Isometric Contractions Are More Analgesic Than Isotonic Contractions for Patellar Tendon Pain: An In-Season Randomized Clinical Trial

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Objective: This study aimed to compare the immediate analgesic effects of 2 resistance programs in in-season athletes with patellar tendinopathy (PT). Resistance training is noninvasive, a principle stimulus for corticospinal and neuromuscular adaptation, and may be analgesic.

Design: Within-season randomized clinical trial. Data analysis was conducted blinded to group.

Setting: Subelite volleyball and basketball competitions.

Participants: Twenty jumping athletes aged more than 16 years, participating in games/trainings 3 times per week with clinically diagnosed PT.

Interventions: Two quadriceps resistance protocols were compared; (1) isometric leg extension holds at 60 degrees knee flexion (80% of their maximal voluntary isometric contraction) or (2) isotonic leg extension (at 80% of their 8 repetition maximum) 4 times per week for 4 weeks. Time under load and rest between sets was matched between groups.

Main Outcome Measures: (1) Pain (0-10 numerical rating score) during single leg decline squat (SLDS), measured preintervention and postintervention sessions. (2) VISA-P, a questionnaire about tendon pain and function, completed at baseline and after 4 weeks.

Results: Twenty athletes with PT (18 men, mean 22.5 ± 4.7 years) participated (isotonic n = 10, isometric n = 10). Baseline median SLDS pain was 5/10 for both groups (isotonic range 1-8, isometric range 2-8). Isometric contractions produced significantly greater immediate analgesia ($P < 0.002$). Week one analgesic response positively correlated with improvements in VISA-P at 4 weeks ($r^2 = 0.64$).

Conclusions: Both protocols appear efficacious for in-season athletes to reduce pain, however, isometric contractions demonstrated significantly greater immediate analgesia throughout the 4-week trial. Greater analgesia may increase the ability to load or perform.

Key Words: isometric, isotonic, resistance training, analgesia, in-season, patellar tendinopathy, exercise

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INTRODUCTION

Patellar tendon pain can be debilitating and cause attrition from physical activity[1] #237. However, athletes can often continue to play with tendon pain yet at reduced training volumes or frequency to prioritize participation in games/competition. Performance might be compromised in people with chronic or recurrent pain because of physical deficits associated with tendinopathy[2] #6699[3]; #9, excessive cognitive demand associated with pain[4] #8505, decreased cognitive resources[5] #8651, or disrupted spatial and motor representations associated with evaluation of ongoing threat (see[6] #98[3]; #9 for relevant reviews). Thus, it is important to investigate methods of reducing tendon pain in-season that allow the athlete to fulfill their playing and training commitments.

Exercise-based treatments are but one type of the many available treatments for tendinopathy. Other options include injection therapies[7] #8652[8]; #8653, extracorporeal shockwave therapy[9] #8654[10]; #8507, surgery[11] #8656[12]; #376, and many other treatments that are not without risk and often come at great expense. Furthermore, invasive interventions are frequently based on animal models of induced tendon injury that may not replicate the pathoaetiology of human load–based tendinopathy (i.e., collagenase injections[13] #8643) nor do they have long-term data on their efficacy. Finally, and importantly, athletes are often reluctant to follow advice to have downtime after such interventions, which means they either have the treatment but not the downtime, or decline the treatment altogether.

Tendon load through exercise is the only stimulus that positively affects the tendon matrix[14] #8657 and has been shown to reduce pain perception and improve function over

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time[15] #6118. There are a number of variably efficacious exercise programs for tendinopathy[16] #2772[17]; #4; however, few studies have compared the effect of different exercise regimes on immediate analgesia. Immediate improvement in symptoms throughout an exercise-based rehabilitation program may lead to better adherence or improved performance.

Several studies have evaluated eccentric exercise in patellar tendinopathy (PT) with clinical outcomes. It has been shown that eccentric exercise increased pain in the first 2 to 4 weeks[18] #1186. Investigations of eccentric exercise in-season have either shown no benefit[19] #198 or worse outcomes[20] #195. Given that eccentric exercise is poorly tolerated by the in-season athlete, other muscle contraction protocols warrant investigation.

One study has directly compared isotonic contractions (heavy slow resistance) with isolated eccentric exercise. Isotonic contractions were as effective as eccentric only exercise in PT and with higher patient satisfaction over time[21] #6066. The immediate effect (either increase or decrease in tendon pain) was not reported. Athletes in that study remained active if their pain was less than 3/10 on a numerical rating scale (NRS) and activity levels were not significantly different from baseline, thus findings may not be applicable to the in-season environment. Rio et al, (2015) reported that isometric contractions demonstrated superior pain relief in terms of immediate effect on single leg decline squat (SLDS) pain lasting at least 45 minutes and without a decline in muscle performance.[44] However, this was a single intervention and the cumulative effect of the intervention in-season is unknown. Neither isometric nor isotonic contractions resulted in an increase in pain in the Rio et al, (2014) study, thus these contraction types may be better tolerated than eccentric contractions in an in-season trial.[44]

There are clear benefits to inducing immediate analgesia without muscle fatigue in a sporting environment. Athletes may choose to complete the protocol immediately before training or competition, which could result in continued and/or greater participation in competitive sport. Therefore, the primary aim of this study was to compare the immediate effect of resistance training that involved either isometric or isotonic muscle contractions on patellar tendon pain during a 4-week competitive season in jumping athletes. It was hypothesized that isometric muscle contractions would provide greater immediate analgesia than isotonic contractions. The secondary aim of the study was to compare the effect of isometric and isotonic contractions on pain and function as measured by the VISA-P after 4 weeks. It was hypothesized that both groups would improve more than the minimum clinically important difference (MCID) after 4 weeks.

METHOD

This randomized clinical trial over 4 weeks had 2 intervention arms, either isometric or isotonic quadriceps muscle contractions. Twenty-nine male and female volleyball and basketball athletes aged more than 16 years were recruited from subelite and elite competitions. The study was approved by the Monash University Human Research Ethics Committee, Australia (CF12/0230—2012000067). This trial was registered in the Australian New Zealand Clinical Trial Registry (ACTRN12613000871741) and all athletes provided written informed consent. These data formed part of larger trial (van Ark et al, 2016).[45]

Clinical diagnosis of PT was defined as pain localized to the inferior pole of the patella during jumping and landing activities and during testing on the SLDS, a reliable patellar tendon pain provocation test[22] #1173,[23]; #8626. The diagnosis was confirmed by the presence of characteristic features on ultrasound imaging (eg, hypoechoic area and/or tendon thickening). Exclusion criteria were the existence of other knee pathology, previous patellar tendon rupture, previous patellar tendon surgery, inflammatory disorders, metabolic bone diseases, and type II diabetes, use of fluroquinolones or corticosteroids in the last 12 months, known familial hypercholesterolemia and fibromyalgia.

Baseline Testing

Participant height (cm) (Seca 213, Birmingham, West Midlands UK) and weight (kg) were recorded (Omron HN283 Port Melbourne, Victoria, Australia) without footwear. Measurements were recorded 3 times and the mean was recorded if there was any variability. VISA-P, a questionnaire about patellar tendon pain and athletic function were completed where a score of 100 represents full pain-free function[24] #236. Baseline maximal voluntary isometric contraction was tested and recorded for participants randomized to the isometric group. Eight repetition maximum was tested for isotonic group. This provided the starting weight for week 1. All testing was completed on the same leg extension machine that each individual participant used for the duration of the trial.

Randomization Procedure

Randomization was completed using the random number generator function (Excel 2007, Redmond, WA) and concealed inside an unmarked, individual opaque envelope[25] #7789. Participants selected a small envelope from a larger opaque, unmarked envelope that contained the code for the groups.

Intervention

Investigators determined the starting weights in the first session as described above. This session also demonstrated the intervention and the exercise diary. The exercise diary recorded the weight completed for each session and the preexercise and postexercise pain scores. This was a NRS from zero to 10 while completing 1 single repetition on the SLDS for each leg.

Both protocols were completed on a leg extension machine (Table 1). The leg extension machine was chosen as a way of isolating the quadriceps muscle group without pain (Rio et al, 2015).[44] Because muscle work during isometric and isotonic muscle contractions cannot be directly measured, protocols were matched for ratings of perceived exertion during pilot studies. All participants were provided with an auditory recording, which also served to pace participants and match time under tension and rest periods. The recovery length of 1 minute was chosen to allow muscle recovery[26] #33. Athletes were requested to avoid other quadriceps exercises during the 4 weeks but were free to complete all other gym, training, and competition.

TABLE 1. Isometric and Isotonic Muscle Contraction Protocols Used in the Study

	Isotonic	Isometric
Parameters	4 × 8 @ 80% 8RM	5 × 45 second holds @ 80%MVIC
	Seven seconds per repetition: 4-second eccentric phase immediately followed by a 3-second concentric phase	
Recovery	One minute between sets	One minute between sets
Knee joint angle	Through a chosen, comfortable range of motion between 10 and 90 degrees	60 degrees flexion
External pacing	Audible recording with metronome set at 1 Hz and verbal instructions to retain attention to task	Audible recording including metronome set at 1 Hz and verbal instructions to retain attention to task
Progression	2.5% progressive overload weekly if able	2.5% progressive overload weekly if able

8 RM, eight repetitions maximum; MVIC, maximal voluntary isometric contraction.

A researcher contacted each participant weekly and weight was increased by 2.5% if all sessions were completed at the previous weight and if the athlete felt they could increase the weight. Otherwise, the weight was maintained for a further week. Participants were instructed to lower the weight on the machine for the next repetition if they were not able to complete their repetitions (for example owing to fatigue-induced muscle shaking). Therefore, they still complete the entire session so that there was equal time under tension.

Follow-up

At the end of 4 weeks, participants completed a VISA-P and returned their completed exercise diaries.

Outcome Measures

The primary outcome measure for the study was the difference in pain during a SLDS before and after every intervention session. Secondary outcome measure was the VISA-P completed at baseline and 4 weeks, a change in score of more than 13 has been shown to be the MCID for the VISA-P[27] #638.

Data and Statistical Analysis

For those athletes with bilateral symptoms, the side that they reported the highest NRS on the SLDS at baseline training was chosen for analysis. If this was equal, the limb was chosen at random. Change in pre-NRS and post-NRS pain scores were calculated by subtracting the prescore from the postscore for every session. If the data did not satisfy assumptions of parametric statistical tests, then the equivalent nonparametric analysis was used. Starting weights were recorded and mean and SD is presented. For those participants who returned their diaries but missed sessions, the last observation carried forward (LOCF) method was applied. Athletes who were randomized but did not complete any sessions were excluded from analysis[28] #8642. Intention to treat analysis was performed for athletes who failed to return their booklets but were known to complete at least 1 session; they were allocated a pre-NRS score of 5 and a post-NRS score of 5 so that the change score was zero. This conservative option was selected to avoid overestimating the effect using the group median[28] #8642. Area under the curve was used to measure exposure, in this case analgesia from the intervention training. A correlation was performed between the response in week 1 and the final VISA-P change score to identify potential responders to in-season training. Significance was set at $\alpha = 0.05$.

RESULTS

Twenty-nine athletes were randomized to the study, 7 athletes did not complete any of the intervention sessions because they were unable to be contacted by the researchers after randomization. Two athletes dropped out during the intervention period, 1 for personal reasons and the other for an unrelated injury (both prevented basketball participation). Both were excluded from analysis because they were no longer playing/training 3 times per week. Twenty athletes were included in the analysis,10in each group. One athlete in the isotonic group and 2 athletes in the isometric group did not return their booklet and were therefore allocated a change score of zero for the duration of the intervention period. The groups did not differ at baseline for measures of tendon pain and function (SLDS and VISA-P) and starting load (Table 2). Athletes in both groups continued to play and train 3 times per week, with no athlete missing any games or team training sessions because of tendon pain. Data were not normally distributed and nonparametric analysis was used.

Reduction in pain between premeasures and postmeasures of every intervention session was greater for the isometric group (mean ± SD change = 1.8 ± 0.39) than it was for the isotonic group (0.9 ± 0.25, Cohens $d = 2.75$, $P < 0.001$; Figure 1). This corresponded to a greater volume of area under the curve that is increased analgesia in the isometric group (AUC isometric 26.00, isotonic 14.23).

Both groups improved their VISA-P over the 4 weeks, and there were no significant differences between groups at follow-up ($P = 0.99$). There was variability in the response including 2 athletes whose VISA-P score was worse in the isotonic group and 2 whose scores did not change (one in each group) (Figure 2). Neither group median was greater than the MCID, the isotonic group score change was 10.5

TABLE 2. Baseline Comparison of the Intervention Groups

	Isotonic, N = 10	Isometric, N = 10
Bilateral symptoms, sex	N = 5, N = 9 men	N = 3, N = 9 men
SLDS (median + range)	5/10 (1-8)	5/10 (2-8)
VISA-P (0-100) median + range	69.5 (46-83)	72.5 (13-88)
Starting weight (mean ± SD), kg	29.5 ± 9.88	29.5 ± 9.59

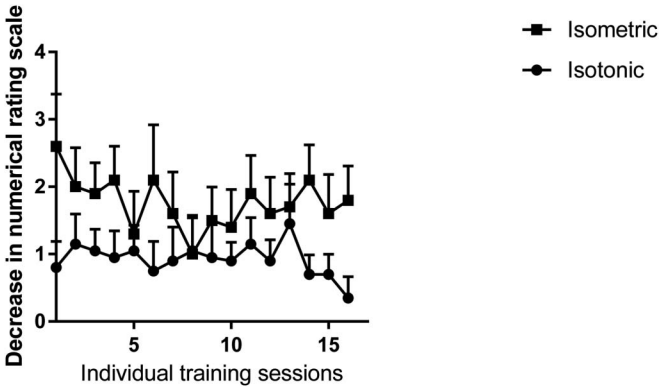

FIGURE 1. Mean ± SEM decrease in pain between premeasures and postmeasures for the isotonic group (circles) and isometric group (squares) for each training session.

points, and the isometric group change was 11.5 points. The median VISA-P in both groups was greater than 80/100 at the end of the 4-week intervention (isotonic group 80/100, range 60-94, and isometric group 84/100, range 41-100). Five athletes out of 10 in the isotonic group achieved greater than 80/100 and 7 athletes out of 10 achieved greater than 80/100 at the end of 4 weeks.

There was a moderate positive correlation between the mean change in NRS in week 1 and the change in VISA-P score ($r^2 = 0.64$). Approximately, 60% of the variance in the VISA-P change from baseline to follow-up was explained by the analgesic response to exercise in week 1.

The starting weight for participants was mean 29.5 ± 9.6 kg in the isometric group and 29.5 ± 9.9 kg in the isotonic group. The weight increase was modest over 4 weeks; 0.9 ± 3.5 kg for the isometric group, and 1.45 ± 1.7 kg for the isotonic group. If athletes had progressed according to the 2.5% increase, the overall increase would have been at least 3 kg for both groups over the 4 weeks.

DISCUSSION

Isometric muscle contractions resulted in significantly greater immediate analgesia than isotonic muscle contractions in a 4-week trial while athletes were playing and training. There are potential benefits to the increased immediate pain relief demonstrated by isometric exercise. First, less pain may lead to higher activity intensity or participation in more training sessions. It is also possible that athletes may spend less time in pain over the course of the week, particularly in light of previous research demonstrating at least a 45-minute effect associated with isometric but not isotonic exercise (Rio, 2015 #9161).[44] There are several additional benefits to reducing evoked pain with resistance training, including removing fear of exercise,[29] #8644, improved self efficacy in that they can modulate their own pain (and this is analgesic in itself)[30] #8646, and an improved sense of control, as anxiety, closely linked to low sense of control, has differential and synergistic effects on pain[31] #8647. Moreover, the contextual cues associated with "active" analgesia imply recovery, health, and capacity, whereas the contextual cues associated with "passive" analgesia, such as ice, imply tissue damage and inflammation. Such cues are potentially powerful modulators of subsequent behavioral choices (e.g., increased participation in rehabilitation), as well as pain (see [Moseley, 2015 #9169] for relevant review). Finally, active analgesia stands to offer benefits at a tissue level, for example, to the quadriceps muscle architecture[32] #8645, tendon properties[33] #4568, and cortical drive to the quadriceps[34] #5966.

The antinociceptive effect of motor activation may be explained by several potential centrally mediated mechanisms. Motor centers have direct projections to the dorsal horn[35] #8667 and also to midbrain centers that are themselves powerful generators of descending inhibition. Completing maximal or near maximal effort without tissue damage reinforces positive effects[36] #8596. Furthermore, fatiguing tasks that require effort and demand attention compete with pain to influence the output generator[37] #8648[38]; #8650. However, these mechanisms may

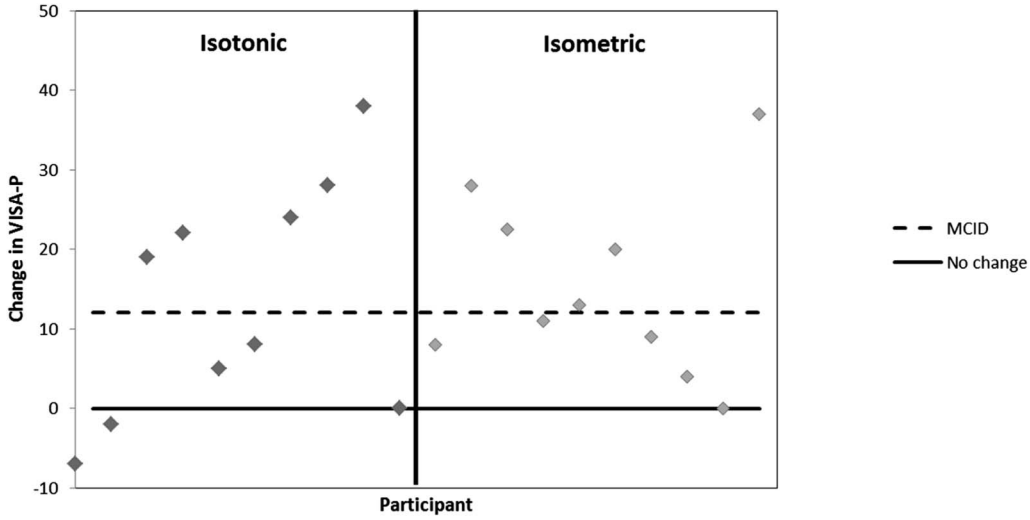

FIGURE 2. Change in VISA-P score after 4-week intervention.

not explain the differences between isometric and isotonic muscle contractions as both protocols required fatiguing motor activation with cognitive demand. Therefore, they may also be differences in the local tissue response to the 2 types of contractions (such as nociceptive receptor stimulation or change to the biochemical environment) and/or unique differences in the cortical activation pattern between isometric and isotonic muscle contractions. Previous studies have reported a hypoalgesic effect of exercise depending on the type; aerobic exercise reduced perception of experimentally induced pain in healthy people (effect size for threshold $d = 0.41$, intensity $d = 0.59$), dynamic/isotonic exercise (threshold $d = 0.83$, intensity $d = 0.75$) and isometric exercise (threshold $d = 1.02$, intensity $d = 0.72$),[39] #8668.

After 4 weeks, there were no differences between groups in the VISA-P and neither group median was greater than the MCID (a change score of 13 or 15.4% of their original score). The VISA-P is a robust measure and is not traditionally repeated in clinical practice or in research after only 4 weeks. Ten athletes (5 in each group) improved more than 13 points, and 12 athletes scored more than 80 on their VISA-P at follow-up (5 in the isotonic group and 7 in the isometric group) demonstrating variability in response. A VISA-P score of less than 80 is considered to represent tendon pain that is causing impairment and reduced function[24] #236 indicating an important clinical shift in about half of the participants here in not just pain but also function.

An increase in analgesia in the first 4 sessions (week 1) was positively correlated with a greater increase in the VISA-P after 4 weeks. Early response to either intervention explained approximately 60% in the variance of the final VISA-P score. Our objective here was not to compare the 2 approaches for their long-term effects on VISA-P score, and we were underpowered to add another primary hypothesis, but this relationship between short-term analgesia and long-term VISA-P score suggests that it may be possible to identify after a single session those athletes most likely to respond to in-season training of the kind used here.

Athletes with bilateral symptoms were included in this study to maximize participant numbers[21] #6066. Bilateral symptoms are common in PT and thus including those with either unilateral or bilateral symptoms is representative of the active population with PT (Lian, 2005 #635).[43] Studies examining jumping ability and performance have not investigated a difference in those with unilateral or bilateral symptoms (Lian, 2003 #8756; Lian, 1996 #9146)[41,42] and numbers were too small to enable any comparison between those with unilateral and those with bilateral symptoms within groups. Future studies should aim to maximize participant numbers and investigate potential differences in responses of these subgroups.

The 2 athletes who scored lower in the VISA-P at the end of the intervention in the isotonic group reported pain reduction throughout the intervention in their preexercise and postexercise scores. These results are difficult to reconcile and future studies may consider inclusion of qualitative data to better identify individual factors that lead to a positive outcome.

This pragmatic randomized clinical trial demonstrated that both isometric and isotonic exercise were well tolerated in the in-season athlete. Both protocols seem to be efficacious in-season in contrast with previous studies investigating eccentric exercise[20] #11,[19] #198. Athletes did not miss any game or training sessions because of tendon pain, which is important as training sessions are sometimes sacrificed to prioritize games even at the subelite and elite levels.

The weight increase for both groups was small and half of what was calculated based on a 2.5% weekly increase. The projected increase was based on hypertrophy studies and may not be possible on top of in-season loads or in a cohort with musculoskeletal pain. Alternatively, supervision of sessions actually may have assisted weight progression, because heavy load has been shown to be important in reducing tendon pain perception (Rio, 2015 #9161).[44] It is possible that athletes were fearful of overload and too conservative. The most plausible explanation is that increments on the leg extension machines were more than 2.5%, thus the next increment was too great and in many cases it was difficult to find small appropriate weights.

This study had multiple strengths that provide immediate clinical utility. First, it was an in-season intervention (when tendon pain is highest) that was specifically aimed at providing analgesia. Second, it was a short-term study, and this may have improved adherence, although adherence is likely to be high with an intervention that reduces pain. Athletes could choose when to complete the intervention, thus making it convenient. They could also then use the analgesia at a time they considered most beneficial and that may be before games and/or after games. Third, it was a pragmatic trial, it reflects real life where training loads and game volume were uncontrolled; for example, volleyball matches can be up to 5 sets but may only be 3.

This study had limitations, most importantly the missing exercise booklets from athletes. Using a zero change score is conservative because the median change score of both groups was positive. This approach can dilute the effect size, whereas using the group median may inflate the effect size. Importantly, these athletes were not drop outs (in which case it may be considered that they dropped out because of a negative effect). The VISA-P score for the athlete in the isotonic group was unchanged (so perhaps using a change score of zero is appropriate) but the 2 athletes in the isometric group for whom LOCF was used, VISA-P changed by 4 and 13 points, thus using a change score of zero may not reflect their analgesic response. The 2 athletes who dropped out during the trial were also excluded because they were no longer playing/training 3 times per week, and therefore scores may artificially improve because of reduced tendon load.

Because this was a pragmatic trial, there was no supervision of sessions and thus may not have all been completed. As athletes chose when to complete the intervention sessions, it was not feasible to provide supervision. Athletes were reporting consistent pain reduction with the protocols (in both groups), therefore it is expected that adherence was high (as it was beneficial) and that the exercise diaries were completed accurately. Future studies of this nature should record how long the analgesia lasted, although it is also important to minimize participant burden especially when conducting in-season research.

A control group was not included because natural history of PT does improve during a season[19] #198 and can

last for years (Ferretti, 1985 #8525).[40] Furthermore, because these were in-season athletes with pain competing at the elite and subelite level, we considered a sham to be unethical. We investigated 2 types of muscle contractions because no previous study had found a positive result for any active in-season intervention leaving clinicians without in-season rehabilitation guidelines.

Athletes were requested to remove other quadriceps exercises from their training for 4 weeks. This was due to 2 factors. First, as part of this study, corticospinal responses were recorded from a subset of the population and other quadriceps training would have impacted on those results. Second, it is a clinical observation that many of the other quadriceps exercises that people complete are actually provocative for patellar tendon pain, such as lunges where the knee is forward of the ankle. Therefore, it was preferable to reduce nociceptive drive where possible by limiting these and evaluating the effect of one nonprovocative quadriceps exercise. It is possible athletes continued quadriceps exercises and did not inform researchers.

The audio file was provided to externally pace and counters the potential variability in the way the exercises were completed, but it is not known if this was used by all athletes for every session. The same results may not have been observed without the use of the auditory pacing because this has been shown to be important for modifying both corticospinal excitability and inhibition (Leung et al, *in press*) and these processes may underpin the results observed. Future studies should consider recording when the athletes completed the protocol in relation to pre/post training or games or on rest days. This would provide more information about when the timing of such interventions has the greatest benefit.

Ethical Considerations

Only active interventions were offered because these were elite and subelite athletes, in pain in-season, and thus it was considered unethical to offer a sham intervention.

In conclusion, isometric and isotonic protocols have a role in the in-season athlete and that individualized clinical decision making could further enhance athlete response. This is not possible in an randomized clinical trial. This study however provides clinicians with 2 potential options in athletes with PT in-season without fear of increasing tendon pain. Pragmatically, clinicians can select the protocol that provided more pain relief as this is likely to be preferable for the athlete, and these data would support the use of isometric exercise in that instance. Week 1 NRS response also seems to be correlated with VISA-P change at 4 weeks. Exercise-based analgesia could be used to reduce pain after high intensity sessions or before games/trainings. Future studies should attempt to record load beyond participation to determine whether increased pain relief allows athletes to load more and if this has positive or negative ramifications.

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