“Does isometric exercise improve leg stiffness and hop pain in subjects with Achilles tendinopathy? A feasibility study"

MANTOVANI, Lisa <http://orcid.org/0000-0002-4163-2923>, MAESTRONI, Luca, BETTARIGA, Francesco <http://orcid.org/0000-0002-4977-5494>, GOBBO, Massimiliano <http://orcid.org/0000-0003-1383-6213>, LOPOMO, Nicola Francesco <http://orcid.org/0000-0002-5795-2606> and MCLEAN, Sionnadh <http://orcid.org/0000-0002-9307-8565>

“Does isometric exercise improve leg stiffness and hop pain in subjects with Achilles tendinopathy? A feasibility study”

Authors

Lisa Mantovani [a], Luca Maestroni [a,b,c], Francesco Bettariga [a], Massimiliano Gobbo [e,f] , Nicola Francesco Lopomo [d,e,f], Sionnadh McLean [g]

[a] Studioerre, Via della Badia 18, 25127 Brescia (BS)

[b] Smuoviti, Viale Giulio Cesare, 29, 24121 Bergamo (BG), Italy

[c] London Sport Institute, School of Science and Technology, Middlesex University, Greenlands Lane, London, United Kingdom

[d] Department of Information Engineering, University of Brescia, Italy

[e] Laboratory of Clinical Integrative Physiology, University of Brescia, Italy

[f] Department of Clinical and Experimental Sciences, University of Brescia, Italy

[g] School of Health, Wellbeing and Life Sciences, Sheffield Hallam University, Broomhall Road, Sheffield, United Kingdom

Lisa Mantovani e-mail: mantovani1981ft@hotmail.com
Luca Maestroni e-mail: lucamae@hotmail.it
Francesco Bettariga e-mail: francescobettariga@gmail.com
Massimiliano Gobbo: massimiliano.gobbo@unibs.it
Nicola Francesco Lopomo e-mail: nicola.lopomo@unibs.it
Sionnadh McLean e-mail: s.mclean@shu.ac.uk

Corresponding author
Lisa Mantovani e-mail: mantovani1981ft@hotmail.com
Via della Badia 18, 25127 - Brescia (BS)

ORCID ID: https://orcid.org/0000-0002-4163-2923

“Does isometric exercise improve leg stiffness and hop pain in subjects with Achilles tendinopathy? A feasibility study”

ABSTRACT

Background: In Achilles tendinopathy (AT) the ability to store and recycle elastic energy during ground contact phase is often altered. A measure of this function is represented by leg stiffness (LS). Immediate responses in LS following therapeutic intervention have not been examined.

Objective: The aim of this paper was to examine the feasibility of the protocol in participants with AT.

Design: Single cohort feasibility study.

Participants: Adults with persistent AT pain, symptoms on palpation and less than 80 points on the Visa-A questionnaire.

Intervention: heavy isometric exercise sequence in plantarflexion

Outcome Measures: Feasibility was assessed by evaluating: the willingness of participants to enroll into the study, the number of eligible participants, the recruitment rate, adherence to the intervention, the drop-out rate, the tolerability of the protocol. LS, reactive strength index, pain and rate of perceived effort were secondary outcomes.

Results: 22 AT were eligible for data collection and 19 entered the statistical analysis. The intervention was well tolerated, no withdrawals. Pain scores were low during both the intervention and the assessment. Immediate improvements in LS and pain were recorded.

Conclusions: The isometric exercise protocol was feasible. Future research should investigate its effectiveness.

Highlights

A heavy isometric exercise protocol performed in standing with the ankle in plantarflexion was feasible in subjects with AT.

An inclined machine was used to reduce the load during the hop tasks, this may have facilitated the execution, and thus, the tolerability and the low levels of pain.

The possibility to manipulate the load during the intervention seems to be helpful for the feasibility of the protocol and it is easily transferable to clinical practice.

Similar to previous studies, this intervention did not produce clinically significant changes in the pain levels. However, this improved LS in the SM jump task, thus suggesting further investigation. Considering that most patients report AT symptoms with SSC function, it may be important to reassess the efficacy of the rehabilitation strategies during dynamic task performance by including similar specific tasks, such as single-legged continuous jumps.

Keywords

Achilles Tendinopathy, Isometric, Leg Stiffness, Rate of perceived exertion, Stretch-Shortening cycle

1.0 INTRODUCTION

Achilles tendinopathy (AT) affects around 2% of the general population and 9% of the athletic population (de Jonge et al., 2011; M. Murphy et al., 2018). It can be debilitating and compromise physical and sports performance (Debenham et al., 2016). Cross-sectional studies of subjects with AT have demonstrated alterations in tendon mechanical properties, plantar-flexor muscle strength (Malliaras & O'Neill, 2017; O'Neill et al., 2019), stretch shortening cycle (SSC) performance, leg stiffness (LS) and rate of force development (RFD)(Obst et al., 2018; Wang et al., 2011). These features have important connotations as potential risk factors for AT, thus being potential targets for primary prevention strategies. Moreover, they represent persistent deficits relevant for both secondary and tertiary prevention strategies (Jacobsson & Timpka, 2015; Maestroni et al., 2019). Alterations in the repetitive SSC of the muscle-tendon unit occurring in activities such as jumping, running and walking, are associated with AT (Debenham et al., 2016). The ability to store and recycle elastic energy during the ground contact phase is underpinned by LS (Maquirriain, 2012), which is used as a measure of SSC function (Croix et al., 2017). In most SSC activities LS depends primarily on ankle stiffness (Brazier et al., 2017), thus highlighting the importance of the ankle complex in human locomotion and dynamic tasks. In research, LS is often calculated as the ratio between peak vertical ground reaction forces and peak center of mass displacement during ground contact (Croix et al., 2017). In clinical settings, the reactive strength index (RSI) is widely employed to assess the SSC function. This provides insights about the resistance to the deformation of the lower limb in response to an applied force

(Flanagan & Comyns, 2008). A direct correlation between lower extremity stiffness and risk of injury or recurrence has not been established yet (Debenham et al., 2016; Lorimer & Hume, 2016; Pruyn et al., 2012).
A variety of isometric, isotonic and eccentric loading programs have been shown to be beneficial for patients with AT (Head et al., 2019; M. Murphy et al., 2018; M. C. Murphy et al., 2019; Vlist et al., 2020) and isometric exercise have been shown to provide an heterogeneous response on pain without an overall clinically meaningful change (O'Neill et al., 2018; Vlist et al., 2020).

To our knowledge, research investigating the immediate effect of isometric contractions on SSC function during dynamic task performance in subjects with AT is lacking (Oranchuk et al., 2019). This may reveal important implications for rehabilitation strategies because it reflects a more complex adaptation of the musculoskeletal system in a specific task (Morin & Samozino, 2016). Therefore, the primary aim of this study was to test the feasibility of a heavy isometric exercise protocol in participants with persistent AT in a dynamic task.

2.0 METHODS

2.1 Study design

A single group before-after study was designed to test the feasibility of the protocol. This study complied with the Declaration of Helsinki (2008) and an ethical approval for this study was obtained from the local ethics committee (Comitato Etico di Bergamo, REG. SPERIM N 205/19) and the Sheffield Hallam University

Ethics Committee. The study was reported following the CONsolidated Standard of Reporting Trials for pilot and feasibility studies (CONSORT-PF) statement (Eldridge et al., 2016).

2.2 Setting, Participants and Recruitment

The research was conducted in a private physiotherapy clinic in Italy between May and August 2019. A convenience sample of voluntary subjects with AT was recruited through advertisement in gyms, clubs, sports teams and physiotherapy services. Participants were eligible if they: were aged over 18, had experienced AT for at least 12 weeks, reported pain located on the Achilles Tendon, reported pain on tendon palpation (Hutchison et al., 2013), scored less than 80 points out of 100 on the VISA-A questionnaire (Robinson, 2001). Patients with both bilateral and unilateral symptoms were recruited to maximize the sample size. Participants were excluded if they: had an injury in the last 6 months affecting the lower limb resulting in current disability, had undergone surgery in the affected lower limb in the last 6 months, had reported pain in other areas of the lower quadrant (low back, hip, knee, foot & ankle), had co-existing pathology or other visual/motor impairments, had received physiotherapy or specific exercise for AT in the last 3 months, had performed vigorous physical activity in the week prior to data collection. Participants voluntarily contacted the main author via email or phone to find out more about the study and to plan a date for possible recruitment and data collection. At this meeting participants received an information sheet; they had the opportunity to ask questions and were as-

sessed for eligibility. Those that were eligible and willing to participate signed a written informed consent form prior to testing.

2.3 Equipment used

A TOTALGYM® Gravity Training System GTS (see Fig 2 and 3, supplementary file) was used to perform the jump task. The GTS is a commercial inclined machine used to reduce the bodyweight by altering the board inclination. This also allows plyometric exercise while the trunk is lying on the board. In our setting, the thigh was fixed to the mobile board with a belt to focus the movement on the ankle.

Vertical and antero-posterior components of force, peak of force, time to achieve force and impulse were measured using the PASCO (PS-2142, PASCO, Pass-port PS-2142, Roseville, USA) force platform. This was attached to the base of the TOTALGYM®GTS (GTS) using a dedicated mechanical link (see Figure 2, supplementary). PASCO PS-2142 has demonstrated good reliability, precision and accuracy in comparison to a gold standard platform in all variables (Silveira et al, 2016) (Peterson Silveira et al., 2017).

Finally, a Smith-machine (Multipla Technogym ®) (see Fig 1, supplementary) was used to manage the load with weights in a safe position during the administration of the isometric exercise protocol.

2.4 Isometric exercise protocol

Participants were asked to perform a heavy isometric contraction in plantarflexion close to inner range, in standing position in the Smith-machine. They were

asked to hold the contraction for 45 seconds for five sets with 1-minute rest between sets. During the rest period, participants were asked if they wanted to raise, maintain or reduce the load.

Insert Exercise description table n. 1*

2.5 Outcome measures

2.5.1 Primary outcomes: Feasibility

The primary outcome of the study was related to the feasibility for a future adequately powered trial. Feasibility was assessed by evaluating: 1) the willingness of participants to enroll in the study, 2) the number of eligible participants, 3) the recruitment rate, 4) adherence to the intervention, 5) the drop-out rate, 6) the tolerability ~~of the protocol~~ was assessed by asking participants to rate on a 0-10 scale where “0” was not at all tolerable and “10” was very tolerable, a value above 5 was considered tolerable (Calatayud et al., 2019).

The willingness to use this intervention was investigated asking participants to answer “yes” or “no” whether they would adhere to this intervention in a rehabilitation program. Patients were also asked to verbally report about adverse events experienced, discomfort, inconveniences during the data collection and the exercise protocol.

2.5.2 Secondary outcomes

Before and after participants completed the isometric exercise protocol, the following data were collected.

2.5.2.1 Physical function and capacity: Leg Stiffness (LS) and Reactive Strength Index (RSI)

LS and RSI are used as a measure for SSC function of the muscle-tendon unit (Brazier et al., 2014, 2017; Croix et al., 2017). Both submaximal (SM) and maximal (M) hops have been chosen here to assess the LS and RSI, as described in previous studies (Debenham et al., 2016) in sub-maximal jump. LS was calculated using the data (body mass, ground contact time and flight time) collected during the jumps on the force platform and the formula described previously by Brazier and colleagues (Brazier et al., 2014, 2017). Reactive strength index (RSI) was calculated as the quotient of the jump height and contact time (jump height (m) / ground contact time (sec))(Struzik et al., 2016).

2.5.2.2 Pain and disability levels

Pain and disability were assessed at the beginning, as one of the inclusion criteria, with the Victorian Institute of Sport Assessment- Achilles (VISA-A), a disease specific outcome (Robinson, 2001). Pain during the SM and M hop tasks were collected before and after the intervention for each jump using the Numerical Pain Rating Scale (NPRS), a subjective measure in which participants rate their pain on an eleven-point numerical scale, where “0” equals not pain at all and “10” equals the worst imaginable pain (Haefeli & Elfering, 2006). Pain intensity during the 5 sets of the intervention (NPRSiso) was measured and recorded. The mean value was then calculated. Pain variation during the intervention was also calculated (∆NPRSiso).

2.5.2.3 Effort during the intervention

Rate of perceived effort (RPE) is a quantitative measure (0-10 modified Borg scale) of perceived effort during physical activity, training or competition (Grant et al., 1999). It was recorded at the end of each of the 5 sets. Subjects were asked how much effort they perceived on a scale from 0 to 10, where 0 were "no exertion" and 10 was "maximal exertion, the hardest they have ever experienced". The variation of RPE during the intervention was also calculated (∆RPE).

2.5.2.4 Other measures

The amount of load used during the intervention (kg) was collected during the 5 sets. The load normalized to bodyweight (%bodyweight) and its variation during the intervention (∆%bodyweight) were also calculated.

2.6 Procedure

After signing the consent form, age (years), gender, standing height (meters) and weight (kilograms) were collected for each participant. The duration of the symptoms was determined by asking participants, "How long have you had your pain for?", responses were converted into months. Total activity level was assessed with the International Physical Activity Questionnaire (IPAQ score) (Wolin et al., 2009). Participants completed the VISA-A score. The included participants were asked to participate in baseline objective evaluations. The objective evaluations were taken by the same assessor with the help of a second one where required. To begin with participants lay on the board of the GTS machine where the head, trunk and lower limb were comfortably supported (see Fig 2

and 3, supplementary). The affected leg was fixed by a belt at the level of the mid-thigh which prevented knee and hip flexion/extension moment and isolated the movements at the ankle. The GTS was inclined at 22 degrees (see Figure 3, supplementary file) with the aim to reduce body weight to 60% and the impact while jumping. The platform was reset before each application of the test. Participants were instructed on the performance of the two jump tasks: SM and M jumps on the GTS. They could try three jumps to gain confidence with the task before starting the data collection. In the SM jump participants hopped at a level that could be sustained for an “indefinite” amount of time on their affected leg for a 15-second trial, before a 30-second rest period. Two trials were repeated. Then the two M hop tasks were assessed. In this task, participants were asked to jump as high as they could for 5 consecutive times. A 30-second rest period separated the two trials. Following the baseline assessment, the patient moved to the Smith Machine for the intervention. After that, the baseline measures were repeated, SM and M jumps were tested again (after) using the same standardized sequence.

2.7 Data collection

Data collected via the force platform software were processed using Matlab (Matlab 2019b, The Mathworks USA). For each trial raw normal force was normalized with respect to the body weight. Time moments corresponding to the peak force landing and take-off phases were identified for each hop (Figure 4, supplementary file). A signal was analyzed through the entire trial from the first instant of take-off. The force signal was used to calculate several parameters

related to each hop including: hop time (s), contact time (s), flight time (s), peak force (N), LS (kN/m) as defined by Dalleau and colleagues (Dalleau et al., 2004)(considering the inclination angle); mechanical power (W), as defined by Dalleau and colleagues (Dalleau et al., 2004), taking into account the inclination angle; net impulse (N*s)(Kirby et al 2011), RSI (m/s) (Flanagan & Comyns, 2008). Every parameter was evaluated for each hop and then averaged on the whole trial. Mean and standard deviation (SD) values were reported for LS and RSI.

2.8 Statistical Analysis

The statistician was blinded to the recruitment, data collection and intervention. Sigmaplot11 (Systat Software) was used for data analysis. The data were analyzed using descriptive statistics (e.g. mean, standard deviation). The normality of data distribution was examined using the Kolmogorov-Smirnov test. Despite not being the main aim of our study, we included information regarding inferential statistics when the sample size was appropriate to provide the readers with an understanding of the magnitude of the effect generated by our intervention. Differences between baseline and follow-up LS and pain data for SM jump were tested with a paired t-test. To determine the magnitude of differences, Cohen's d effect size (ES) was calculated and interpreted using the following thresholds: ES > 0.2 = small; ES > 0.5 = moderate; ES > 0.8 =large.

3.0 RESULTS

3.1 Recruitment and characteristics of the sample

Twenty-three potential participants were invited to participate in this study from May to August 2019 (see Fig 1), two patients with bilateral symptoms were included for a total of twenty-five AT cases. Patients were mainly invited through external contacts within the sports field and rehabilitation centers.
Three participants were excluded because they did not fulfill the inclusion criteria. The sample were heterogeneous in terms of duration of symptoms, VISA-A score and amount of total physical activity per week. Participants' characteristics are reported in Table 2.

***** Insert Figure 1 about here *****

***** Insert Table 2 about here *****

3.2 Primary Outcomes: Feasibility of the intervention

22 AT were eligible for data collection, three traces from the plot had insufficient quality for consequent analysis, therefore the final statistical analysis was performed on 19 AT (17 participants in which only two participants had bilateral symptoms). The intervention was quite well tolerated (mean 6.3±2.2) and there were no withdrawals (see table 4 ~~3~~). Furthermore, during both the intervention and the assessment the pain scores were low on average ($NPRS_{iso}$ 2.8± 2.6; NPRS SM before 2.35±2.6, SM after 1.1±1.5; NPRS M before 2.39±2.2, SM after 1.2±1.5). At the end of the procedure 5 out of 19 participants reported an uncomfortable feeling in their neck and upper limbs caused by the load em-

ployed. Only three subjects reported discomfort in the calf or the lower limb due to the contraction during the exercise. All participants (17/17) considered this protocol potentially useful for their rehabilitation process (see table 4). No adverse events were detected during the data collection and no complaints were registered.

3.3 Secondary Outcomes

3.3.1 Physical function and capacity: Leg Stiffness and RSI

There was a significant increase in LS after the intervention in the SM jumps only (+ 1100.59 kN/m ±1258.45; ES=0.87, p≤0.001). Varied responses in LS during SM hop task are depicted in Figure 4. Mean Changes in LS are depicted in Figure 3. RSI showed a trend of improvement (SM RSI_{before}: 0.17m/s ±0.12 vs RSI_{after} 0.24 m/s±0.16; M RSI_{before} 0.67m/s±0.43 pre vs RSI_{after} 0.73m/s±0.47).

***** Insert Table 3 about here *****

***** Insert Figure 3 about here*****

*****Insert Figure 4 about here*****

3.3.2 Pain

Pain levels reached a statistically significant reduction in SM (ES=0.49, p=0.047) and in M (ES= 0.58, p=0.02) after the intervention. Individual responses are depicted in Figure 5a and 5b. Over the 5 sets there was a statistically significant reduction in pain during the heavy isometric exercise ($\Delta NPRS_{iso}$ -1.3 ± 2.1, ES=0.57, p=0.02).

3.3.3 Effort during the intervention

During the intervention RPE was on average 5.8±1.8 with a mean increment of 1.4±1.9 at the end of the 5 sets (ES=0.72 p=0.006)(see table 4).

3.3.4 Other analyses

During the intervention participants employed a mean load normalized to body weight (%BW) of 48.74%±6.4 with a mean reduction of -0.45%±19 during the 5 sets. Sample size was estimated on the pre/post mean values and standard deviations of the LS in SM obtained in this study (alpha= 0.05 and a power of 80% with 95% CI) (Bhalerao & Kadam, 2010). The sample size resulted in 14 participants; moreover, considering a 24% of total dropouts (6/25: 3 ineligible cases and 3 who were not included in the statistical analysis due to poor traces), the final number calculated for a future study was 17 participants. This number is feasible for potential future studies. The estimated sample size for M hop task was 70 participants.

***** Insert Figure 5a+5b about here *****

*****Insert Table 4 about here*****

4.0 DISCUSSION

The isometric exercise protocol was feasible and produced a meaningful improvement in LS in SM jump task. Pain levels decreased, although they did not reach clinically meaningful improvements. Other outcomes are discussed in this section as exploratory data for future studies.

4.1 Primary Outcomes

According to the results, the isometric exercise protocol was feasible, and immediate changes in LS and RSI could be detected during dynamic SM and M jump tasks. Pain levels reported during the assessment and intervention were low. This confirmed the feasibility of the procedures used in this study. However, there is a twofold consideration when examining these results. Firstly, the low levels of pain found at baseline may have facilitated the execution, and thus, the tolerability of the jump tasks. Secondly, they may have reduced the potential overall impact of the intervention on pain changes (i.e. low mean pain change). No participants withdrew from this study. All subjects judged the intervention as “tolerable” and considered the strategy employed feasible for rehabilitation. This may be mediated by the adoption of the GTS inclined at twenty-two degrees, which reduced AT loads, thus reducing symptom perception during dynamic tasks (NPRS SM before =2.35±2.6; SM after=1.1±1.5; NPRS M before=2.3±2.2; M after=1.2±2.2). The sample size, estimated via pre-post variation in LS during SM jumps, was feasible for potential further studies. Instead,

the sample size needed for the M task was much higher, thus appearing more feasible if included in a multi-center trial.

4.2 Secondary Outcomes

In our study the change in LS in SM jumps showed a statistically significant improvement and a moderate effect size after the intervention. Since there is support from other studies that found reduced LS in the affected limb during SM jumps (Debenham et al., 2017; Maquirriain, 2012; Otsuka et al., 2018; Sancho et al., 2019), we consider our results important for further investigations. Debenham and colleagues (Debenham et al., 2017) described changes in the SSC behaviour (increase of lower limb stiffness from 5.9 to 6.8 Nm^{-1}) 7 days after a single eccentric loading intervention in 11 healthy subjects. Sancho and colleagues (Sancho et al., 2019) demonstrated significant increases (ES 0.54) in LS in SM jumps in male recreational runners with mid-portion AT after a 12-week rehabilitation programme including education, exercise and hopping. This highlights the potential positive adaptations induced by loading programmes on maladaptive mechanism affecting the SSC in AT. Cross-sectional studies revealed imbalances between excitatory and inhibitory motor pathways, which can influence muscle activation, hence SSC function (McAuliffe et al., 2016; Wang et al., 2011). These motor changes are likely to be influenced by both central and peripheral mechanisms (Wang et al., 2011). Contrary to our hypothesis, pain changes showed a significant improvement, but they did not reach any minimally clinical important difference (MCID). Also, over the 5 sets employed during the intervention, a statistically significant reduction in pain with a

moderate effect size was reported for both SM and M tasks. However, the magnitude of change was around 1 point (0-11 NPRS), which arguably could be considered clinically significant. Moreover, the individual response was very varied (see figure 7). This is in line with a recent study by O'Neill and colleagues (O'Neill et al., 2018) where 18 participants with mid portion AT did not show consistent pain reductions following 5 sets of 45 seconds heavy seated isometric plantar-flexor contractions.

4.3 Strengths and Limitations

The protocol used in this study has been selected for its simple implementation in rehabilitation settings and for its tightly controlled force application. Furthermore, subjects were allowed to manipulate loads according to their willingness to increase, maintain or decrease the load. We consider the latter to be a relevant feature transferable in an ordinary clinical practice, although the factors underpinning this decision need to be further investigated. Specific and tightly controlled isometric load regimes (≥ 70% of their maximal voluntary isometric contraction MVIC) were applied in other small studies (Holden et al., 2020; Rio et al., 2017) investigating acute effects of pain in subjects with patellar tendinopathy with contrasting results. Despite more rigorous in their application, these controlled load regimes may represent a limitation in their applicability in clinical settings. Instead, a pragmatic protocol based on each individual bodyweight may facilitate translation from research to clinical practice. It may be interesting to further explore the correlation between RPE and MVIC. They may reveal the presence of a cut-off value for RPE to elicit meaningful changes in

pain and LS. In this study RPE was monitored together with pain levels during the intervention because the relationship between exercise induced hypoalgesia (EIH) and perceived effort was described previously (Koltyn et al., 2014). However, no study investigated RPE and EIH in in symptomatic AT cohorts. Future studies should aim to explore this thoroughly. Another strength of this study is the choice of the continuous jump as a task to assess the LS and the isolated ankle movement, fixing the thigh with a belt on the board of the GTS machine; this setting was never investigated before. A limitation of this study is related to the heterogeneity in the sample, especially for the duration of the disorder, for the location of the symptoms (i.e. mid portion vs insertional) and for the physical activity level. These may underpin different stiffness characteristics and pain behaviours, thus altering the response to the intervention. Therefore, these should be taken into account for future studies. As mentioned before, due to the main aim of this study being its feasibility, a relevant limitation is that the pair t-test did not account for multiple variables which could impact the results (e.g. baseline VISA-A, baseline physical activity levels, baseline symptom duration or baseline BMI).

4.4 Implications for future studies

This exercise protocol appears feasible for being adopted in a fully powered study and it may be compared to different loading programmes (e.g. isotonic) or type of exercise (e.g. aerobic) in RCTs aimed to explore acute LS changes in AT populations and other predictive factors. Considering that most patients report AT symptoms with SSC activities, similar specific tasks, such as single-

legged continuous jumps, should be used to reassess immediate clinical changes.

It would also be important to understand if the differences found in the two tasks (SM and M) are related to specific underlying factors. Indeed, relevant aspects such as beliefs, fear of jumping, confidence with the task, physical activity levels and athleticism, may affect maximal strength capability and neural drive (Abate et al., 2013; Edwards et al., 2016; Kozlovskaia et al., 2017; Linton & Shaw, 2011; Mallows et al., 2018; Scott et al., 2015; Yue et al., 2014). Therefore, we recommend a multidimensional assessment to account for the multiple variables that may influence the outcomes. In particular, the correlation between pain and load manipulation needs to be further investigated. In this study the isometric exercise was performed in a standing position to maximize the whole calf muscle complex involvement during the isometric contractions. In a previous study O'Neill et al (O'Neill et al., 2018, 2019) used a similar protocol, albeit in a seated position, to specifically increase the recruitment of the soleus muscle. The selected position may play a role for AT population in terms of specific provocative activity and/or targeted muscles deficits. This should be further investigated. Furthermore, bilateral symptoms and previous lower limb injuries should be entered into a linear mixed model to evaluate their influence on stiffness characteristics and response to exercise.

5.0 CONCLUSION

This study confirmed our primary hypothesis that the protocol was feasible in a heterogeneous cohort presenting with persistent AT. The isometric exercise protocol produced immediate significant changes in LS and pain for SM jumps, but not for RSI, demonstrating its potential to be clinically useful. Studies with larger sample sizes, control/placebo/sham intervention arms, or larger studies powered for analysis of multiple covariates (e.g. baseline VISA-A, baseline physical activity levels, baseline symptom duration or baseline BMI) are required in order to test the effectiveness of this isometric exercise protocol and to detect whether these effects are statistically and clinically meaningful.

References

Abate, M., Schiavone, C., Salini, V., & Andia, I. (2013). Occurrence of tendon pathologies in metabolic disorders. *Rheumatology*, *52*(4), 599–608. https://doi.org/10.1093/rheumatology/kes395

Bhalerao, S., & Kadam, P. (2010). Sample size calculation. *International Journal of Ayurveda Research*, *1*(1), 55. https://doi.org/10.4103/0974-7788.59946

Brazier, J., Bishop, C., Simons, C., Antrobus, M., Read, P. J., & Turner, A. N. (2014). Lower extremity stiffness: Effects on performance and injury and implications for training. *Strength & Conditioning Journal*, *36*(5), 103–112.

Brazier, J., Maloney, S., Bishop, C., Read, P. J., & Turner, A. N. (2017). Lower Extremity Stiffness: Considerations for Testing, Performance Enhancement, and Injury Risk. *Journal of Strength and Conditioning Research*, 1. https://doi.org/10.1519/JSC.0000000000002283

Croix, M. B. D. S., Hughes, J. D., Lloyd, R. S., Oliver, J. L., & Read, P. J. (2017). Leg stiffness in female soccer players: Intersession reliability and the fatiguing effects of soccer-specific exercise. *The Journal of Strength & Conditioning Research*, *31*(11), 3052–3058.

Dalleau, G., Belli, A., Viale, F., Lacour, J.-R., Bourdin, M. (2004). A Simple Method for Field Measurements of Leg Stiffness in Hopping. *International Journal of Sports Medicine*, *25*(3), 170–176. https://doi.org/10.1055/s-2003-45252

de Jonge, S., van den Berg, C., de Vos, R. J., van der Heide, H. J. L., Weir, A., Verhaar, J. A. N., Bierma-Zeinstra, S. M. A., & Tol, J. L. (2011). Incidence of midportion Achilles tendinopathy in the general population. *British Journal of Sports Medicine*, *45*(13), 1026–1028. https://doi.org/10.1136/bjsports-2011-090342

Debenham, J. R., Gibson, W. I., Travers, M. J., Campbell, A. C., & Allison, G. T. (2017). Modulation of Stretch-Shortening-Cycle Behavior With Eccentric Loading of Triceps Surae: A Possible Therapeutic Mechanism. *Journal of Sport Rehabilitation*, *26*(2), 151–158. https://doi.org/10.1123/jsr.2015-0129

Debenham, J. R., Travers, M. J., Gibson, W., Campbell, A., & Allison, G. T. (2016). Achilles tendinopathy alters stretch shortening cycle behaviour during a sub-maximal hopping task. *Journal of Science and Medicine in Sport*, *19*(1), 69–73. https://doi.org/10.1016/j.jsams.2014.11.391

Edwards, R. R., Dworkin, R. H., Sullivan, M. D., Turk, D. C., & Wasan, A. D. (2016). The Role of Psychosocial Processes in the Development and Maintenance of Chronic Pain. *The Journal of Pain*, *17*(9), T70–T92. https://doi.org/10.1016/j.jpain.2016.01.001

Eldridge, S. M., Chan, C. L., Campbell, M. J., Bond, C. M., Hopewell, S., Thabane, L., & Lancaster, G. A. (2016). CONSORT 2010 statement: Extension to randomised pilot and feasibility trials. *BMJ*, i5239. https://doi.org/10.1136/bmj.i5239

Flanagan, E. P., & Comyns, T. M. (2008). The use of contact time and the reactive strength index to optimize fast stretch-shortening cycle training. *Strength & Conditioning Journal*, *30*(5), 32–38.

Haefeli, M., & Elfering, A. (2006). Pain assessment. *European Spine Journal*, *15*(S1), S17–S24. https://doi.org/10.1007/s00586-005-1044-x

Head, J., Mallows, A., Debenham, J., Travers, M. J., & Allen, L. (2019). The efficacy of loading programmes for improving patient- reported outcomes in chronic midportion Achilles tendinopathy: A systematic review. *Musculoskeletal Care*, *17*(4), 283–299. https://doi.org/10.1002/msc.1428
Holden, S., Lyng, K., Graven-Nielsen, T., Riel, H., Olesen, J. L., Larsen, L. H., & Rathleff, M. S. (2020). Isometric exercise and pain in patellar tendinopathy: A randomized crossover trial. *Journal of Science and Medicine in Sport*, *23*(3), 208–214. https://doi.org/10.1016/j.jsams.2019.09.015
Hutchison, A.-M., Evans, R., Bodger, O., Pallister, I., Topliss, C., Williams, P., Vannet, N., Morris, V., & Beard, D. (2013). What is the best clinical test for Achilles tendinopathy? *Foot and Ankle Surgery*, *19*(2), 112–117. https://doi.org/10.1016/j.fas.2012.12.006
Jacobsson, J., & Timpka, T. (2015). Classification of Prevention in Sports Medicine and Epidemiology. *Sports Medicine*, *45*(11), 1483–1487. https://doi.org/10.1007/s40279-015-0368-x
Koltyn, K. F., Brellenthin, A. G., Cook, D. B., Sehgal, N., & Hillard, C. (2014). Mechanisms of Exercise-Induced Hypoalgesia. *The Journal of Pain*, *15*(12), 1294–1304. https://doi.org/10.1016/j.jpain.2014.09.006
Kozlovskaia, M., Vlahovich, N., Ashton, K. J., & Hughes, D. C. (2017). Biomedical Risk Factors of Achilles Tendinopathy in Physically Active People: A Systematic Review. *Sports Medicine - Open*, *3*(1). https://doi.org/10.1186/s40798-017-0087-y
Linton, S. J., & Shaw, W. S. (2011). Impact of psychological factors in the experience of pain. *Physical therapy*, *91*(5), 700–711.
Lorimer, A. V., & Hume, P. A. (2016). Stiffness as a Risk Factor for Achilles Tendon Injury in Running Athletes. *Sports Medicine*, *46*(12), 1921–1938. https://doi.org/10.1007/s40279-016-0526-9
Maestroni, L., Read, P., Bishop, C., & Turner, A. (2019). Strength and Power Training in Rehabilitation: Underpinning Principles and Practical Strategies to Return Athletes to High Performance. *Sports Medicine*. https://doi.org/10.1007/s40279-019-01195-6
Malliaras, P., & O'Neill, S. (2017). Potential risk factors leading to tendinopathy. *Apunts. Medicina de l'Esport*, *52*(194), 71–77. https://doi.org/10.1016/j.apunts.2017.06.001
Mallows, A. J., Debenham, J. R., Malliaras, P., Stace, R., & Littlewood, C. (2018). *Cognitive and contextual factors to optimise clinical outcomes in tendinopathy*. BMJ Publishing Group Ltd and British Association of Sport and Exercise Medicine.
Maquirriain, J. (2012). Leg Stiffness Changes in Athletes with Achilles Tendinopathy. *International Journal of Sports Medicine*, *33*(07), 567–571. https://doi.org/10.1055/s-0032-1304644
McAuliffe, S., McCreesh, K., Culloty, F., Purtill, H., & O'Sullivan, K. (2016). Can ultrasound imaging predict the development of Achilles and patellar tendinopathy? A systematic review and meta-analysis. *British Journal of Sports Medicine*, *50*(24), 1516–1523. https://doi.org/10.1136/bjsports-2016-096288
Morin, J.-B., & Samozino, P. (2016). Interpreting Power-Force-Velocity Profiles for Individualized and Specific Training. *International Journal of Sports Physiology and Performance*, *11*(2), 267–272. https://doi.org/10.1123/ijspp.2015-0638
Murphy, M. C., Travers, M. J., Chivers, P., Debenham, J. R., Docking, S. I., Rio, E. K., & Gibson, W. (2019). Efficacy of heavy eccentric calf training for treating mid-portion Achilles tendinopathy: A systematic review and meta-analysis. *British Journal of Sports Medicine*, *53*(17), 1070–1077. https://doi.org/10.1136/bjsports-2018-099934

Murphy, M., Travers, M., Gibson, W., Chivers, P., Debenham, J., Docking, S., & Rio, E. (2018). Rate of Improvement of Pain and Function in Mid-Portion Achilles Tendinopathy with Loading Protocols: A Systematic Review and Longitudinal Meta-Analysis. *Sports Medicine*, *48*(8), 1875–1891. https://doi.org/10.1007/s40279-018-0932-2
Obst, S. J., Heales, L. J., Schrader, B. L., Davis, S. A., Dodd, K. A., Holzberger, C. J., Beavis, L. B., & Barrett, R. S. (2018). Are the Mechanical or Material Properties of the Achilles and Patellar Tendons Altered in Tendinopathy? A Systematic Review with Meta-analysis. *Sports Medicine*, *48*(9), 2179–2198. https://doi.org/10.1007/s40279-018-0956-7
O'Neill, S., Barry, S., & Watson, P. (2019). Plantarflexor strength and endurance deficits associated with mid-portion Achilles tendinopathy: The role of soleus. *Physical Therapy in Sport*. https://doi.org/10.1016/j.ptsp.2019.03.002
O'Neill, S., Radia, J., Bird, K., Rathleff, M. S., Bandholm, T., Jorgensen, M., & Thorborg, K. (2018). Acute sensory and motor response to 45-s heavy isometric holds for the plantar flexors in patients with Achilles tendinopathy. *Knee Surgery, Sports Traumatology, Arthroscopy*. https://doi.org/10.1007/s00167-018-5050-z
Oranchuk, D. J., Storey, A. G., Nelson, A. R., & Cronin, J. B. (2019). Isometric training and long-term adaptations: Effects of muscle length, intensity, and intent: A systematic review. *Scandinavian Journal of Medicine & Science in Sports*, *29*(4), 484–503. https://doi.org/10.1111/sms.13375
Otsuka, M., Kurihara, T., & Isaka, T. (2018). Bilateral deficit of spring-like behaviour during hopping in sprinters. *European Journal of Applied Physiology*, *118*(2), 475–481. https://doi.org/10.1007/s00421-017-3791-x
Pruyn, E. C., Watsford, M. L., Murphy, A. J., Pine, M. J., Spurrs, R. W., Cameron, M. L., & Johnston, R. J. (2012). Relationship between leg stiffness and lower body injuries in professional Australian football. *Journal of Sports Sciences*, *30*(1), 71–78. https://doi.org/10.1080/02640414.2011.624540
Rio, E., Kidgell, D., Moseley, G. L., Gaida, J., Docking, S., Purdam, C., & Cook, J. (2016a). Tendon neuroplastic training: Changing the way we think about tendon rehabilitation: a narrative review. *Br J Sports Med*, *50*(4), 209–215.
Rio, E., Kidgell, D., Moseley, G. L., Gaida, J., Docking, S., Purdam, C., & Cook, J. (2016b). Tendon neuroplastic training: Changing the way we think about tendon rehabilitation: a narrative review. *British Journal of Sports Medicine*, *50*(4), 209–215. https://doi.org/10.1136/bjsports-2015-095215
Rio, E., van Ark, M., Docking, S., Moseley, G. L., Kidgell, D., Gaida, J. E., van den Akker-Scheek, I., Zwerver, J., & Cook, J. (2017). Isometric contractions Are more analgesic than isotonic contractions for patellar tendon pain: An in-season randomized clinical trial. *Clinical Journal of Sport Medicine*, *27*(3), 253–259.
Robinson, J. M. (2001). The VISA-A questionnaire: A valid and reliable index of the clinical severity of Achilles tendinopathy. *British Journal of Sports Medicine*, *35*(5), 335–341. https://doi.org/10.1136/bjsm.35.5.335
Sancho, I., Malliaras, P., Barton, C., Willy, R. W., & Morrissey, D. (2019). Biomechanical alterations in individuals with Achilles tendinopathy during running and hopping: A systematic review with meta-analysis. *Gait & Posture*, *73*, 189–201. https://doi.org/10.1016/j.gaitpost.2019.07.121
Scott, A., Zwerver, J., Grewal, N., de Sa, A., Alktebi, T., Granville, D. J., & Hart, D. A. (2015). Lipids, adiposity and tendinopathy: Is there a mechanistic link? Critical review.

British Journal of Sports Medicine, *49*(15), 984–988. https://doi.org/10.1136/bjsports-2014-093989
Vlist, A. C., Veldhoven, P. L. J., Oosterom, R. F., Verhaar, J. A. N., & Vos, R. (2020). Isometric exercises do not provide immediate pain relief in Achilles tendinopathy: A quasi- randomized clinical trial. *Scandinavian Journal of Medicine & Science in Sports*, sms.13728. https://doi.org/10.1111/sms.13728
Wang, H.-K., Lin, K.-H., Wu, Y.-K., Chi, S.-C., Shih, T. T.-F., & Huang, Y.-C. (2011). Evoked Spinal Reflexes and Force Development in Elite Athletes With Middle-Portion Achilles Tendinopathy. *Journal of Orthopaedic & Sports Physical Therapy*, *41*(10), 785–794. https://doi.org/10.2519/jospt.2011.3564
Yarnitsky, D., Granot, M., & Granovsky, Y. (2014). Pain modulation profile and pain therapy: Between pro- and antinociception: *Pain*, *155*(4), 663–665. https://doi.org/10.1016/j.pain.2013.11.005
Yue, P., Xu, G., Li, L., & Wang, S. (2014). Prevalence of musculoskeletal symptoms in relation to psychosocial factors. *Occupational Medicine*, *64*(3), 211–216. https://doi.org/10.1093/occmed/kqu008

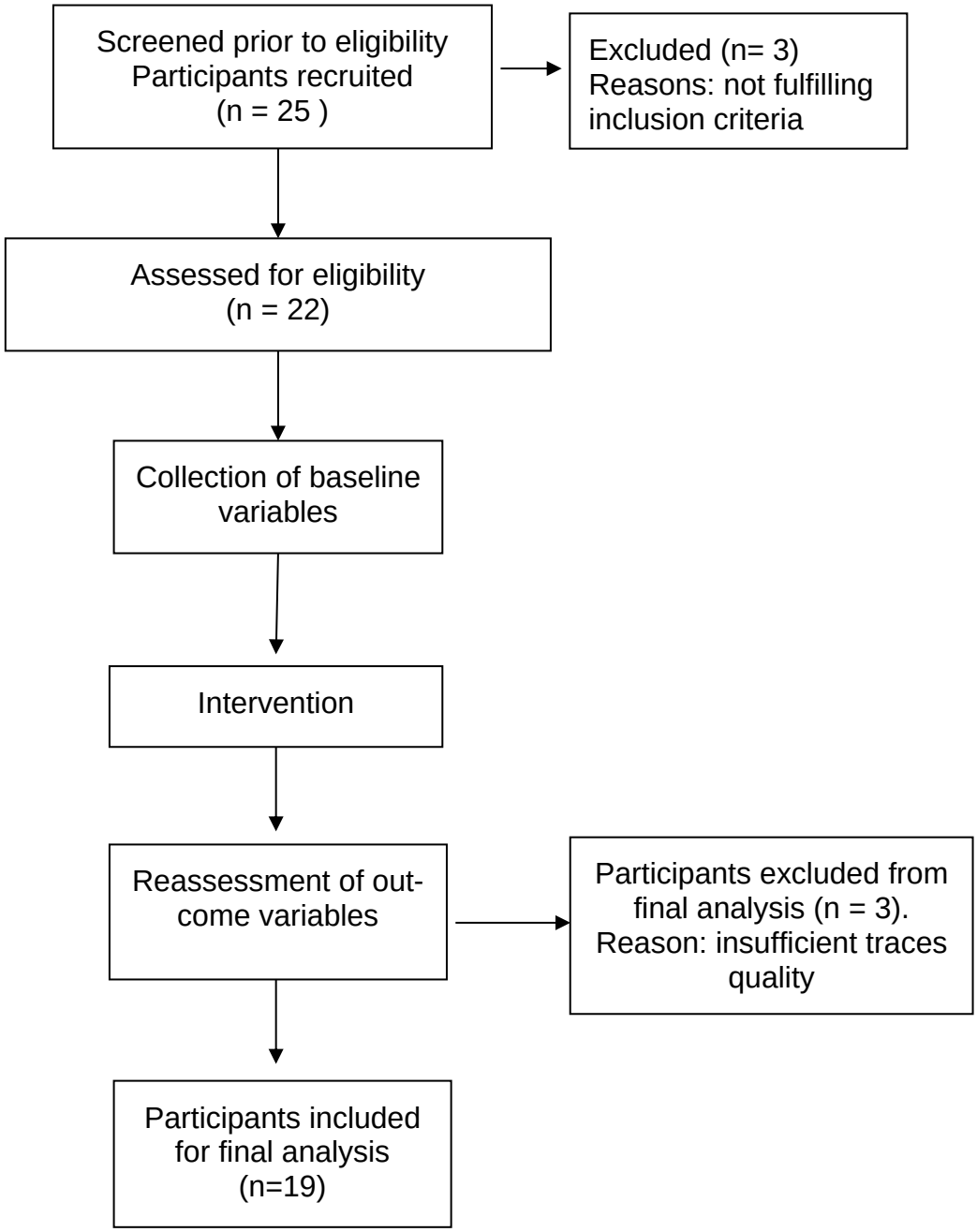

Figure 1 Flow chart of the study according to CONSORT 2010 (Eldridge et al., 2016)

Figure 2. Leg Stiffness in Submaximal (SM) hop task: Individual Responses in the before assessment and after assessment, mean value in black

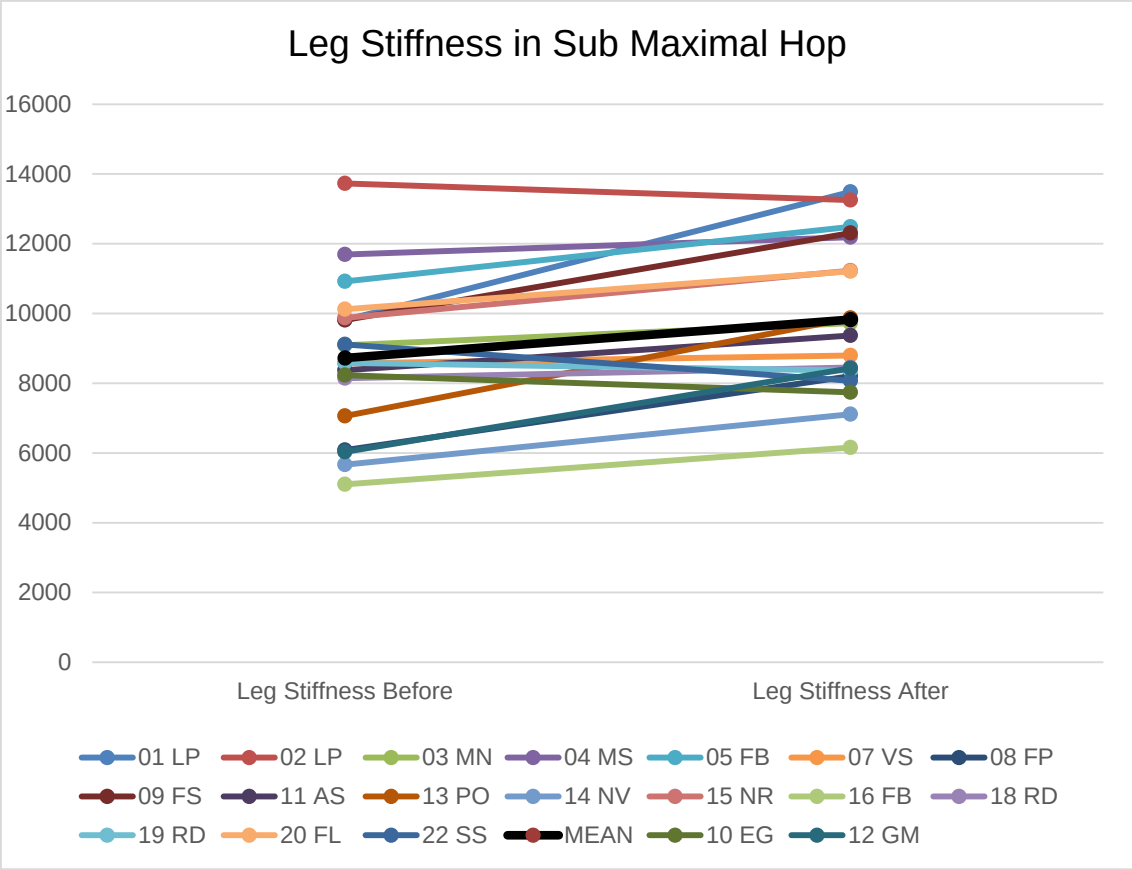

Figure 3. Changes in Leg Stiffness (LS) in Sub-Maximal (SM) and Maximal (M) hop tasks

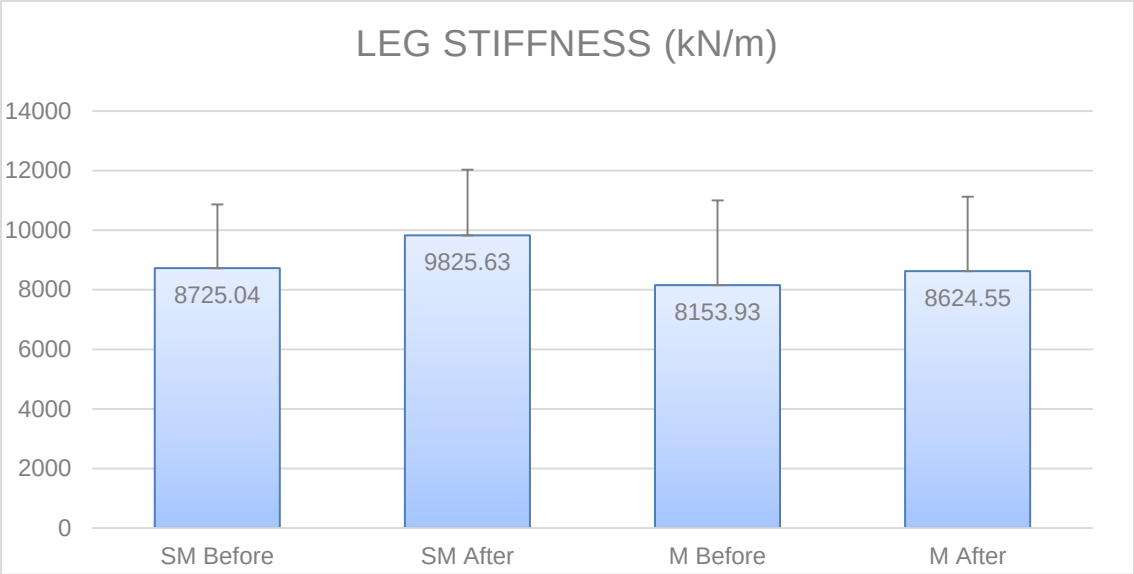

Figure 4. Leg Stiffness LS (kN/m) in Submaximal (SM) hop task: Individual Responses in the before assessment and after assessment, mean value in black

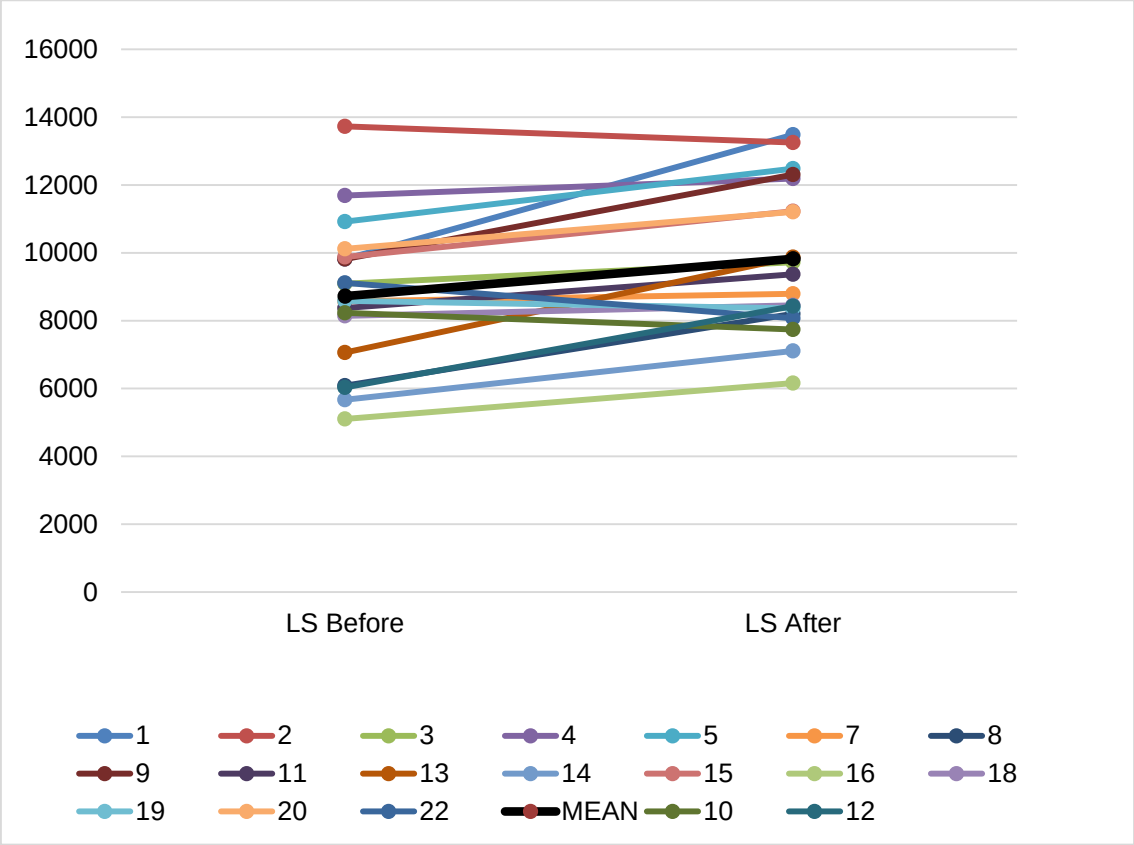

Figure 5a. Assessment Before and after: Pain Level (NPRS) during Sub-Maximal (SM) Hop Task. Mean Values in black

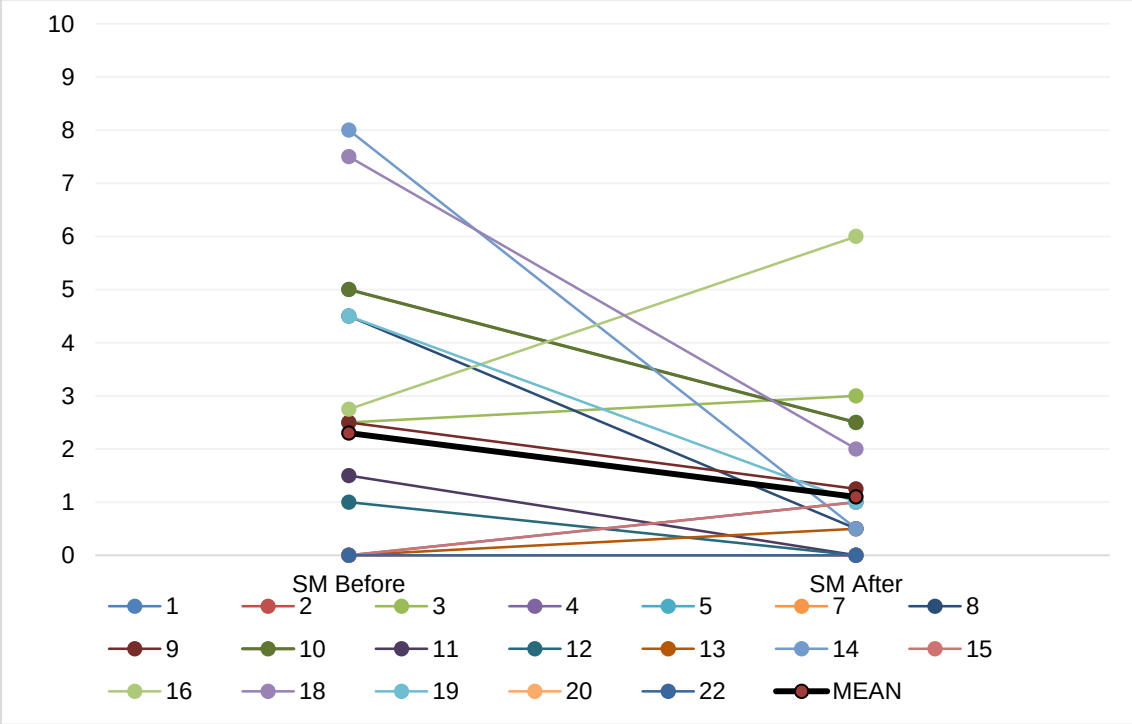

Table n. 1: Intervention description according to the Modified Consensus on Exercise Reporting Template (CERT) for Therapeutic Exercise Interventions (Page et al. 2017)

Exercise intervention: 45seconds x 5 repetitions of isometric contractions in ankle plantarflexion			
Item category	**Item n.**	**Abbreviated Description**	**Details**
What: materials	1	Smith Machine	In this study a machine MULTIPLA® Technogym was used. A similar tool from another brand can be used
Who: provider	2	Physiotherapist	In this study a physiotherapist followed each patient individually
How: delivery	3	Exercise individually performed	In this study a physiotherapist assisted each patient. Once trained, the patient can perform the exercise programme without supervision
	4	Exercise: supervised	In this study the exercise was supervised. However, the patient can perform this intervention unsupervised in a gym
	5	Measurement and reporting of adherence	Amount of load used: Kg RPE (rate of perceived exertion) VAS or NPRS
	6	Details of motivation strategies	A physiotherapist can verbally motivate the patient to keep the position requested using the following sentence: “Maintain as high as you can, hold it... hold it…hold it”
	7	Decision rules for the progression of the exercise	After each repetition, the physiotherapist asked the patient: “Do you want to maintain, increase or decrease the amount of weight?”
	8	Exercise description	Detailed instruction: the Smith machine is initially set at 50% of the patient’s bodyweight taking into consideration that the machine bar weights 9 kilograms. The patient is standing on two feet while unlocking the machine bar. Then the patient moves in maximal heel-raise position with both feet (full plantarflexion). When the patient feels ready, he/she goes back to the starting position where he/she maintains the affected leg almost fully in plan-

			tar-flexion and flexes the other leg at 90 degrees of hip flexion and 90 degrees of knee flexion. The patient maintains this position for 45 seconds. At the end of the 45 seconds the patient comes back to the standing position on two feet. After having repositioned the bar in the lock position he/she is allowed to move around during the 60-second rest period. Then the patients can decide to maintain, increase or decrease the load for the next repetition. The load is adjusted accordingly, and the same aforementioned procedure starts again. The patient repeats the exercise for 5 times with a 60-second rest period in between. At the end of each repetition the patient is asked about the pain and the rate of perceived exertion experienced.
	9	Non exercise component	The patient needs to be instructed on how to unlock the bar and how to reach the right position for the exercise
	10	How adverse events that occur during exercise are documented and managed	Pain during the exercise is monitored. Patients are instructed on the use of the machine and the correct position to be adopted
Where	11	Setting for the exercise	Rehabilitation centre or gym
When How much	12	Detailed description of the exercise	5 repetitions of 45 seconds of isometric contractions near full plantarflexion position The starting load is 50% of the bodyweight. After each repetition maintain, increase or decrease the amount of weight according to the patient's choice
Tailoring	13	Exercise is tailored to the individual	The patient starts with an amount of load calculated on his/her bodyweight. Each patient can manipulate the amount of weight during the following repetitions. The position is standardized at the patient's maximal plantarflexion.
	14	Content of any home	Not required for the study

		programme	
	15	Decision rules that determines the starting level of the exercise	The amount of load used is tailored to the patient's bodyweight. A standard initial load (50% bodyweight) was used to provide a sufficient training stimulus.
How well	16	Exercise is delivered and performed as planned	The effort during the isometric contractions needs to provide a sufficient training stimulus (usually quantified as RPE ≥6)

Table 2 Demographics and characteristics of the sample

	Sample n= 19	**Mean (SD)**
Gender	32% Female	
Affected limb	6 (L) 13(R)	
Dominance	6 (L) 13(R)	
Age		39.2 (11.2)
Weight (kg)		76.8 (13.4)
Height (cm)		177.3 (10.7)
Duration (months)		22.7 (28.4)
VISA-A score		55.8 (15.1)
IPAQ score		4008.4 (4314.2)

(SD) standard deviation, (L) left, (R) right, (VISA-A Score) Victorian Institute of Sports Assessment Achilles, (IPAQ) International physical activity questionnaire

Table 3 Data from the force platform in the before-after sub-maximal (SM) and maximal (M) hop task (mean value and ±SD)

HOP TASK	**Sub-Maximal (SM)**			**Maximal (M)**		
	Before	**After**	**Effect size**	**Before**	**After**	**Effect size**
Leg Stiff-ness (kN/m)	8725.04 (2139.93)	9825.63 (2208.46)	ES=0.87 **p≤0.001**	8153.93 (2845.18)	8624.55 (2500.11)	p=0.15
RSI (m/s)	0.17 (0.12)	0.24 (0.16)	p=0.17	0.67 (0.43)	0.73 (0.47)	p=0.45
Pain (NPRS)	2.35 (2.67)	1.12 (1.53)	ES=0.49 **p=0.047**	2.39 (2.26)	1.21 (1.57)	ES=0.58 **p=0.02**

Leg Stiffness (kN/m), RSI: Reactive Strength Index (m/s), Pain level (NPRS), Effect size (ES)

Table 4 Intervention: Pain during intervention ($NPRS_{iso}$), rate of perceived exertion (RPE), load applied (Kg), load normalized to bodyweight (% Kg/BW) were collected during the intervention. Exercise tolerability scores and willingness to use the intervention were recorded at the end of the intervention (mean value and ±SD).

$NPRS_{iso}$	**Pain change during the intervention ($\Delta NPRS_{iso}$)**	**RPE**	**Variation of RPE (Δ RPE)**	**Load (kg)**	**Load normalized to bodyweight (%bodyweight)**	**Variation of load application (Δ % bodyweight)**	**Exercise tolerability score**	**Willingness to adopt the intervention**
2.76 (2.63)	-1.26 (2.21) ES=0.57 **p=0.02**	5.85 (1.87)	1.42 (1.98) ES=0.72 **p=0.006**	37.5 (8.2)	48.7 (6.4)	-0.45 (19.0) p=0.96	6.3 (2.2)	17/17 Yes

Pain during intervention ($NPRS_{iso}$), rate of perceived exertion (RPE), load applied (Kg), load normalized to bodyweight (% Kg/BW) Pain during the intervention (Pain change during the intervention ($\Delta NPRS_{iso}$), Variation of RPE (Δ RPE), Variation of load application (Δ % bodyweight)