FL SEVIER

Full length article

Contents lists available at ScienceDirect

Gait & Posture



journal homepage: www.elsevier.com/locate/gaitpost

The effects of McConnell patellofemoral joint and tibial internal rotation limitation taping techniques in people with Patellofemoral pain syndrome



A.M. Clifford^{a,*}, S. Dillon^b, K. Hartigan^c, H. O'Leary^d, M. Constantinou^e

^a School of Allied Health and Health Research Institute, University of Limerick, Limerick, Ireland

^b School of Health and Human Performance, Dublin City University, Dublin 9, Ireland

^c School of Allied Health, University of Limerick, Limerick, Ireland

^d Physiotherapy Department, University Hospital Kerry, Kerry, Ireland

e School of Allied Health, Faculty of Health Sciences, Australian Catholic University, Brisbane, Queensland, Australia

ARTICLE INFO

Keywords: Anterior knee pain Rehabilitation Kinematics Taping Patellofemoral

ABSTRACT

Background: Taping is frequently used as part of the multi-modal management for patellofemoral pain syndrome (PFPS). McConnell Patellofemoral Joint Taping (PFJT) and Tibial Internal Rotation Limitation Taping (TIRLT) are proposed to be useful adjuncts to the management of PFPS. However, it is unclear if TIRLT offers similar benefits to PFJT, and its effect on pain and lower limb kinematics have not been investigated previously. *Research question:* What are the effects of TIRLT, PFJT and no taping on perceived pain and lower limb kinematics during a lunge and single leg squat (SLS) in people with PFPS?

Methods: This cross-sectional study compared the effects of TIRLT, PFJT and no taping, on knee pain and lower limb kinematics during two pain-provoking movements in people with PFPS. Participants with PFPS (n = 23) performed a lunge and SLS under three randomised conditions: TIRLT, PFJT and no taping. The Codamotion system captured and analysed lower limb kinematic data in the sagittal, transverse and coronal planes. Peak knee pain intensity during the movement was assessed using the Numerical Rating Scale (NRS).

Results: Participants reported significantly less pain with the TIRLT and PFJT techniques compared with no tape during the lunge (p = 0.005 and p = 0.011, respectively) and SLS (p = 0.002 and p = 0.001, respectively). There was no evidence of altered lower limb kinematics accompanying pain reductions with either taping technique. *Significance*: Both forms of taping may be useful adjuncts as the short-term benefit of pain relief may enable participation in more active forms of rehabilitation.

1. Introduction

Patellofemoral pain syndrome (PFPS) is a common musculoskeletal condition with an annual prevalence of 22.7 % [1]. It is characterised by anterior knee pain and/or pain in the retropatellar and/or peripatellar region that typically increases with flexion-related activities such as squatting, kneeling, stair climbing and after prolonged sitting [2]. The underlying causes of PFPS are multifactorial and may be associated with biomechanical and or neurophysiological changes at the pelvis, hip, knee or ankle regions [48]. Numerous factors including a larger quadriceps (Q) angle [3], dynamic knee valgus [4], increased rear-foot eversion on heel strike [5] have been linked to the aetiology of PFPS. Additionally, altered activation of the vastus lateralis (VL) and vastus medialis oblique (VMO) muscles [6], reduced hip abduction strength

and deficits in knee extension strength have been observed in people with PFPS compared to healthy controls [7].

Systematic reviews and consensus statements have indicated that effective management of PFPS requires an individually tailored and multimodal approach, with taping suggested to be potentially useful as an adjunct to other rehabilitation and exercise interventions [8–10]. According to expert opinion, taping can have value in early management to gain patient trust and facilitate active engagement in the prescribed rehabilitation programme [8], though approaches to taping in research vary and evidence has been inconsistent [11].

Various taping protocols exist for the management of PFPS, which largely aim to normalise the altered lower limb biomechanics that are thought to cause PFPS [12,13]. The McConnell Patellofemoral Joint Taping (PFJT) technique [14] is a popular method of taping that is

https://doi.org/10.1016/j.gaitpost.2020.09.010

Received 21 May 2019; Received in revised form 31 August 2020; Accepted 3 September 2020 Available online 15 September 2020

0966-6362/© 2020 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

^{*} Corresponding author. E-mail address: Amanda.clifford@ul.ie (A.M. Clifford).

proposed to correct the excessive lateral glide, tilt and rotation of the patella, commonly observed among people with PFPS [13]. Evidence supports the effectiveness of PFJT in providing short-term pain relief in people with PFPS during a range of functional activities [15]. The McConnell PFJT technique has been shown to move the patella inferiorly within the femoral groove, which may increase the patellofemoral contact area [16]. Redistribution of the load over a larger area is thought to decrease contact stress with a consequent improvement of symptoms. However, this only addresses one potential cause of PFPS, patellar tilt, which may explain why a proportion of individuals are not responsive to this method of taping [45]. It is postulated that targeting other commonly reported biomechanical changes associated with PFPS may provide relief of symptoms for individuals with patellofemoral pain.

According to the 3rd Patellofemoral Pain Consensus Statement changes in lower limb mechanics including tibial rotation can influence PFPS [10]. Evidence suggests that increased internal rotation of the tibia, coupled with greater rear-foot eversion and subtalar pronation are observed in subjects with PFPS [5,17,18]. Indeed research has identified greater shank internal rotation among runners with PFPS compared to controls [46]. Pronation is commonly targeted in treatment plans [19,9] using foot orthoses to alter biomechanics distally by modifying the position of the foot [5] and subsequently reducing excessive tibial internal rotation. An alternate way of limiting excessive internal rotation of the tibia and any associated dynamic knee valgus is the Tibial Internal Rotation Limitation Taping (TIRLT) technique [14], which is a spiral taping technique that utilises a mobilisation with movement principle to reduce excessive internal tibial rotation to a more neutral position [47]. TIRLT proposes to use a proximal solution, by facilitating a more neutral, less internally rotated tibial position at the knee joint [14]. As such, by addressing the biomechanical factors relating to PFPS in a novel manner, TIRLT may offer a new and potentially alternative taping technique to the popular PFJT method. To the authors knowledge, no published literature has evaluated the effectiveness of the TIRLT technique in patients with PFPS, compared to the widely used PFJT method. Thus, it is not clear how this method compares to PFJT with respect to alterations in joint kinematics and pain reduction in people with PFPS. There is also a paucity of published evidence investigating the effect of taping on lower limb kinematics during the lunge, a movement frequently used as an objective marker of strength and motor control deficits and prescribed as part of PFPS rehabilitation programmes [20, 21]. Therefore, this study proposes to investigate the effects of taping on the lunge and single leg squat (SLS) on both pain levels and lower limb kinematics.

The aim of this study was to compare the immediate effects of the TIRLT taping, PFJT and no taping on perceived pain levels during a lunge and SLS among people with PFPS. A secondary aim was to compare the effect of the TIRLT technique, PFJT and no taping on lower limb range of motion (ROM) in the sagittal, transverse and coronal planes during the lunge and SLS in this sample.

2. Materials and methods

2.1. Study design

This ethically approved study (ethics number 2015_05_34_EHS) was a cross-sectional experimental design performed during a single testing session.

2.2. Participants

Twenty-three volunteers 18 years and older from the staff and student population of the University were recruited via email. Volunteers were deemed eligible if they had unilateral or bilateral anterior or peripatellar/retropatellar pain of gradual onset, ongoing for a minimum of three months, that was aggravated by at least two of the following: prolonged sitting, squatting, stair climbing, kneeling, and running or hopping/jumping. [22]. The following exclusion criteria were screened for via pre-testing questionnaire: a history of traumatic, inflammatory or infectious pathology in the lower extremity, a history of dislocation or subluxation of the knee joint, previous surgery of the knee, hip or ankle joint, signs of secondary osteoarthritis in the knee joint. An inability to perform a lunge/squat or an allergy to tape also resulted in participant exclusion [22]. All participants attended a movement analysis laboratory at the University for a single one-hour testing session. Prior to testing, all subjects were screened for eligibility and provided informed written consent to participate.

2.3. Measures

Joint kinematics were recoded using the Cartesian Optoelectronic Dynamic Anthropometer (Codamotion) analysis system mpx64 (Charnwood Dynamics Ltd., Leicestershire, UK). The Codamotion system is a widely used instrument that has proven reliable in research settings to capture the three-dimensional (3D) motion of each participant's test limb and measure sagittal, transverse and coronal plane ROM [23]. The Codamotion system captured infrared light signals emitted by 22 diodes within a marker box. Each marker was placed on specific anatomical landmarks on the participants' pelvis and lower limb using wands and double-sided adhesive tape in accordance with the manufacturer's guidelines and published protocols [24] by two researchers trained in this process. Researchers were final year physiotherapy students, who had received training in three-dimensional motion analysis by a postdoctoral researcher who had five years' experience using the system and set-up in a number of previous studies. Familiarization with marker application and system set-up and five pilot practice trials of the study protocol were completed prior to testing and trial data acquisition.

Data was recorded at a sampling rate of 200 Hz for the duration of each test movement performed. Range of motion at the hip knee and ankle on the sagittal, coronal and transverse planes were reported for each participant during each of the movement tasks under the different taping conditions. Range of motion from the initiation of each movement task from an upright standing position to the return to the start position was recorded and was defined as the maximum less the minimum angle based on previous research [25].

The Numerical Rating Scale (NRS) was used to categorise respondents perceived pain intensity on an 11-point scale, with the severity of pain increasing from no pain (0) to 'the worst pain imaginable' (10). The NRS has been validated for a number of chronic musculoskeletal disorders [26], and has been used among people with anterior knee pain in various research settings [24].

2.4. Procedure

Demographic data were collected via questionnaire and anthropometric data were collected in accordance with guidelines [27]. If symptoms were bilateral, the most provocative knee was chosen. The order of taping and test movements were randomly allocated using sealed envelopes selected by the participant. Three trial conditions were used: no taping, PFJT and TIRLT techniques. Under each of the three randomised taping conditions participants performed a lunge and SLS (order also randomised). With the taping (if applicable) and markers in situ, subjects stood barefoot between two infra-red cameras. For the lunge, participants began the movement with their arms across their chest and lunged forwards leading with the index knee as far as was comfortable before returning to the starting position (Fig. 1). To perform the SLS, participants were asked to squat down on the affected limb as far as comfortably possible and return to the start position in one continuous movement (Fig. 2). Participants were requested to rate their peak pain during the provocative movement using the NRS. To limit risk of aggravating symptoms pain, scores in excess of seven resulted in the cessation of the trial. To minimize the risk of excessive symptom irritation and fatigue, following demonstration and practise only one lunge



Fig. 1. The Codamotion system set-up during a lunge trial.



Fig. 2. The Codamotion system set-up during a single leg squat trial.

or SLS trial per taping condition was performed [13,28]. For a trial to be accepted the participant was required to execute the movement smoothly with arms folded, while maintaining balance throughout

(Figs. 1 and 2).



Fig. 3. The application of the McConnell Patellofemoral Joint Taping technique (PFJT).

2.5. Taping

For both taping conditions 3.8 cm width rigid zinc oxide tape with 5 cm hypoallergenic underlay were applied to the symptomatic leg in accordance to guidelines outlined by Constantinou and Brown (2010). To reduce performance bias, one researcher applied the TIRLT technique while another consistently applied PFJT. Both researchers were practised in performing the techniques and were observed and trained in the technique by an expert in the field. The PFJT technique was applied in long sitting with the knee bent to approximately 30 degrees using a standardised cylinder under the selected knee (Fig. 3). Following the application of hypoallergenic underlay over the patella, zinc oxide tape was applied from the middle to the lateral aspect of the patella to tilt it medially. Next, a medial glide was applied with one hand, while gathering the medial tissues of the knee with the other. The tape was anchored from the lateral to the medial aspect of the knee as the medial tissues were released (Fig. 3). The knee was then actively flexed as the researcher applied pressure to each side of the tape to ensure it would be secure during the movement.

The TIRLT technique was applied to the participants' affected knee in a standing position with the knee in approximately 20 degrees flexion. A strip zinc oxide tape was applied starting approximately two cm medial to tibial tuberosity. The tape was tensioned whilst simultaneously applying an external rotational glide on the tibia up to the neutral rotation position (Fig. 4) and applied obliquely from medial to lateral crossing the knee joint posteriorly, finishing in a laterally directed tension on the superior aspect of the thigh (Fig. 4).

2.6. Data analysis

Data was analysed using IBM SPSS Version 22. Descriptive statistical analysis was performed on the demographic data. Data was assessed for normality using the Shapiro Wilkes Tests. A one-way repeated measures ANOVA was conducted to compare ROM between the different taping conditions (no taping, PFJT, TIRLT) for both the lunge and the SLS. Significance for kinematic data was reported using Wilks' Lambda. As pain data was not normally distributed, it was analysed non-parametrically using Friedman's test for K-related samples and using the Wilcoxon Sign Rank Test for post hoc analysis. Significance was set to p < 0.05 for all values. The above tests were performed, as appropriate, for pain values and ROM (maximum-minimum values) at the hip, knee and ankle during the lunge and squat on the sagittal, transverse and coronal planes. ROM values of all movement data were reported. Mean

and standard deviation (SD) were reported; however, where nonparametric tests were used, medians and interquartile range (IQR) were provided, this was the case for the pain variables only.

3. Results

The demographic, anthropometric and baseline data for the participants (n = 23) is summarised in Table 1.

3.1. Pain

During the lunge participants reported a significant reduction in pain with both the TIRLT technique (median NRS = 1, IRQ = 2) and the PFJT technique (median NRS = 1, IQR = 2) compared with the no tape condition (median NRS = 2, IRQ = 3, p = 0.005 and p = 0.011, respectively). Similarly, while performing a SLS participants indicated significantly less pain with TIRLT technique (median NRS = 2, IQR = 3) and PFJT technique (median NRS = 2, IQR = 2) compared with the no tape condition (median NRS = 3, IQR = 3, p = 0.002 and p = 0.001 respectively). There was no significant difference in reported pain scores between the two taping conditions for either the lunge (p = 0.045) or the SLS (p = 0.232).

3.2. Kinematic data

While performing the lunge, participants displayed no differences between taping conditions for any of the sagittal, transverse or coronal plane kinematic data at the hip, knee or ankle. Range of motion angles of the lower limb joints during the lunge are presented in Table 2.

Similarly, during the SLS there was no significant difference between the taping conditions for any of the sagittal, transverse and coronal

Table 1

Demographic, anthropometric and baseline data for participants (n = 23).

| Characteristic | |
|--|-----------------------------------|
| Gender, female (%) | 12 (52.2) |
| Age, years (mean \pm SD) | 29.1 ± 10.7 |
| Height, cm (mean \pm SD) | 175.4 ± 9.5 |
| Weight, kg (mean \pm SD) | $\textbf{75.0} \pm \textbf{11.8}$ |
| Number of aggravating factors identified (median, range) | 4 (2-6) |
| Baseline NRS at rest (median, range) | 0 (0-3) |
| | |

NRS: numerical rating scale; SD: standard deviation.



Fig. 4. The Tibial Internal Rotation Limitation Taping (TIRLT) technique.

Table 2

Range of motion at the hip, knee and ankle angles during the lunge.

| | No tape | PFJT | TIRLT | p- value |
|------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------|
| Hip Angle | | | | |
| (Degrees) | | | | |
| Flexion | 81.12 ± 12.44 | 80.11 ± 10.53 | 80.42 ± 12.31 | 0.78 |
| (mean \pm SD) | | | | |
| Adduction | 17.35 ± 5.04 | 18.80 ± 5.49 | 17.08 ± 6.09 | 0.18 |
| (mean \pm SD) | | | | |
| Internal rotation | $\textbf{22.78} \pm \textbf{13.39}$ | $\textbf{20.54} \pm \textbf{5.90}$ | $\textbf{18.76} \pm \textbf{5.75}$ | 0.10 |
| (mean \pm SD) | | | | |
| Knee Angle | | | | |
| (Degrees) | | | | |
| Flexion | 89.53 ± 12.73 | 89.56 ± 10.94 | $\textbf{90.26} \pm \textbf{10.40}$ | 0.88 |
| (mean \pm SD) | | | | |
| Valgus (mean \pm SD) | 12.38 ± 4.07 | 13.37 ± 6.23 | 11.46 ± 3.60 | 0.37 |
| Internal rotation | 21.60 ± 5.65 | 21.03 ± 8.23 | 19.38 ± 7.18 | 0.38 |
| (mean \pm SD) | | | | |
| Ankle Angle | | | | |
| (Degrees) | | | | |
| Dorsiflexion | 51.71 ± 19.88 | $\textbf{48.42} \pm \textbf{19.66}$ | 49.89 ± 20.23 | 0.51 |
| (mean \pm SD) | | | | |
| Adduction | 21.70 ± 5.65 | 21.08 ± 4.78 | 20.64 ± 5.56 | 0.71 |
| (mean \pm SD) | | | | |
| Pronation | 29.36 ± 11.09 | 26.61 ± 11.33 | $\textbf{24.99} \pm \textbf{10.70}$ | 0.08 |
| (mean \pm SD) | | | | |

TIRLT: Tibial Internal Rotation Limitation Taping; SD: standard deviation; PFJT: McConnell Patellofemoral Joint Taping .

plane data. Range of motion angles in the lower limb joints during the SLS are presented in Table 3.

4. Discussion

This novel study investigated the immediate effect of the TIRLT and PFJT techniques on pain in people with PFPS and directly compared the effect on lower limb kinematics during a lunge movement and SLS. Results indicate that both TIRLT and PFJT techniques are as effective as each other at providing immediate pain relief, however the reductions in pain were not accompanied by alterations in lower limb kinematics, when compared to no tape. This reduction in pain could be considered

Table 3

| Range of motion at the hip | , knee and | i ankle angles | s during | the single | leg squat |
|----------------------------|------------|----------------|----------|------------|-----------|
|----------------------------|------------|----------------|----------|------------|-----------|

| | No tape | PFJT | TIRLT | p- value |
|------------------------|------------------------------------|-------------------------------------|------------------------------------|-------------|
| Hip Angle | | | | |
| (Degrees) | | | | |
| Flexion | 63.79 ± 21.23 | $\textbf{62.50} \pm \textbf{19.43}$ | 63.66 ± 17.59 | 0.76 |
| (mean \pm SD) | | | | |
| Adduction | 15.68 ± 4.98 | $\textbf{18.47} \pm \textbf{8.36}$ | 16.96 ± 5.68 | 0.20 |
| (mean \pm SD) | | | | |
| Internal rotation | 14.48 ± 3.87 | 14.90 ± 6.08 | 14.31 ± 4.47 | 0.89 |
| (mean \pm SD | | | | |
| Knee Angle | | | | |
| (Degrees) | | | | |
| Flexion | 62.17 ± 14.39 | 60.95 ± 12.33 | 64.01 ± 10.90 | 0.15 |
| (mean \pm SD) | | | | |
| Valgus (mean \pm SD) | $\textbf{9.83} \pm \textbf{5.58}$ | $\textbf{9.49} \pm \textbf{5.48}$ | $\textbf{8.77} \pm \textbf{5.79}$ | 0.76 |
| Internal rotation | 11.08 ± 4.29 | $\textbf{9.99} \pm \textbf{3.53}$ | $11.43 \pm \textbf{4.51}$ | 0.32 |
| (mean \pm SD) | | | | |
| Ankle Angle | | | | |
| (Degrees) | | | | |
| Dorsiflexion | $\textbf{27.69} \pm \textbf{9.04}$ | $\textbf{27.94} \pm \textbf{10.42}$ | $\textbf{28.26} \pm \textbf{8.28}$ | 0.89 |
| (mean \pm SD) | | | | |
| Adduction | 12.18 ± 3.58 | 12.98 ± 3.48 | 13.72 ± 4.05 | 0.27 |
| (mean \pm SD) | | | | |
| Pronation | 15.49 ± 8.62 | 13.65 ± 6.26 | 15.71 ± 7.74 | 0.39 |
| $(mean \pm SD)$ | | | | |

TIRLT, Tibial Internal Rotation Limitation Taping; PFJT, McConnell Patellofemoral Joint Taping; SD, Standard Deviation.

clinically significant, given that participants presented with lower pain levels, where small changes can represent a clinical improvement [29]. It has been hypothesised that the TIRLT technique reduces pain by facilitating the tibia into a neutral position and limiting excessive internal rotation of the tibia thereby altering sub-talar mechanics and patellofemoral joint stress [14]. The present study found no evidence to support changes in lower limb kinematics during the movements selected in this cohort of participants. Under the taping conditions kinematic data did not demonstrate an alteration in tibial or femoral rotation, nor were there any significant changes in lower limb kinematics at the hip, knee or ankle. Hickey et al. (2016) found that a similar Mulligan taping technique, applying force in the position of internal rotation of the tibia was accompanied by a reduction in hip internal rotation during a single leg squat among females with PFPS [30]. One potential reason for the lack of a kinematic effect of TIRLT techniqure in the current study may relate to the single repetition of the test movement. Similar to Hickey et al. (2016) multiple repetitions of the test movement may have identified kinematic differences to become more apparent between the taped and non-taped condition. However, one lunge or SLS trial per taping condition was specifically selected to minimise the risk of symptom exacerbation with repeated movements, as two different movements were being investigated. Significant kinematic changes with the use of medial glide McConnell PFJ taping techique has been found during running among subjects with PFPS in the form of increased hip and knee angles during the swing phase [31]. However, the lack of significant changes with the application of PFJT technique in this study is in line with a systematic review that found insufficient or inconsistent evidence on the biomechanical effects of PFJT during functional tasks associated with PFPS [32]. Our study was confined to monitoring lower limb kinematics and any potential alterations with patellar biomechanics were not quantified. The biomechanics of the patellofemoral joint are challenging to assess with 3-dimensional motion analysis without accompanying radiology. This could explain why changes in patellofemoral alignment have not been widely studied, and why there is little evidence to suggest that patellar taping alters patellar positioning [32]. Additionally, it is notable that motor responses to pain can vary between individuals and can be influenced by contextual factors including pain-related sensory or psychological factors [33]. Changes in movement may require consideration of these factors together with motor re-learning to correct adaptive movement patterns and facilitate recovery.

The pain-relieving effects of taping may be explained by changes in quadriceps muscle activation, specifically the timing of VMO contraction relative to VL. Moderate evidence supports earlier onset of VMO activation with the application of PFJT [8]. It is not known if TIRLT technique produces any alterations in muscle activation. Several studies found comparable levels of pain reduction between taping protocols and sham taping [12,34]. Patellar taping decreased pain in subjects with PFPS, irrespective of how taping was applied [35,36]. Sham femoral rotation taping, applied without tension, also had a therapeutic effect on pain, of a similar magnitude to that of femoral taping, despite minimal evidence of kinematic changes associated with the sham tape [12]. A meta-analysis demonstrated that while sham taping had positive effects these explained 50 % of the pain reduction associated with medially directed patellar tape [37]. Nevertheless, the reduction of pain by tape that exerts no appreciable force, and lack of a kinematic effect with therapeutic taping protocols, suggests pain effects may be attributable to other factors beyond a biomechanical explanation. Another proposed mechanism of action for taping may relate to sensory or proprioceptive effects. Altered sensory and pain processing pathways have been identified in some individuals with PFPS [38]. Taping could positively influence the sensory abnormalities accompanying PFPS by providing afferent sensory input [34]. Pain relief may also be partially attributed to the placebo effect. Patient expectation is closely related to patient outcomes in musculoskeletal pain conditions [39], and an important component of the placebo effect [40]. The application of tape,

irrespective of technique, may create an expectation of improvement. The placebo effect is at its height directly after the intervention [41]. It is unclear if the magnitude of the immediate pain reduction changes with repeated application of the tape. Further evaluation of taping effects beyond the short-term is thus recommended [15].

Irrespective of the mechanism of action, the provision of immediate pain relief through both types of taping techniques in this study could provide a valuable tool in order to gain patient trust. Both types of taping techniques used in this study could provide a pain-free opportunity to engage in more active forms of treatment, such as therapeutic exercise. Despite the lack of consensus regarding its mechanisms of action there is good evidence to support various forms of taping as an adjunct to exercise in the management of PFPS [42].

Among the limitations to the study was the possibility of sampling bias. Participants were recruited via convenience sampling from the same university source potentially limiting the generalizability of the study findings to other populations [42]. Blinding participants to the different conditions was not possible due to the nature of the study. The aim of this study was to assess and compare the immediate effects of two different types of taping techniques and thus did not include sham taping. This was to reduce the amount of tape application, number of repetitive movements and any possible carry over. Future studies could include the addition of a sham taping effect to further investigate a possible placebo effect due to taping. Investigating the three conditions in a single-session allowed subjects to act as their own controls, randomisation of the sequencing of conditions was performed to reduce the possibility of contamination affecting the results however, a carry-over effect cannot be ruled out with complete certainty [13]. The number of repetitions of the movements were limited to avoid excessive pain provocation, however an increase in the number of repetitions in relation to other movements has been found to maximise intrarater reliability of the system [44]. The current findings relate to the immediate effect of taping. Future studies could investigate the supplementation of exercise with this taping over a longer time period. A diagnosis of PFPS represents a heterogenous population and future studies involving stratification of patients by biomechanical abnormality may be useful. As the TIRLT tTechnique aims to correct excessive pronation and internal rotation of the tibia, it may be useful to determine the effectiveness of TIRLT technique in a homogenous sub-group.

TIRLT technique had a similar pain reducing effect to the widely used PFJT technique. While this study did not find evidence of a kinematic effect for either taping technique, it suggests that both PFJT and TIRLT may be a useful adjunct to rehabilitation. This short-term benefit of pain relief may allow therapists the opportunity to engage patients in active forms of intervention with proven long-term effectiveness, such as exercise.

Declaration of Competing Interest

The authors report no declarations of interest.

Acknowledgement

The authors also thank the participants for their time, without whom this study could not have been conducted.

References

- B.E. Smith, J. Selfe, D. Thacker, P. Hendrick, M. Bateman, F. Moffatt, et al., Incidence and prevalence of patellofemoral pain: a systematic review and metaanalysis, PLoS One 13 (1) (2018), e0190892, https://doi.org/10.1371/journal.
- [2] K.M. Crossley, M. van Middelkoop, M.J. Callaghan, N.J. Collins, M.S. Rathleff, C. J. Barton, Patellofemoral pain consensus statement from the 4th International Patellofemoral Pain Research Retreat, Manchester. Part 2: recommended physical interventions (exercise, taping, bracing, foot orthoses and combined interventions), Br. J. Sports Med. 2016 (50) (2016) 844–852.
- [3] D. Kaya, M.N. Doral, Is there any relationship between Q-angle and lower extremity malalignment? Acta Orthop. Traumatol. Turc. 46 (2012) 416–419.

- [4] G.D. Myer, K.R. Ford, K.D. Barber Foss, A. Goodman, A. Ceasar, M.J. Rauh, J. G. Divine, T.E. Hewett, The incidence and potential pathomechanics of patellofemoral pain in female athletes, Clin. Biomech. (Bristol, Avon) 2010 (25) (2010) 700–707.
- [5] C.J. Barton, H.B. Menz, P. Levinger, K.E. Webster, K.M. Crossley, Greater peak rearfoot eversion predicts foot orthoses efficacy in individuals with patellofemoral pain syndrome, Br. J. Sports Med. 45 (2014) 697–701.
- [6] K. Hyunhee, H.S. Chang, Comparison of the VMO/VL EMG ratio and onset timing of VMO relative to VL in subjects with and without patellofemoral pain syndrome, J. Phys. Ther. Sci. 24 (12) (2012) 1315–1317.
- [7] N.E. Lankhorst, S.M. Bierma-Zeinstra, M. van Middelkoop, Factors associated with patellofemoral pain syndrome: a systematic review, Br. J. Sports Med. 47 (2013) 193–206.
- [8] C.J. Barton, S. Lack, S. Hemmings, S. Tufail, D. Morrissey, The 'best practice guide to conservative management of patellofemoral pain': incorporating level 1 evidence with expert clinical reasoning, Br. J. Sports Med. 2015 (49) (2015) 923–934, https://doi.org/10.1136/bjsports-2014-093637.
- [9] L.A. Bolgla, M.C. Boling, An update for the conservative management of patellofemoral pain syndrome: a systematic review of the literature from 2000 to 2010, Int. J. Sports Phys. Ther. 6 (2) (2011) 112–125. http://www.ncbi.nlm.nih. gov/pubmed/21713229.
- [10] E. Witvrouw, M.J. Callaghan, J.J. Stefanik, et al., Patellofemoral pain: consensus statement from the 3rd International Patellofemoral Pain Research Retreat held in Vancouver, September 2013, Br. J. Sports Med. 48 (2014) 411–414.
- [11] K.M. Crossley, M. van Middelkoop, M.J. Callaghan, N.J. Collins, M.S. Rathleff, C. J. Barton, 2016 Patellofemoral pain consensus statement from the 4th International Patellofemoral Pain Research Retreat, Manchester. Part 2: recommended physical interventions (exercise, taping, bracing, foot orthoses and combined interventions), Br. J. Sports Med. 50 (14) (2016) 844–852, https://doi.org/10.1136/bjsports-2016-096268.
- [12] C.-Y. Song, H.-Y. Huang, S.-C. Chen, J.-J. Lin, A.H. Chang, Effects of femoral rotational taping on pain, lower extremity kinematics, and muscle activation in female patients with patellofemoral pain, J. Sci. Med. Sport 18 (2014) 388–393.
- [13] M. Campolo, J. Babu, K. Dmochowska, S. Scariah, J. Varughese, A comparison of two taping techniques (kinesio and mcconnell) and their effect on anterior knee pain during functional activities. Int. J. Sports Phys. Ther. 8 (2013) 105.
- [14] M. Constantinou, M. Brown, Therapeutic Taping for Musculoskeletal Conditions, Elsevier, Australia, 2010.
- [15] C. Barton, V. Balachandar, S. Lack, D. Morrissey, Patellar taping for patellofemoral pain: a systematic review and meta-analysis to evaluate clinical outcomes and biomechanical mechanisms, Br. J. Sports Med. 48 (2014) 417–424.
- [16] A. Derasari, T.J. Brindle, K.E. Alter, F.T. Sheehan, McConnell taping shifts the patella inferiorly in patients with patellofemoral pain: a dynamic magnetic resonance imaging study, Phys. Ther. 90 (3) (2010) 411–419, https://doi.org/ 10.2522/ptj.20080365.
- [17] P. Levinger, W. Gilleard, Tibia and rearfoot motion and ground reaction forces in subjects with patellofemoral pain syndrome during walking, Gait Posture 25 (2007) 2–8.
- [18] T.L. Bellchamber, A.J. van den Bogert, Contributions of proximal and distal moments to axial tibial rotation during walking and running, J. Biomech. 33 (2000) 1397–1403.
- [19] M.C. Boling, D.A. Padua, S.W. Marshall, K. Guskiewicz, S. Pyne, A. Beutler, A prospective investigation of biomechanical risk factors for patellofemoral pain syndrome, Am. J. Sports Med. 37 (11) (2009) 2108–2116, https://doi.org/ 10.1177/0363546509337934.
- [20] S. Zaffagnini, D. Dejour, E. Arendt, Patellofemoral Pain, Instability, and Arthritis: Clinical Presentation, Imaging, and Treatment, Springer, Berlin, 2010.
- [21] M.C. Boling, L.A. Bolgla, C.G. Mattacola, T.L. Uhl, R.G. Hosey, Outcomes of a weight-bearing rehabilitation program for patients diagnosed with patellofemoral pain syndrome, Arch. Phys. Med. Rehab. 87 (2006) 1428–1435.
- [22] J. Mostamand, D.L. Bader, Z. Hudson, The effect of patellar taping on joint reaction forces during squatting in subjects with Patellofemoral Pain Syndrome (PFPS), J. Bodyw. Mov. Ther. 14 (2010) 375–381.
- [23] J.L. McGinley, R. Baker, R. Wolfe, M.E. Morris, The reliability of three-dimensional kinematic gait measurements: a systematic review, Gait Posture 29 (2009) 360–369.
- [24] A.M. Clifford, E. Harrington, The effect of patellar taping on squat depth and the perception of pain in people with anterior knee pain, J. Hum. Kinet. 37 (2013) 109–117.
- [25] M. Tierney, A.M. Clifford, K. O'Sullivan, Differences in landing strategies between previously injured and uninjured limbs in senior college level gaelic footballers, Physiother. Pract. Res. IOS Press 32 (2) (2011) 12–17, https://doi.org/10.3233/ PPR-2011-32203.
- [26] M.P. Jensen, J.A. Turner, J.M. Romano, L.D. Fisher, Comparative reliability and validity of chronic pain intensity measures, Pain 83 (1999) 157–162.
- [27] T.G. Lohman, A.F. Roche, in: R. Martorell (Ed.), Anthropometric Standardization Reference Manual, Vol. 177, Human kinetics books, Champaign, 1988, pp. 3–8.
- [28] G.Y. Ng, J.M. Cheng, The effects of patellar taping on pain and neuromuscular performance in subjects with patellofemoral pain syndrome, Clin. Rehab. 16 (2002) 821–827.
- [29] F. Tubach, P. Ravaud, G. Baron, B. Falissard, I. Logeart, N. Bellamy, et al., Evaluation of clinically relevant changes in patient reported outcomes in knee and hip osteoarthritis: the minimal clinically important improvement, Ann. Rheum. Dis. 64 (2005) 29–33.

- [30] A. Hickey, D. Hopper, T. Hall, C.Y. Wild, The effect of the mulligan knee taping technique on patellofemoral pain and lower limb biomechanics, Am. J. Sports Med. 44 (2016) 1179–1185, https://doi.org/10.1177/0363546516629418.
- [31] A. Pelletier, P. Sanzo, D. Kivi, C. Zerpa, The effect of patellar taping on lower extremity running kinematics in individuals with patellofemoral pain syndrome, Phys. Theory Pract. (2018) 1–9.
- [32] D.C. Leibbrandt, Q.A. Louw, The use of McConnell taping to correct abnormal biomechanics and muscle activation patterns in subjects with anterior knee pain: a systematic review, J. Physiol. Ther. Sci. 27 (2015) 2395–2404.
- [33] K.A. Butera, E.J. Fox, S.Z. George, Toward a transformed understanding: from pain and movement to pain with movement, Phys. Ther. 96 (10) (2016) 1503–1507, https://doi.org/10.2522/ptj.20160211.
- [34] N. Sai Kumar, K. Vinod Babu, V.R. Ayyappan, Stuti Ragesh Shah, Immediate effect of kinesio versus mcconnell taping on patellofemoral pain syndrome during functional activities – a comparative study, Int. J. Physiol. 2 (2015) 1077–1084.
- [35] T. Wilson, N. Carter, G. Thomas, A multicenter, single-masked study of medial, neutral, and lateral patellar taping in individuals with patellofemoral pain syndrome, J. Ortho. Sports Phys. Ther. 33 (2003) 437–448.
- [36] E.A. Christou, Patellar taping increases vastus medialis oblique activity in the presence of patellofemoral pain, J. Electromyogr. Kinesiol. 14 (2004) 495–504.
- [37] S.J. Warden, R.S. Hinman, M.A. Watson, K.G. Avin, A.E. Bialocerkowski, K. Crossley, Patellar taping and bracing for the treatment of chronic knee pain: A systematic review and meta-analysis, Arthritis Care Res. 59 (2008) 73–83, https:// doi.org/10.1002/art.23242.
- [38] B. Noehren, L. Shuping, A. Jones, D.A. Akers, H.M. Bush, K.A. Sluka, Somatosensory and biomechanical abnormalities in females with patellofemoral pain, Clin. J. Pain 2016 (32) (2016) 915–919.

- [39] J.E. Bialosky, M.D. Bishop, J.A. Cleland, Individual expectation: an overlooked, but pertinent, factor in the treatment of individuals experiencing musculoskeletal pain, Phys. Ther. 90 (2016) 1345–1355.
- [40] A. Abhishek, M. Doherty, Mechanisms of the placebo response in pain in osteoarthritis, Osteoarthr. Cartil. 21 (2013) 1229–1235.
- [41] F. Benedetti, Placebo Effects, Oxford University Press, USA, 2014.
- [42] C.A. Logan, A.R. Bhashyam, A.J. Tisosky, D.B. Haber, A. Jorgensen, A. Roy, M. T. Provencher, Systematic review of the effect of taping techniques on patellofemoral pain syndrome, Sports Health 2017 (9) (2017) 456–461.
- [44] K. Monaghan, E. Delahunt, B. Caulfield, Increasing the number of gait trial recordings maximises intra-rater reliability of the CODA motion analysis system, Gait Posture 25 (2) (2007) 303–315.
- [45] T.Y. Lan, W.P. Lin, C.C. Jiang, H. Chiang, Immediate effect and predictors of effectiveness of taping for patellofemoral pain syndrome: a prospective cohort study, Am. J. Sports Med. 38 (8) (2010) 1626–1630.
- [46] B. Noehren, et al., Proximal and distal kinematics in female runners with patellofemoral pain, Clin. Biomech. 27 (4) (2012) 366–371, https://doi.org/ 10.1016/j.clinbiomech.2011.10.005. Elsevier.
- [47] T.Q. Lee, G. Morris, R.P. Csintalan, The influence of tibial and femoral rotation on patellofemoral contact area and pressure, J. Orthop. Sports Phys. Ther. 33 (11) (2003) 686–693.
- [48] J. Selfe, J. Janssen, M. Callaghan, et al., Are there three main subgroups within the patellofemoral pain population? A detailed characterisation study of 127 patients to help develop targeted intervention (TIPPs), Br. J. Sports Med. 50 (14) (2016) 873–880.