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an observational study

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Research

New exercise-integrated technology can monitor the dosage and quality of exercise performed against an elastic resistance band by adolescents with patellofemoral pain: an observational study

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A B S T R A C T

Question: Is the exercise-integrated Bandcizer™ system feasible for recording exercise dosage (time under tension (TUT) and repetitions) and pain scores among adolescents with patellofemoral pain? Do adolescents practise the exercises as prescribed (TUT and repetitions)? Do adolescents accurately report the exercises they do in an exercise diary? **Design:** Observational feasibility study. **Participants:** Twenty adolescents between 15 and 19 years of age with patellofemoral pain. **Intervention:** Participants were prescribed three exercise sessions per week (one with and two without supervision) for 6 weeks. The exercises included three hip and one knee exercise with an elastic resistance band. Participants were instructed to perform three sets with a predefined TUT (3 seconds concentric; 2 seconds isometric; 3 seconds eccentric; 2 seconds pause), equating to 80 seconds for 10 repetitions (one set). **Outcome measures:** The exercise-integrated system consisted of a sensor attached to the elastic resistance band that was connected to the Bandtrainer app on an electronic tablet device. Pain intensity was reported on a visual analogue scale on the app. Participants also completed a self-report exercise diary. **Results:** No major problems were reported with the system. Participants performed 2541 exercise sets during the 6 weeks; 5% were performed with the predefined TUT (ie, within 10 seconds of the 80-second target) and 90% were performed below the target TUT. On average, the participants received 15% of the instructed exercise dosage based on TUT. The exercise dosage reported in the exercise diaries was 2.3 times higher than the TUT data from the electronic system. Pain intensity was successfully collected in 100% of the exercise sets. **Conclusion:** The system was feasible for adolescents with patellofemoral pain. The system made it possible to capture detailed data about the TUT, repetitions and sets during home-based exercises together with pain intensity before and after each exercise. **[Rathleff MS, Bandholm T, McGirr KA, Harring SI, Sørensen AS, Thorborg K (2016) New exercise-integrated technology can monitor the dosage and quality of exercise performed against an elastic resistance band by adolescents with patellofemoral pain: an observational study.** Journal of Physiotherapy **62: 159–163]**
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Introduction

Knee pain is common during adolescence, with a reported prevalence of up to 25%.[1,2] Patellofemoral pain has a prevalence of 6 to 7%, making it the most common knee condition amongst adolescents.[3] Pain is typically long-standing and results in severe reductions in function and health-related quality of life.[4] Symptoms of patellofemoral pain include diffuse anterior knee pain provoked by squatting, sitting for extended periods of time, and descending and ascending stairs.[5]

The latest Cochrane systematic review concluded that lower-extremity exercise therapy is effective in reducing knee pain in patients with patellofemoral pain.[6] Exercise dosage may be an important aspect of the intervention because a higher self-reported exercise dosage is associated with improved odds of recovery.[3,7] Adherence to prescribed exercises is likely to be important because low adherence would be expected to reduce the magnitude of their effect.[3,7] This is a challenge because adherence to exercise protocols is approximately 50% for clinic-based programs, and reportedly lower for home-based exercise.[8]

Adherence involves a number of factors, including how often the patient performs the exercises, whether the quantity of the exercise performed is sufficient to provide a therapeutic benefit, and how long the patient continues to perform the exercises.[9] Pain

during exercises may help to explain non-adherence to exercise programs, which is why continuous pain monitoring may be an important factor in explaining adherence.[10]

The latest systematic review on self-reported adherence to home-based intervention rehabilitation programs concluded: 'The results expose a gap in the literature for well-developed measures that capture self-reported adherence to prescribed but unsupervised home-based rehabilitation exercises'.[9] A lack of objective measurements limits the ability of clinicians and researchers to evaluate the outcome of exercise interventions. This makes it virtually impossible to ascertain if a lack of improvement is due to the incorrect exercise, dosage, or due to poor adherence. In a recent series of studies,[11–13] technology that measures these factors has been developed and validated; the Bandcizer™ is an in-built sensor attached to an elastic resistance band and connected to an iPad, hereafter referred to as the exercise monitoring system. In lab-based studies, the exercise monitoring system has shown that it can validly quantify exercise data, such as the number of repetitions and sets, as well as the time under tension.[11] The feasibility of using the exercise monitoring system connected to an iPad (hereafter referred to as the tablet device) during week-long home-based interventions in clinical populations is currently unknown and, thus, it is too premature to use the system in clinical trials or clinical practice. It is therefore pertinent to test the feasibility of the system and record any issues associated with using it during home-based unsupervised interventions.

The general research question for this study related to whether it is feasible to use the exercise monitoring system connected to a tablet device to measure exercise adherence and dosage among adolescents with patellofemoral pain.

Therefore, the research questions for this feasibility study were:

1. Is the exercise monitoring system feasible for recording exercise dosage (time under tension and repetitions) and pain scores among adolescents with patellofemoral pain?
2. Do patients perform exercises as prescribed, with respect to time under tension and repetitions?
3. Do patients accurately report the exercises that they perform in an exercise diary?

Methods

Design

The study was designed as a feasibility study. The term feasibility study refers to studies that are carried out in preparation for future large-scale definitive studies such as randomised trials or observational studies, and to address key issues of uncertainty[14] – in this case, uncertainty related to the home-based use of the Bandcizer™ system. The study investigated whether the exercise monitoring system could be used to record exercise dosage and pain, to test whether adolescents with patellofemoral pain perform their exercises as prescribed, and to test whether they report their adherence accurately in their exercise diary. This was tested among 20 adolescents with patellofemoral pain that were prescribed 6 weeks of exercises.

Participants, therapists, centres

Participants were recruited from upper secondary schools using a similar process to that described by Rathleff et al.[3] In short, adolescents in these schools answered an online questionnaire on musculoskeletal pain and if they reported knee pain, they were contacted by telephone and offered a clinical examination by a physiotherapist to determine the specific knee condition. As the present study was a feasibility study, no formal sample-size calculation was conducted. Twenty adolescents between 15 and 19 years of age with patellofemoral pain were included. Two were

males and 18 were females. Their average age was 17 years (range 15 to 19), height was 167 cm (SD 6), weight was 60 kg (SD 8) and pain duration was 3.5 years (SD 1.4).

Inclusion criteria were: the insidious onset of anterior knee or retropatellar pain lasting > 6 weeks and provoked by at least two of the following activities – prolonged sitting, prolonged kneeling, squatting, running, hopping or stair climbing; tenderness on palpation of the patella; pain when stepping down or double-leg squatting; and worst pain intensity during the previous week of > 30 mm on a 100-mm visual analogue scale. Exclusion criteria were: injury to other areas of the body; pain in the hip, lumbar spine or other areas of the knee (eg, participants with Osgood-Schlatter disease or other knee conditions not related to patellofemoral pain would be excluded); previous knee surgery; self-reported patellofemoral instability; knee joint effusion; physiotherapy treatment for knee pain within the previous year; and weekly or more frequent usage of anti-inflammatory drugs.[3]

Intervention

Exercises

The description of the exercise intervention follows the Template for Intervention Description and Replication (TIDieR) checklist.[15] The exercise intervention lasted 6 weeks and covered three weekly exercise sessions (one group-based session at the local hospital and two sessions at home without supervision). The exercises were prescribed by two physiotherapy students under the supervision of a senior physiotherapist with 7 years of clinical experience in musculoskeletal physiotherapy. Before they prescribed the exercises to the participants, the physiotherapy students attended 2 hours of training on prescribing the exercises. The exercise program included three hip and one knee exercise with an elastic band. Participants were instructed to perform the exercises with a predefined time under tension (3 seconds concentric; 2 seconds isometric; 3 seconds eccentric; 2 seconds pause), equating to 80 seconds for 10 repetitions in a set, with a total of three sets prescribed. They were instructed to perform the exercises at 10 repetition-maximum and used exercises previously used for treating patellofemoral pain.[16] The exercises were: knee extension (loading from 90 deg flexion to full extension), hip external rotation (loading starting from 0 deg external rotation to full external rotation), hip abduction (loading starting from 0 deg hip abduction progressing to full hip abduction) and hip extension (loading starting from 20 deg hip flexion to full hip extension) (see Figure 1). During the supervised exercise sessions, the participants were repeatedly told that adherence was important and would improve their likelihood of recovery. During the supervised group sessions, the participants received instructions to ensure proper exercise form.

Equipment

The exercise monitoring system consisted of a Bandcizer™ attached to the elastic exercise band used to resist the exercises, connected via Bluetooth to the Bandtrainer app installed on an iPad tablet device (Figure 1). The University of Southern Denmark and the National Danish Partnership UNIK developed the Bandcizer™ and the Bandtrainer app. The Bandcizer™ consists of two connected parts that are mounted on either side of an elastic band, held together by internal magnets. The two parts form a sensor that measures deformation and, thereby, stretch of the elastic band. The measured data are transmitted via Bluetooth-4 low energy, directly to the tablet device.[11] The Bandtrainer app has an inbuilt visual analogue scale where users record their current knee pain intensity before and after each exercise set. The exercises are shown on the tablet and the participant selects which exercise they wish to perform by tapping on a picture of the relevant exercise (see screenshot in Figure 1). Both the Bandcizer™ and the tablet device need charging at least once every week.
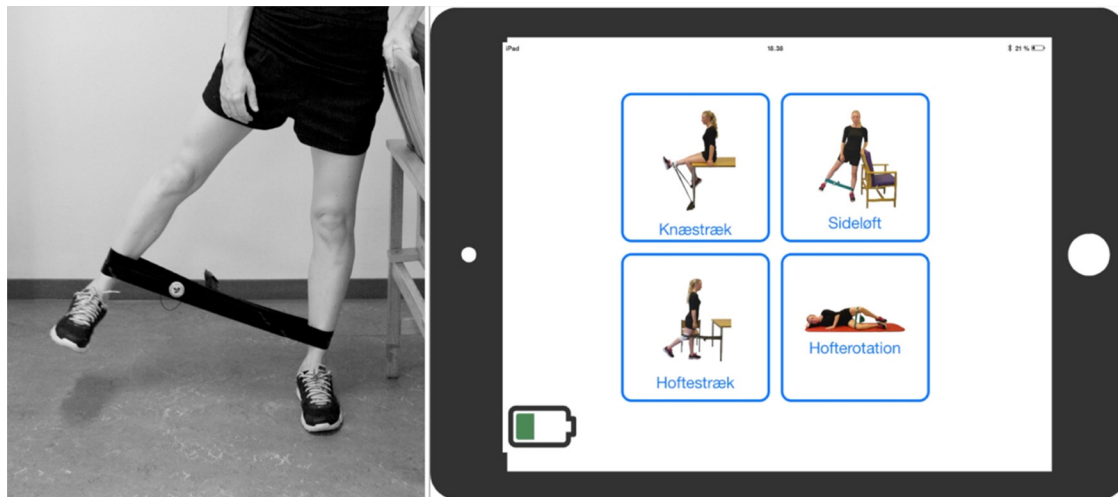
Figure 1. Bandcizer™ attached to an elastic band and connected through Bluetooth to an iPad.

Outcomes

Strength testing

At baseline and after the intervention, isometric strength measurements were recorded for knee extension and hip abduction, external rotation and extension using strap-mounted, hand-held dynamometry. The test protocol was based on previous studies by Rathleff et al[13] for knee extension, hip abduction and external rotation, and the short-lever hip extension test described by Thorborg et al.[17] The reliability of the strength measurements was above ICC 0.88.[17,18]

Feasibility and adherence

For exploratory purposes, and to inform a future large-scale trial on exercise dosage, the participants were asked to continually fill out an exercise diary during the 6 weeks and had their strength measured before and after the 6-week intervention. This allowed for the association between self-reported adherence and objectively assessed adherence to exercise to be explored. All problems were recorded by asking the participants and the physiotherapists to document all issues with the exercise monitoring system.

Data analysis

Data from the exercise monitoring system, stored on the tablet device, were transferred to a computer and an automatic algorithm extracted the number of repetitions, sets and time under tension from the data. The algorithm accurately measures time under tension in four steps: stretches are amplified using a Gaussian filter designed for stretches with duration between 1 and 10 seconds; individual stretches are identified and counted by peak-detection and thresholding of the filtered data; the relaxation level between stretches is identified as the minimal tension occurring between peaks; and the threshold for tension is chosen as 10% above the relaxed state with respect to the peak tension, and the time under tension of each stretch is measured as the time where the tension is above this threshold. For each exercise, a report is generated, which includes a graphic plot of measured tension versus time, annotated with the calculated thresholds and time under tension of each individual stretch, as well as the total time under tension and time for the exercise. The reports allow manual verification of data quality as well as the quality of the automatic time under tension measurement.

Issues with using the exercise monitoring system were described narratively while the association between self-reported adherence and data from the exercise monitoring system were described using an unpaired *t*-test and the Pearson correlation coefficient. Changes in isometric strength and knee pain before and after each exercise set were tested using a paired-samples *t*-test. An exploratory analysis was performed to test the association between total time under tension and the average composite change in hip and knee strength. This was tested using a Pearson correlation coefficient. Normality was checked with Q-Q plot.

Results

Is the system feasible for monitoring?

No major problems were reported with the exercise monitoring system. Two participants reported that the sensor fell off the elastic band twice and two participants reported they had to restart the tablet app 'a couple of times' during the 6 weeks.

Do adolescents adhere to the training prescription?

Based on data from the exercise monitoring system, the 20 participants performed 2541 of the 8640 prescribed exercise sets during the 6-week intervention period. The average time under tension was 53 seconds (95% CI 51 to 55): 5% were performed with the predefined time under tension (ie, within 10 seconds of the 80-second target), 5% were above the target time under tension and 90% were below the target time under tension. The median number of repetitions per set was 10 (IQR 9 to 10). Overall, 52% of the exercise sets contained the predefined number of repetitions (10) and 24% had a lower number of repetitions. On average, the participants received 15% (range 0 to 52) of the instructed exercise dosage based on time under tension.

Do adolescents report their exercises accurately?

According to the self-report data, the participants performed 3069 exercise sets and received 36% (range 0 to 78) of the prescribed exercise dosage based on time under tension. An exploratory analysis showed a significant association between self-reported data and time under tension data from the exercise monitoring system ($r = 0.77$, $p < 0.001$); however, the exercise dosage reported in the exercise diaries was 2.3 times higher than the time under tension data from the exercise monitoring system.

Isometric strength and exercise dosage

Six participants did not attend the follow-up strength measurement session. The follow-up strength measurements were performed on the remaining 14 participants the day after the intervention period ended. On average, the participants increased their knee and hip strength by 11% (95% CI 4 to 13). Knee extension strength increased by an average 24 N, corresponding to 8% (95% CI –2 to 18). Hip abduction strength increased by 17 N, corresponding to 12% (95% CI 2 to 22). Hip external
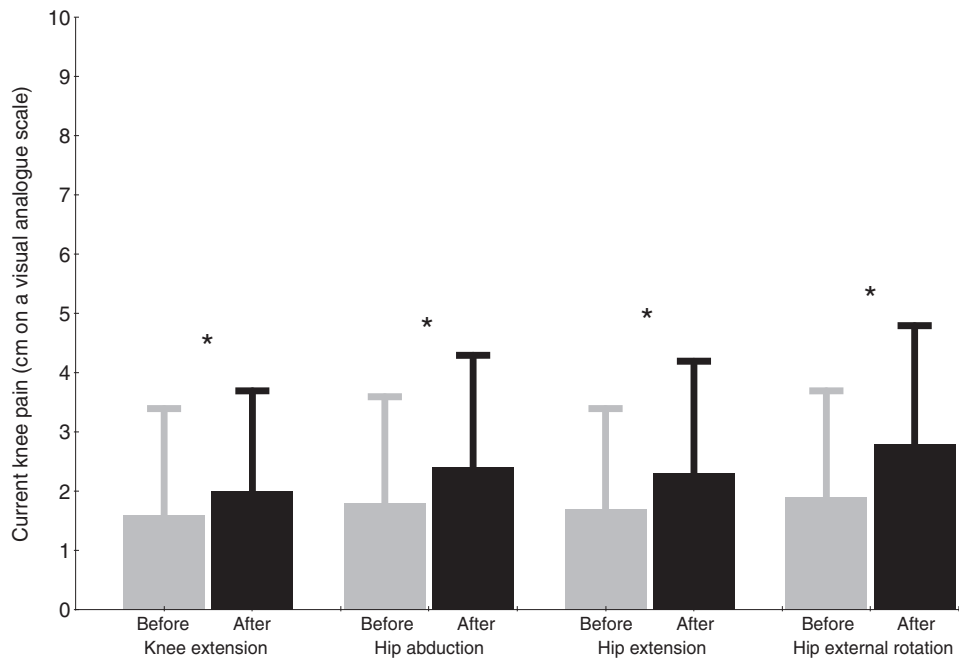
Figure 2. Current knee pain before and after each of the four exercises. Error bars indicate one standard deviation. Asterisks denote a statistically significant change from before to after the exercise.

rotation strength increased by 10 N, corresponding to 11% (95% CI 3 to 18). Hip extension strength increased by 18 N, corresponding to 14% (95% CI –2 to 29). An exploratory analysis showed a positive association between average increase in isometric knee and hip strength and the total exercise dosage recorded by the exercise monitoring system ($r = 0.49$, $p = 0.07$).

Pain intensity before and after exercises

Pain intensity was successfully collected before and after each exercise set in 100% of the exercise sets. On average, their current knee pain increased significantly by 0.4 to 0.9 cm on the visual analogue scale during each of the four exercises, with the last exercise (hip external rotation) associated with the largest increase in knee pain (Figure 2).

Discussion

The present study reports novel objective measurement of adherence collected during a 6-week exercise program with two weekly unsupervised sessions and one weekly supervised session. The exercise monitoring system proved to be feasible for use in a clinical population of adolescents with patellofemoral pain, with only minor issues with the system having been reported. The sensor in the exercise monitoring system fell off the elastic exercise band a few times. Subsequent use of stronger magnets that secured the sensor more firmly to the elastic band appears to solve this issue. This is important because adherence is underestimated if the sensor is not connected to the elastic band at all times.

The exercise monitoring system allowed calculation of the total exercise dosage and recording of pain intensity before and after each exercise. The objective data from the exercise monitoring system revealed that the participants only received 15% of the prescribed exercise dosage and still improved isometric hip and knee strength. The participants reported much higher adherence in their exercise diaries, with an average of 36% of the prescribed exercise dosage. The discrepancy between objective data and self-reported data suggests that training diaries from this population should be interpreted with great care, as they may severely overestimate the actual exercise dosage.

Most of the exercise sets were performed with a time under tension much lower than the target. This resulted in a lower

exercise stimulus than prescribed. The reason for the low time under tension is unknown, but perhaps the participants did not receive adequate feedback during their supervised exercise sessions. A possible solution could be to use the tablet to deliver real-time feedback on the exercise execution, or to use a mobile phone with a metronome. Previous research among adolescents with patellofemoral pain has suggested that adherence is important and improves recovery. Specifically, Rathleff and colleagues showed a dose-response association between the average number of home-based training sessions per week and the odds of being recovered after 12 months.[3] This finding was based on self-report data and may have been biased because of strong overestimation of exercise adherence in the self-report training diaries, given the findings of the present study. However, the association between objective and self-reported exercise dosage was preserved in the current study, which could suggest that the association between adherence and effect may still hold true despite large overestimation of self-reported exercise dosage.

Similar to what has previously been reported,[3] the average adherence was low in the present study. To address low adherence issues, there is a need to investigate the minimum exercise dosage required to obtain a clinical effect and how much exercise is needed to obtain the largest possible effect. This is important information in both the clinical setting and research. Until now, it has not been possible to investigate the dose-response association. The present study suggests that the exercise monitoring system is feasible for use in adolescents with patellofemoral pain and will allow researchers to explore such questions in future randomised, controlled trials. Likewise, it will give clinicians and patients an opportunity to receive information on exercise dosage during unsupervised training, which may in some cases encourage better adherence and help clinicians to adjust exercise dosage.

The participants who received the largest dose of exercise during the 6 weeks showed the largest increases in knee and hip strength. The total exercise dose was expressed as total time under tension; total time under tension refers to the total time of all concentric, quasi-isometric and eccentric contraction phases in a single training set.[19] In combination with load and movement velocity, time under tension is an important descriptor of strengthening exercises because it reflects the time factor of the exercise stimulus.[20,21] Increasing the amount of time under tension has been shown to increase myofibrillar protein synthesis after a single, work-matched, strength-training session in healthy

subjects.[21,22] Likewise, a higher duration of tendon strain per contraction (3 seconds cycling loading versus 1 second cycling loading) led to a superior adaptation, which improved the mechanical and structural properties of the Achilles tendon.[23] Hence, the total time under tension in combination with the relative intensity (repetition maximum) is a relevant combined measure of the total exercise dosage during an exercise program, as it relates to the tissue-specific response.

The self-reported pain intensity levels increased < 1 cm on average after each exercise. This suggest that exercises performed unsupervised at 10 repetition maximum are tolerated by adolescents with patellofemoral pain. This is important because it suggests that low adherence may not be caused by large increases in pain after each exercise set. However, the error bars in Figure 2 are quite wide, which suggests a large variance in knee pain intensity before and after each exercise. Changes in pain during home exercises may be highly relevant to monitor for both clinical and research purposes as this may be a major barrier to exercise adherence. The exercise monitoring system would allow clinicians to monitor their patient's knee pain during home exercises. This may help to tailor the exercise dose to each individual and continuously adjust the exercise dose based on the individual patient's pain response.

This study was conducted among a highly selected age group, where previous research has documented low levels of adherence to exercise programs.[5] Therefore, the low levels of adherence and poor association between data from the exercise monitoring system and the exercise diaries may not be transferable to other clinical populations or other age groups. In addition, the price of a tablet device makes it an expensive solution for measuring adherence. A less costly solution would be to record the data directly on the sensor itself. However, this would remove the option of recording knee pain intensity before and after each exercise set.

In summary, the exercise monitoring system proved to be feasible for use in adolescents with patellofemoral pain, and only minor issues were reported. This new system makes it possible for clinicians and researchers to capture a detailed description of time under tension, number of repetitions and sets during home-based exercises, together with pain intensity before and after each exercise. Data from the exercise monitoring system revealed that adolescents with patellofemoral pain only received 15% of the total exercise dosage that they were prescribed. Comparison of the methods of recording the exercises suggests that self-report diary cards provide an overestimate of adherence.

What is already known on this topic: Exercise therapy reduces patellofemoral pain in adolescents. The dose of exercise performed may be important to achieve the reduction in pain, but adherence is typically low, especially for home-based exercise.
What this study adds: A new system of monitoring adherence can capture detailed information about adherence to exercises performed against an elastic resistance band. These data show that self-report diaries typically overestimate adherence.

Ethics approval: The Ethics Committee of the North Denmark Region approved this study (2011-0069). All participants gave written informed consent before data collection began.

Competing interests: One of the authors of this study is a patent holder for the elastic band sensor (ASS). ASS contacted the researchers (MSR, KT and TB) to collaborate on a scientific evaluation of Bandcizer™. ASS was involved in the design of the study, including the pre-specified plan for data reduction and statistical analyses, but was not involved in the data collection, and was not allowed to see the results until the final approval of the manuscript was required. At this point, ASS was allowed to comment on the results and interpretation. In any case of disagreement with that in the manuscript draft, the first (MSR), second (TB), and last (KT) authors, who are not patent holders and have no possible financial conflicts of interest with respect to the elastic band sensor, had the final say. No disagreements occurred.

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