurons and altered kinetic and kinematic patterns (Hertel, 2002a; Moisan et al., 2017) as well as in a decreased postural control (Munn et al., 2010; Wikstrom et al., 2010a, b).

A deficit in the reflex loop can be identified in altered time-to-stabilization (TTS) after a jump landing (Hiller et al., 2011b; Munn et al., 2010). Thus, TTS is a parameter which quantifies the dynamic postural control and measures the time required to get a stable position for example when landing following a jump (Ross et al., 2005). Treatment recommendation to tackle FI problems includes sensorimotor training and strength training (Hall et al., 2018; Holmes and Delahunt, 2009).

A good understanding of the feasibility of the study design and methodology is required prior to the start of a large, expensive study (Thabane et al., 2010). Therefore, the present study assessed the feasibility of the protocol for a larger randomized controlled trial with cross-over design that will evaluate the efficacy of manual therapy techniques on FI in patients with CAI. Primary aim of this present study was to assess the following criteria of success: adherence, attrition and adverse events when applying six manual therapy sessions in patients with CI. Secondary aims were preliminary treatment effects of manual therapy techniques on muscular activity (measured by surface electromyography) and on dynamic balance (measured by time to stabilization test) in such patients.

2. Methods

2.1. Study design

This current feasibility study used a randomized controlled AB/BA cross-over study design in which each participant experiences the MTT intervention and the control conditions. The assessor was blinded against the group while the physiotherapist was blinded against the measurement results. This study was approved by the Ethics Committee of Canton Berne, Switzerland, and was registered in the German Clinical Trials Register (DRKS00012300). The preparation of this article followed the reporting guideline for pilot randomized controlled studies according to Thabane et al. (2010).

This current feasibility study was conducted in two periods. Enrolment and randomization of the participants into group A or group B. Demographic data and baseline values (T0) of the secondary outcomes (see below) were collected. Period 1: Group A received six interventions over a three weekc period. Group B received no intervention during these three weeks (control). At the end of period 1, post-intervention measurements (T1) of the secondary outcomes were performed in both groups. A washout period of at least ten days was integrated between period1 and 2 to avoid carrying over of treatment effects. In period 2, the groups crossed over. Group A received no intervention during three weeks while group B received now six interventions during three weeks. At the beginning and end of period 2, pre-intervention measurements (T2) and post-intervention measurements (T3) of the secondary outcome measures were again collected in both groups. Fig. 1 represents the study flow.

2.2. Randomization

In feasibility studies, a sample size calculation is not required because the presentation of intervention effects is not a primary but rather a secondary objective (Thabane et al., 2010). The participants were randomized into two independent groups after measurement 1 in period 1. The randomization was carried out by an independent blinded statistician using computer-generated random numbers. The random numbers were filed by the statistician in an opaque envelope and stored in a locked cabinet.

2.3. Participants

The selection and screening of the participant for eligibility was conducted at the Bern University of Applied Sciences between April and July 2016. The inclusion criteria were patients with CAI, aged 18–40 years, living in the Canton of Berne (Switzerland), a score of $\geq$11 on the Identification of Functional Ankle Instability (IdFAI)-questionnaire and having experienced at least two "giving way" sensations in the last twelve months. Exclusion criteria were defined as physiotherapy treatment since the last injury needing rest (no sport) because of CAI-complaints of one or more days, surgery on the affected leg or trunk during the past six months, osteoporosis, neurological diseases, medications that may influence postural control, and unexpected pain occurring during measurement of postural control and muscle activity or MTT intervention.

2.4. Intervention condition

The ankle joint was treated based on the mobilization concept of Maitland (Hengeveld and Banks, 2008) over a period of 10 min. T treatment dosage and mobilization direction were set as follows: For traction, in anterior-to-posterior mobilization and posterior-to-anterior mobilization with grade 3 and 4 the duration was 6 sessions of 10 s with an easy-off by 15 s. For grad 3 and 4 oscillation in traction, anterior-to-posterior mobilization, and posterior-to-anterior mobilization the duration was 60 s with an easy-off by 15 s (Supplement Table 1). The treatments were performed by two experienced physiotherapists.

2.5. Control condition

The participant remained resting in supine position on the treatment table for 10 min. No treatment was performed during the control condition.

2.6. Outcome

2.6.1. Primary outcome

Thabane et al. (2010) and Rogan and Karstens (2018) postulated that feasibility of a study protocol should be demonstrated prior to the planning and implementation of a large and resource-hungry study. The term feasibility can be described as the criteria of success and should

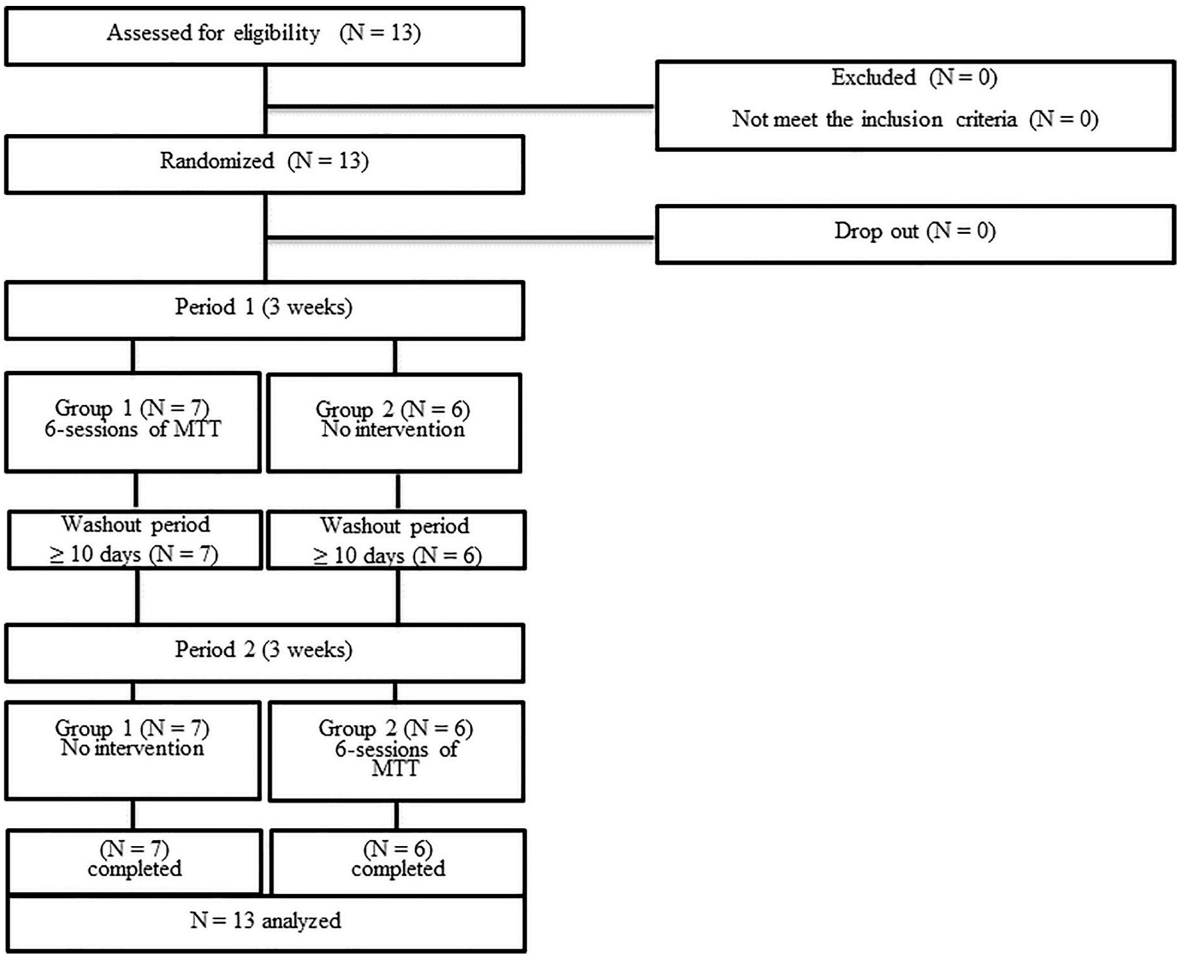

Fig. 1. Flow chart of the study.

always be stated in a feasibility study (Rogan and Karstens, 2018; Thabane et al., 2010). The criteria of success provide information on how and whether it is possible to proceed with a main study. In general, the results of a feasibility study can be interpreted as follows:1. Stop - the main study is not feasible. 2. A continuation occurs only when a modification of the study protocol is performed, then a continuation by a modification is feasible. 3. Continuing without modification, but with close monitoring. 4. A continuation is possible without modifications.

For this present feasibility study a priori criteria of success were defined for adherence, attrition, and safety.

The literature postulated no recommendations regarding the adherence. For this reason, the criteria of success parameters of the pilot study of Rogan et al. (2013) was used. Prior to the start of this current feasibility study 85% adherence were considered acceptable. The attendance of the participants was listed on the attendance register that was handled by the physiotherapist performing the MTT intervention. In total each participant should get six MTT intervention sessions. Adherence was measured through the relative number of intervention sessions compared to the number of potential sessions. From a total of 78 MTT sessions, 66 MTT session had to be completed. For attrition, the number of participants that volunteered at T0 and T3 was collected to calculate a withdrawal value. A priori, maximal attrition was set at 15%. Attrition for the intervention protocol was calculated using the formula: "Number of MTT/the total number of possible MTT sessions x 100" (Rogan et al., 2021). A priori maximal AE tolerance was set at 0%. The safety of the joint mobilization was recorded during the intervention or measurements by means of a questionnaire (Carlesso et al., 2011; Carnes et al., 2010).

2.6.2. *Secondary outcome*

Dynamic balance (time-to-stabilization) and muscle activity (EMG) were analysed during forward single leg jump landing (FSLJL).

Dynamic postural control was assessed using the time-to-stabilization test (TTS) (Ross and Guskiewicz, 2003). The TTS is a test that quantifies dynamic postural control in patients with functionally stable and unstable ankles after a single leg jump. After familiarization, participants performed three FSLJL of 70 cm, barefoot per affected leg. The participants started on their affected leg, held their hands on the hips with opened eyes. They performed a single leg jump at 50% at their maximum height to the centre of the force plate. Landing was performed on the affected leg. Participants were asked to stabilize the landing position during minimum 20 s. Data collection began as the force plate is triggered by landing.

The muscle activity was evaluated using electromyography (EMG). EMG activity of the peroneus longus muscle, tibialis anterior muscle, gastrocnemius medialis and lateralis muscles were recorded during the TTS.

2.7. *Data analysis*

2.7.1. *Dynamic postural control*

The TTS was calculated from the ground reaction force (GRF) measured with the force plate (AMTI OR6, AMTI Inc., Watertown, USA) and recorded in Vicon Nexus 2.5. The TTS was determined for the anterior-posterior (AP), medial-lateral (ML), and caudal-cranial (CC) force components of the GRF. The landing time was defined at a threshold of 20 N. The data processing and calculation of the TTS was performed with the Matlab R 2016a software (The MathWorks, Inc., Natick, USA). The raw GRF signals were filtered (Butterworth 50 Hz low-pass filter, 2nd order, zero-lag), rectified and normalized to body weight.

The procedure for TTS calculating was determined according to the recommendations of Fransz et al. (2015), which showed a good reliability (ICC >0.8) for the force component vertical (V) and moderate reliability (ICC: 0.6–0.8) for the force components anterior-to-posterior (AP) and medio-to-lateral (ML).

Mean standard deviation of the GRF between 7 and 12 s after foot contact among three trials served to specify stable state to determine the TTS. TTS values of three trials for the FSLJ were averaged for further analysis.

2.7.2. Muscle activity

The muscle activity was recorded with the EMG-system Myon 320 (1 kHz, 12 bit, Myon AG, Schwarzenberg, Switzerland). The application of the bipolar electrodes (Ambu® Blue Sensor) was carried out according to the standard of SENIAM (Hermens et al., 2000). The skin was shaved and disinfected with alcohol. The skin resistance was checked by means of an impedance measurement and had to be $k < 5\ \Omega$. Signal validity was checked by isolated muscle activation. The EMG values were recorded at a sampling frequency of 1000 Hz in the Vicon Nexus 2.5 software. The data was processed with the Matlab R 2016a software (The MathWorks, Inc., Natick, USA) according to the same procedure as in the study by Flei schmann et al. (2011). The EMG data were filtered (Butterworth Bandbass filter 10–500 Hz, 2nd order, zero-lag) and rectified.

Subsequently, in relation to the time of landing for time windows of 30 ms in each case, the average activity was calculated using root-mean-square. Overall, this was done for six windows of time beginning 30 ms before landing until 150 ms after landing.

To normalize the values, the mean amplitude of the stance phase during walking was used. Participants went over the force plate in their freely chosen normal speed. The stance phase was defined as the time from heel strike to toe-off. The heel strike and toe-off times were determined using the synchronously determined GRF and the threshold was set of 20 N. The mean values of the stance phase of ten steps were then averaged (Baur et al., 2010) and defined as 100% muscle activity. Subsequently, for the values of the time windows from the jumps (TTS), the percentage activation was calculated in relation to these 100%.

2.8. Statistical analysis

Nonparametric statistics were used according to Wellek and Blettner (2012). Cross-over effects were estimated using sums of the matched pairs of observation from each participant. Treatment effect was estimated using difference of the matched pairs of observation from each participant. To determine cross-over effects and to evaluate treatment differences between MTT and no intervention, a Wilcoxon test was used. A two-tailed p-value of <0.05 was considered as statistically significant. Cohen's d-consistent effect size was calculated (Cohen, 2013) and interpreted effect sizes as small (d = 0.2–0.5), moderate (d = 0.5–0.8) and large (d = > 0.8). Statistical analysis was carried out using Matlab R 2016a software (The MathWorks, Inc., Natick, USA).

3. Results

This study included 13 participants. Table 1 shows detailed participants characteristics.

3.1. Criteria of success (primary outcome)

The adherence to this intervention study was 100%. The attrition was 0%. No AE were observed. Four out of 26 data sets (15.5%) could not be included in the statistical analysis because of non-readability of the recorded data [T1 CAI08, CAI09, CAI13, CAI14].

Table 1
Age, anthropometrics and side of CAI.

	Group A (n = 7)	Group B (n = 6)
Age (years), mean (SD)	23.43 (2.87)	25.5 (1.53)
BMI (kg/m^2), mean (SD)	22.79 (1.21)	25.44 (3.95)
Male (n, %)	3 (42.8)	0 (0)
Women (n, %)	4 (57.2)	6 (100)
Right ankle	4 (57.2)	4 (66.7)
Left ankle	3 (42.8)	2 (33.3)

3.2. Secondary outcomes

No statistically significant group differences of the variables under evaluations at baseline were found. Carry-over effect analysis showed that all secondary outcomes values at measurement time point T2 returned to baseline values as at T0.

3.2.1. Dynamic balance

MTT intervention did not affect TTS. Table 2 demonstrates the results for the dynamic balance variables.

3.2.2. Muscular activity

A statistically significant effect of MTT on the peroneus longus muscle activity during the FSLJL in the pre-ground contact phase (30 ms–60 ms) (p = 0.003, ES = 1.48) was found. Supplemental Table 2 shows the results of all variables of muscle activity.

4. Discussion

Feasibility studies are an important instrument when planning a randomized control trials of a novel treatment method or a combination of existing treatment methods in new participant' groups. Adherence and attrition data from this current feasibility study demonstrated a high acceptance of the participants towards the study design. Furthermore, no single AE after MTT was observed in this feasibility study. A statistically significant between-groups result (p = 0.03) in peroneus longus muscle activity after jump landing between 30 and 60 ms could be determined.

One of the goals of this study was to demonstrate an adherence above 85%, to avoid any serious threats regarding validity. However, the findings were higher than expected. All included participants (n = 13) adhered to 78 MTT intervention sessions by 100%. Compared with participants' adherence in studies that investigated the effects of spinal joint mobilization by 94.7% and 75% respectively (Haller et al., 2019; Tal et al., 2018). the participants of the present study showed greater adherence. Personal reasons for not attending one MTT intervention session were mentioned only by one participant. A crossover study design allowed each participant to obtain the treatment. This study design offers each participant the opportunity to receive the intervention. This study design may encourage adherence willingness among participants.

This current study could determine any AE after MTT. Fuller and Manford (2011) reported after ankle and foot joint mobilization tingling

Table 2
Overview of the jump direction and.

Junp direction	Force component	Mean difference TTS (CI 95%)	p Value	Effect size
ML	AP	0.08 (−0.15; 0.17)	0.73	−0.42
ML	CC	0.03 (−0.23; 0.21)	0.95	−0.03
ML	ML	−0.09 (−0.64; 1.21)	1.00	0.15
PA	AP	−0.03 (−0.42; 0.44)	0.84	0.03
PA	CC	−0.07 (−0.24; 0.11)	0.45	0.52
PA	ML	0.00 (−0.36; 0.21)	0.73	0.16

AP: anterior-posterior, CC: central component, ML: medio-lateral, PA: posterior-anterior.

as a commonly reported sensory positive symptom. Tingling can be triggered by inadequate hand posture of the therapist during the execution of the examination or mobilization technique, in which nerves and blood vessels are squeezed. In this current study the therapists showed an adequate application of pressure on bone and joint without compressing vessels and nerves.

The goal of this current study was to assess feasibility; therefore, no statistical differences in the secondary outcome measures was expected. The literature described a stabilization time after AP TTS values ranging from 3.22 to 3.27 s for persons with FI (Brown et al., 2004; Ross and Guskiewicz, 2004). This feasibility study showed lower AP TTS values around 2 s. Ross and Guskiewicz (2004) reported AP TTS values by 1.72 (SD 0.58) for patients with FI and for healthy persons an AP TTS value by 1.35 (SD 0.30). Gribble and Robinson (2009)found similarly results in CAI patients for AP TTS 1.61 (SD 0.45) and for healthy persons by mean of 1.29 (SD 0.07). Reasons of such differences are now discussed.

A statistically significant treatment differences between groups was only observed for the peroneus longus muscle at time frame 30–60 ms after initial ground contact. All other muscles and time points showed no differences. The task of the peroneal muscle is to control the amount of inversion of the ankle joint. There is a cascade of neuromuscular events occurring during the preparation phase for landing. This includes a build-up of muscle activity before foot contacts the ground as pre-activation, and during ground contact. The present study could whether find higher pre-activation rates nore during ground contact after MTT intervention. The statistically significant measurement of 30 ms to 60ms suggests a random improvement. On the one hand, the other muscle activities demonstrated no muscle activity changes and on the other hand it is known that 5 out of 100 measurements can show important changes.

An overlapping of reflex mechanism and activation times and amplitude as programmed muscle activity generates muscle force after jump landing. According to Nigg (1985), the inclusion of the programmed muscle activity is essential because of the passive phase of jump landing. Due to the fact that the passive phase is based on the basic assumption that no additional muscle activation can occur during the first 50–80 ms after landing. When these mechanisms are applied to the data from this present study, it becomes possible to verify our statement above.

4.1. Limitations

This current feasibility study used a standardized treatment program. In a clinical setting, manual therapists are used working with finding-oriented MTT. Manual therapists may diagnose joint restrictions and hypomobile joints in order to treat these joints subsequently. The planned, larger trail should include the adjoining foot joints, the subtalar and calcaneocuboidal joints, because hypomobility of these joints may also influence arthrokinematics of the talocrural joint (Donovan and Hertel, 2012).

Osteo-kinematic dorsiflexion of the ankle joint should also be examined by goniometry. The procedure can be performed in supine position on a table or in standing position like stretch position for gastrocnemius muscles.

The treatment method differs in relation to athro-kinematic and osteo-kinematic restrictions. Arthro-kinematic refers to the capsule of the joint. If the arthro-kinematic restriction test is positive then a grade III AP talocrural joint mobilization should be performed or a Mulligan MTT (Bucher-Dollenz and Maitland, 2008; Donovan and Hertel, 2012). If the arthro-kinematic restriction test with pain production is positive, then a grade IV AP talocrural joint mobilization should be performed. In case of an osteo-kinematic restriction, then muscle stretching techniques should be used. In this case, the upcoming main study should use static stretching or PNF stretching as treatment techniques (Hermens et al., 2000).

Donovan and Hertel (2012) postulated an assessment and treatment algorithm to help guide the conservative management of patients with CAI. This algorithm can identify a decreased range of motion, a reduced muscle strength, an impaired sensorimotor function and an altered gait pattern in such patients with CAI. A dorsiflexion range of motion deficit of the ankle joint may be caused by either arthro-kinematic restriction (joint capsule), an osteo-kinematic restriction (muscle-tendon-complex) or a combination of arthro-kinematic and osteo-kinematic restriction. The focus in this present study was on the arthro-kinematic, without a specific examination for arthro-kinematic and osteo-kinematic (gross movements of bones). Arthro-kinematic motions induce translations (glide, slide) and rotations (spin, roll) of the screw axis of the anatomical joints (Cai et al., 2017; Manske et al., 2015). Because arthro-kinematic restrictions may mask the findings of osteo-kinematic tests, it has been recommended to asses first arthro-kinematic (capsular) restrictions and afterwards osteo-kinematic motion (e.g. muscular shortening) (Donovan and Hertel, 2012). The future study should use the posterior talar glide test, the posterior distal fibula glide and anterior proximal fibula glide test to examine joint restrictions. Another important factor is that the findings of both feet should be compared.

Deficits in chronic processes (e.g. patients with CAI) seem less obvious. Persons who can develop strategies or develop a compensatory behavior, where deficits are not detectable, are referred to as “copers” in the literature (Hubbard, 2008). Wilkstrom et al. (2010b) postulated that patients with CAI and copers do not differ from each other. However, copers may show the (better) ability to develop compensatory changes in feed-forward neuromuscular control as compared to the patients with CAI. They illustrated a higher AP stability index by 0.122 (SD 0.014) and ML stability index by 0.047 (SD 0.012) in the coper group compared to healthy by 0.041 (SD 0.007) and by 0.106 (SD 0.01). Son et al. (2017) found that patients with CAI displayed landing positions of less plantarflexion, less inversion, more knee flexion, more hip flexion, and less hip abduction during the first 25% of stance. Patients with CAI displayed altered movement strategies, perhaps in an attempt to avoid perceived position of risk. Wikstrom and Brown (2014) suggested the following seven items to contextualize copers: mechanism of injury, presence of mechanical laxity, number of days immobilized and/or non -weight bearing after the initial sprain, time since latest ankle sprain, percentage of coper with recurrent ankle sprain or giving way episode, current physical activity level and whether copers attended formal rehabilitation for the affected ankle. For the future study copers should be separated from CAI patients.

Statistical analysis of muscle activity data could not be carried out with all data sets. Four of 26 data sets (15.5%) were not available due the non-readability of the data. A reason could be that the skin conduction was not adequate, or the skin was to dry. Also, the transfer of the EMG electrodes to the software could produce a poor data quality. For future studies, recorded EMG data of each participant should be checked for plausibility immediately after transfer to the data carrier.According to Thabane et al. (2019) many feasibility studies have not been published or reported. A reason for this is that the approach defined in advance becomes an inappropriate theory and produces negative results. Our hypothesis that restricted joint mobility due to arthro-kinematic deficits leads to a reduced reflex activity, seems to be more complex as first mentioned and thus, needs to be reconsidered. FI may result from one or a combination of the following factors: 1. Ligament damage, ankle muscle strength deficit, delayed muscle reaction time and sensorimotor deficit at ankle joint (Konradsen and Ravn, 1991; Lephart et al., 1997; Ross et al., 2005).

Future studies could be strengthened by including an active component, because current literature reported short-term treatment effects with MTT in patients suffering from CAI while longer-lasting effects are produced by therapeutic exercise regimes (Plaza-Manzano et al., 2016; Walsh et al., 2020).

The control group did not undergo a sham treatment, and this may introduce bias and/or lack of effort in the first group to serve as a control if the research participants are versed in science and research design.

5. Conclusions

This study assessed the feasibility and evaluated the effects of MTT intervention on dynamic postural control and muscle activity in 13 patients with CAI. Participants were willing to take part and adhere to the MTT intervention. The criteria of success were fulfilled. However, the study protocol should be adapted when planning a larger study. Copers need to be filtered out when including CAI patients into the future study. Examination of arthro-kinematic component and osteo-kinematic component should be examined specifically and the MTT intervention should be based on it. The participants should be given the opportunity, to familiarize to the jumps, and to the test repetitions.

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Author declaration template

We wish to draw the attention of the Editor to the following facts which may be considered as potential conflicts of interest and to significant financial contributions to this work.

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

We understand that the Corresponding Author is the sole contact for the Editorial process (including Editorial Manager and direct communications with the office). He/she is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs.

CRediT authorship contribution statement

Larissa Zesiger: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Conceptualization. **Slavko Rogan:** Writing – original draft, Supervision, Conceptualization. **Jan Taeymans:** Writing – review & editing. **Patric Eichelberger:** Writing – review & editing, Supervision, Software, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare no potential conflict of interest with respect to the authorship and/or publication of this article.

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Appendix A. Supplementary data

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