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## Activity Modification and Load Management of Adolescents With Patellofemoral Pain

*A Prospective Intervention Study Including 151 Adolescents*

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- 1 **Activity modification and load management in adolescents with patellofemoral pain - a**
- 2 **prospective intervention study including 151 adolescents**
- 3

4 **Abstract**

5 **Background:** Patellofemoral pain (PFP) affects 7% of adolescents, especially those that are highly  
6 active. **Exercise-focused treatments** show limited effect, and overlook activity modification and  
7 load management. As many adolescents continue at high levels of sports despite pain, a new  
8 strategy addressing this problem is warranted.

9

10 **Purpose:** Investigate the effects of a treatment strategy **for adolescents focusing** on activity  
11 modification and load management.

12

13 **Study design:** Prospective cohort study

14

15 **Methods:** **One hundred and fifty one adolescents aged** 10-14 years with PFP were included. The  
16 12-week intervention included four supervised sessions with physiotherapist, which both  
17 adolescents and parents were required to attend. The intervention included activity modification  
18 (week 0-4) to reduce loading of the patellofemoral joint using an activity ladder and pain  
19 monitoring, home-based exercises (week 4-12), and return to sport guidance (week 8-12). Primary  
20 outcome was a 7-point global rating of change (GROC), ranging from “much improved” to “much  
21 worse”. Adolescents were considered **to have** a successful outcome if they reported “much  
22 improved” or “improved”. **The p** primary endpoint was at 12 weeks, with additional follow-up at 4,  
23 24 and 52 weeks. Secondary outcomes included Knee Injury and Osteoarthritis Outcome Score  
24 (KOOS), hip and knee torque, sports participation, satisfaction with treatment, and use of pain  
25 killers.

26

27 **Results:** At 12 weeks, 87% completed the full questionnaire, of which 86% reported a successful  
28 outcome, which was 77%, 95%CI: 68-83%at 6 months , and 81%, 95%CI: 73-88% at 12 months .

29 There were large clinically relevant improvements in KOOS pain, sport and recreation and quality  
30 of life (13-24 points). Hip and knee torque increased by 20-33%. In total, 68% were back playing  
31 sport after 3 months, which increased to 79% at 6 months, and 81% at 12 months. The majority  
32 (90%) were satisfied with the treatment, and (95%) would recommend it to a friend.

33

34 **Conclusion:** A treatment strategy focusing on activity modification and load management was  
35 associated with high rates of successful outcomes in adolescents with PFP, at both 12 and 52  
36 weeks. These short and longer term outcomes were supported by improvements in symptoms,  
37 and objective measures of hip and knee torque.

38

39

40 **What is known about the subject:**

- 41 • Patellofemoral pain affects 7% of the adolescent population, especially the high sports  
42 active.
- 43 • Current exercise-focused trials are only effective for 1 in every 3, and substantial  
44 impairments in knee function and pain persists even after a year.

45

46 **What this study adds to existing knowledge:**

- 47 • This novel strategy focusing on educating adolescents and their parents on activity  
48 modification and load management seems promising due high rates of succesfull outcomes  
49 at both 12 and 52 weeks. These short and longer term outcomes were supported by large  
50 improvements in subjective reports of knee specific pain and sporting function, treatment  
51 satisfaction, and in objective measures of hip and knee torque.

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56

57 **Introduction**

58 Musculoskeletal pain affects at least one in three adolescents, with the knee being the most  
59 common pain location<sup>7,18</sup>. Patellofemoral pain (PFP) represents the second most common knee  
60 complaint in adolescents<sup>4,17</sup>. It affects 6-7% of the general adolescent population, with an even  
61 higher prevalence (up to 25%) among sports-active adolescents<sup>17</sup>. PFP is characterised by diffuse  
62 anterior knee pain, provoked by activities that load the knee such as squatting and stair climbing<sup>2</sup>.  
63 Approximately four out of ten adolescents with PFP continue to have pain into early adulthood,  
64 and this is severe enough to impact quality of life, knee function, physical activity and sport  
65 (blinded reference).

66 One of the mainstays in treating PFP in adults is exercise therapy (usually resistance training<sup>7</sup>),  
67 with evidence for its' short and long-term effectiveness on pain and function<sup>2,19</sup>. Adding  
68 supervised exercises to patient education also improves outcomes for adolescents (aged 15-19  
69 years) in the short (3 months), and long term (24 months)<sup>12</sup>. However, the results of an exercise-  
70 focused approach in adolescents are not as promising as data from adults, with only one in three  
71 responding favourably to exercise and education<sup>14</sup>.

72 Intense and frequent sports participation with insufficient recovery is considered a main cause for  
73 developing PFP during adolescence, due to repetitive loads on the knee joint<sup>6,14</sup>. This may be a  
74 period where adolescents are vulnerable, as there is a steep increase in MSK injuries during the  
75 transition into adolescence, indicating they may be more susceptible to MSK problems<sup>18</sup>. Exercise  
76 therapy neglects this potential influence of repetitive activity and knee joint loading during  
77 adolescence, which may explain the limited effect in this population<sup>14</sup>. Successful treatment may  
78 need to consider behaviours such as high physical activity, which are thought to have led to knee

79 pain in the first place<sup>6</sup>. This could include educational components tailored for the cognitive  
80 considerations specific to the needs of adolescents, to help them modify their high sports  
81 participation and manage their current situation. Such information and self-management  
82 strategies could help address how adolescents can reduce their symptoms, while progressively  
83 enabling them to get them back to their desired activity level.

84

85 Therefore, the aim of this study was to test a treatment strategy specific for adolescents with PFP  
86 focusing on educating adolescents on activity modification and load management. The outcomes  
87 were self-reported global rating of change, knee specific function (KOOS), hip and knee strength,  
88 and the use of painkillers. A secondary aim was to explore prognostic factors, and whether  
89 adherence to the intervention (activity modification and exercises) were associated with response  
90 to treatment, in light of other patient characteristics.

91

## 92 **Methods**

### 93 **Study design**

94 This study was designed as a multi-centre single-cohort prospective study (with one centre in  
95 [REDACTED] and one [REDACTED]) on adolescents with PFP. Adolescents with  
96 knee pain were recruited from local schools, social media and general practice, and subsequently  
97 assessed for PFP according to predefined criteria as outlined below. The study was approved by  
98 [REDACTED] and the [REDACTED] Data Protection  
99 Agency and pre-registered on clinical trials ([REDACTED]). Written informed parental consent  
100 was required from all participants prior to inclusion, as well as participant assent. All procedures  
101 were pilot tested on adolescents before initiation of the study to ensure feasibility and that both

102 adolescents and their parents were comfortable with the procedures. The study was conducted  
103 according to the Declaration of Helsinki. Reporting adheres to the STROBE guidelines and checklist  
104 for prospective cohort studies<sup>5</sup>. Reporting of the intervention follows a best-practice approach  
105 combining thorough descriptions, videos and educational material that was used during the study  
106 <sup>7</sup>.

107

## 108 **Recruitment**

109 Potentially eligible adolescents with knee pain were identified between March 2015 and February  
110 2016. This was done by having local schools inviting students (age 10-14) to answer an online  
111 questionnaire on musculoskeletal pain. This was supplemented by using social media to identify  
112 adolescents with knee pain. Potentially eligible participants were subsequently telephoned and  
113 invited for a clinical examination by one of two physiotherapists. This recruitment strategy  
114 recruited participants for both this trial (adolescents with PFP) and an external study on  
115 adolescents with Osgood Schlatter Disease (clinical trial registration XXXXXXXXX).

116

117 The diagnosis of PFP was made by one of two trained physiotherapists according to established  
118 recommended criteria<sup>3</sup> as follows: insidious onset of anterior or retro-patellar knee pain for more  
119 than 6 weeks and provoked by at least two of the following positions or functions; prolonged  
120 sitting or kneeling, squatting, running, hopping or stair walking; tenderness on palpation of the  
121 patella, or pain with stepping down or double leg squatting; worst pain experienced during the  
122 previous week should be reported to be more than 30 mm on a 100 mm Visual Analogue Scale  
123 (VAS). **Exclusion criteria included: currently being treated for PFP, aged less than ten or older than**  
124 **14, previous surgery to the knee, a diagnosis of other knee conditions (e.g. Osgood Schlatter),**



125 patellofemoral instability or concomitant injury or pain from the hip or lumbar spine.

126

## 127 **Intervention**

128 The intervention was developed in collaboration between researchers, clinicians with previous  
129 experience in adolescent musculoskeletal pain, and informed by adolescents and parents from a  
130 previous trial. The aim was to counteract the previous difficulties with compliance and limited  
131 clinical effects<sup>12,14</sup>. The aim of the intervention was to change the behaviour considered one of  
132 the likely contributors to the onset of pain, and persistence of pain in adolescents with PFP: high  
133 knee joint loading through high volumes of physical activity<sup>6,14</sup>. To investigate changes in target  
134 behaviour we used objective measure of physical activity (via wrist Actigraphy) and self-report  
135 questionnaires (see full description in section on outcomes).

136

137 The intervention was delivered by one of two physiotherapists to all adolescents, irrespective if  
138 the currently participated in sport. After the inclusion visit where adolescents were screened for  
139 eligibility and consent, adolescents and parents needed to attend four supervised visits, over a 12-  
140 week period. Parents were required to take part in all five visits. All information from the  
141 physiotherapists was also delivered in a patient leaflet (patient leaflet in English can be seen in  
142 appendix 1 and manual for physiotherapists in appendix 2b).

143

144 The intervention was structured around three blocks of 4 weeks, with specific clinical tools  
145 introduced in each of the three blocks (Table 1, Figure 1, appendix 1). The intervention was  
146 focused on activity modification and load management, where the adolescents, after an initial  
147 reduction in sports participation (to reduce knee joint loads), were gradually introduced and

148 exposed to increasing knee joint loads. The initial activity and load modification in block 1 included  
149 a temporary removal from sports participation from week 0-4, and avoiding activities that  
150 aggravate their knee beyond what the pain monitoring model considered "OK". During block 2  
151 (week 4-8), adolescents were instructed in further load-management via progressive home-based  
152 hip and knee exercises (see full description of exercises in appendix 1), and an activity ladder. The  
153 aim of the activity ladder was to gradually expose the adolescent to activities with higher knee  
154 joint loads based on their own assessment of symptoms (maximum 2 on NRS scale during, after, or  
155 the day after a given activity). When they could perform an activity within the "OK" zone, without  
156 a pain flare-up, they were instructed to progress to the next level.

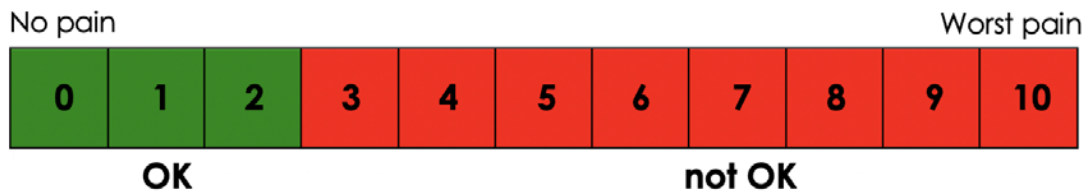
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158

159 **Figure 1: The combined activity ladder and pain monitoring model. The pain monitoring tool**  
160 **(bottom) guided the adolescent through the six steps in the activity ladder.**

## "THE ACTIVITY LADDER"

- 1. Easy walking / cycling (Lowest level)
- 2. Fast walking / medium to hard cycling
- 3. Slow running
- 4. Stairs
- 5. Run at medium speed and jumping
- 6. Run at high speed and jumping (highest level)



161

162 **In block 3, participants** were instructed to perform home-based weight-bearing hip and knee  
163 exercises (see description of exercises in appendix 1), and gradually return to sport using a pre-  
164 planned model starting with participation in warm-up and then adding 15 minutes per week using  
165 the pain monitoring model as guidance. Return to play was only initiated if they had reached level  
166 6 on the activity ladder.

167

168

169

170 Table 1. Overview of content during the three blocks in the intervention period. A full description  
 171 of all the components can be seen in appendix 2 that contains the leaflet and additional details on  
 172 the different components.

	<b>BLOCK 1 (WEEK 0-4)</b>	<b>BLOCK 2 (WEEK 5-8)</b>	<b>BLOCK 3 (9-12)</b>
<b>EDUCATIONAL COMPONENTS</b>	Factors contributing to PFP  Risk of PFP  Load and sport Rationale for treatment	Importance of adherence  Proper exercise form  Monitor and progress	Progression to sport  Monitor and progress  Continued exercises
<b>MODALITIES TO GRADUALLY DECREASE/INCREASE KNEE JOINT LOADS</b>	Activity modification  Double limb bridge  Static holds 10x 30sec (daily)	Hip and knee exercises	Weightbearing hip and knee exercises
<b>SPECIFIC TOOLS INTRODUCED</b>	The activity ladder Pain monitoring	The activity ladder Pain monitoring	Graded return to sport, after step 6 has been reached on "activity ladder"

173

174

### 175 **Self-report outcome measurements**

176 **Self-reported data were collected using written forms. Participants were asked to report their**

177 **most painful knee if they suffered from bilateral knee pain.** The primary outcome was self-

178 reported recovery on a 7-point Global Rating of Change scale (GROC) (ranging from "much

179 improved" to "much worse") at 12 weeks' follow-up. This outcome has been used in previous

180 trials on both adults and adolescents with PFP<sup>2,14,26</sup>. Adolescents were categorized as having a

181 successful outcome if they rated their knee pain as "much improved" or "improved". Additional

182 follow-ups were done at 4 weeks, 8 weeks, 6 months, and 12 months.

183

184 Secondary outcomes included the patient-reported questionnaire Knee Injury and Osteoarthritis

185 Outcome Score (KOOS)<sup>16</sup> which contains five separate subscales (Pain, Symptoms, Activity in Daily

186 Living (ADL), Function in Sport and Recreation (Sport/Rec), knee-related quality of life (QoL)), to  
187 assess the adolescent's opinion about their knee and associated problems. This questionnaire was  
188 chosen as it has previously been used in young adolescents with knee pain<sup>9,12</sup>. Health related  
189 quality of life was measured by the youth version of the European Quality of Life 5 dimensions  
190 (EQ-5D-Y)<sup>1</sup>. Adolescents were asked about worst knee pain during the past weekly using a numeric  
191 rating scale (NRS), and asked if they considered themselves to be completely free of knee pain at  
192 each follow-up.

193

194 Self-reported sports participation was collected using questions about sports participation per  
195 week (both training and competition) and type of sport. This was supplemented by objective  
196 measures of PA, assessed by wrist Actigraphs (ActiGraph, Pensacola, FL). Participants wore  
197 actigraphs after inclusion, for two weeks before the intervention including activity modification  
198 began (to measure baseline PA), and immediately following block 1 (activity modification).

199 Satisfaction with the result of treatment was measured on a five-point Likert scale ranging from  
200 "highly satisfied" to "not satisfied at all". Additionally, participants were asked using the same  
201 scale, if they would be satisfied to live with their current knee symptoms on the same scale and, if  
202 they would recommend the same treatment to a friend with the same type of knee pain, with the  
203 response dichotomized into no/yes. The final question was related to use of pain killers asked as  
204 "do you currently use pain killers for your knee pain".

205

## 206 **Demographics**

207 Weight was measured using a weighing scale, and height was measured using a measuring tape  
208 against the wall, while the participants stood in bare feet.

209

**210 Assessment of hip and knee muscle torque**

211 We assessed isometric knee extension torque, hip abduction and hip extension torque for all  
212 adolescents. Torque was assessed using the best of three consecutive measurements normalized  
213 to body weight and lever length. The testing setup included a portable dynamometer and an  
214 examination table. Torque was tested using a Power Track Commander handheld dynamometer  
215 (JTech Medical, Salt Lake City, Utah), fixed to the examination bed by a belt. All tests were  
216 conducted isometrically and can be seen in web-appendix 1. The testing procedure is identical  
217 with previous work in adolescent's, which demonstrated high reliability<sup>9</sup>.

218

**219 Objective measure of physical activity**

220 Adolescents were asked to wear a wrist worn ActiGraph GT3X+ recording at 30 Hz for a minimum  
221 of one week following the clinical examination and determination of eligibility, prior to the  
222 beginning of the intervention. This was repeated after block 1 of the activity modification. For  
223 further information on data analysis, see supplementary appendix 1.

224

**225 Adherence to the intervention**

226 Adherence to the exercises were collected in self-report training diaries, while adherence to  
227 advice to reduce sports participation was collected via both self-report data, and the ActiGraph  
228 data. Adolescents were instructed to complete the training diary after every exercise session to  
229 record the number of exercises, sets and reps. A missing training diary (i.e. adolescents or parents  
230 did not return or forgot at several occasions to return), was interpreted as having done none of  
231 the exercises.

232

233 **Sample size**

234 Our previous studies in adolescents with PFP has shown that up to 50% of adolescent do not  
235 respond favourable to the intervention<sup>10,12</sup>. We therefore based our sample-size on the ability to  
236 test the association between key baseline characteristics and our primary outcome as well as  
237 return to sport. Using a recommendation of at least 10 events per prognostic factor, and a rate of  
238 successful outcome of around 50% of adolescents<sup>8</sup> we needed around 150 patients to test 5-7  
239 potential prognostic factors. The prognostic factors of interest were physical activity level, severity  
240 of knee pain (defined as symptom duration and intensity of knee pain) and health-related and  
241 knee-related quality of life (EQ5D and KOOS<sub>qol</sub>).

242

243 **Statistical analysis**

244 All data were visually inspected for approximate normality using a Q-Q plot. Mean values and  $\pm$ SD  
245 are reported if data were approximately normally distributed. If data were non-normally  
246 distributed they were presented as median and interquartile range (IQR). Repeated measures  
247 analysis of variance (RM ANOVA) was used to evaluate changes in strength over time with the  
248 independent variable time (baseline, 4 and 12 weeks) for the dependant variables of hip extension  
249 torque, knee extension torque and hip abduction torque. Similarly, RM ANOVA was used to  
250 evaluate the effect of time (baseline, 4 weeks, 8 weeks, 12 weeks, 6 months, and 12 months) on  
251 the KOOS subscales and EQ5D index scores. In cases where the assumption of sphericity was  
252 violated, Greenhouse Geisser correction was used. To explore if any baseline characteristics was  
253 associated with prognosis (assessed as a successful outcome on the GROC-scale) at the primary

254 endpoint, we compared the group having a successful outcome with the group not having a  
255 successful outcome. All calculations were performed using Stata version 11 (StataCorp, College  
256 Station, Texas, USA).

257

258

## 259 **Results**

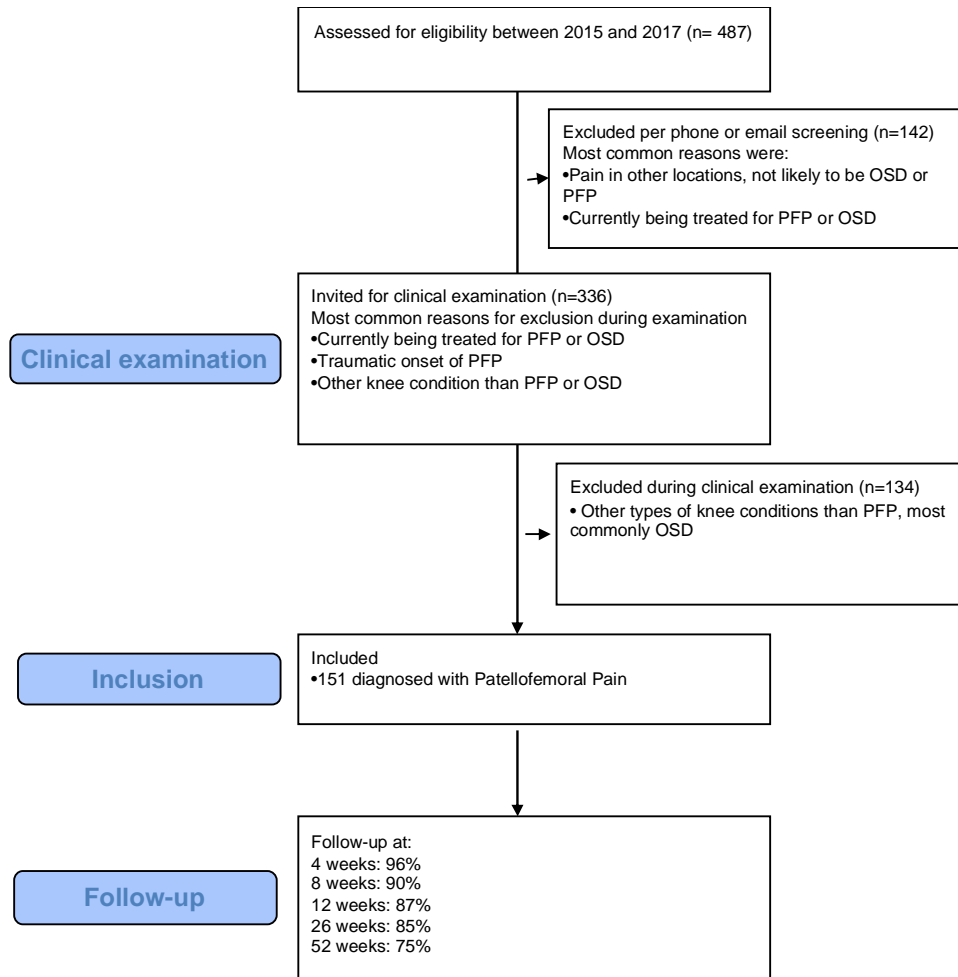
### 260 **Baseline characteristics**

261 During the 12 months of recruitment, 151 adolescents with PFP between 10 and 14 years of age  
262 were recruited (Figure 2). Participants had a median age of 13 years (IQR: 12-14), and a median  
263 self-reported symptom duration of 18 months (IQR: 9-24 months) at inclusion (Table 2). Of these,  
264 83% participated in sports, with the most common types of sport being soccer, handball and  
265 gymnastics. In total, 28% reported having previously been treated for their knee pain and 24%  
266 used analgesics for their knee pain at baseline. The most common treatments were unspecified  
267 treatment with a physiotherapist, shockwave and painkillers.

268

269 Figure 2: Flowchart





270

271 Table 2: Demographics

	Patellofemoral Pain (N=151)
<b>Age</b>	12.6 (1.2)
<b>Gender (% females)</b>	76%
<b>Weight [kg], mean (SD)</b>	50.4 (9.4)
<b>Height [cm], mean (SD)</b>	162.0 (9.6)
<b>BMI [kg/m<sup>2</sup>], mean (SD)</b>	19.0 (17.2-20.8)
<b>Duration of symptoms (n)*</b>	
<b>3-6 months</b>	6
<b>6-12 months</b>	31
<b>&gt;12 months</b>	107
<b>Pain duration [months] median (IQR)*</b>	18 (9-24)
<b>Age when knee pain started [years], mean (SD)]**</b>	11 (10-12)
<b>Bilateral pain (% who replied yes)</b>	73.5%
<b>Previously treated for PFP (% who replied yes)</b>	28%
<b>Participated in sports prior to onset of knee pain (% who replied yes)</b>	98%
<b>Pain medication for knee pain (% who replied yes)</b>	24%

\* 7 adolescents with PFP were not able to remember when their knee pain started and did not respond to the question

272  
273

274 Response rates

275 Response rates ranged from up to 96% at 4-week follow-up, 88% at the primary endpoint (12  
276 weeks), and down to 75% at 12 months follow-up.

277

278 Compliance to the intervention

279 On average the adolescents decreased moderate to vigorous activity (MVPA) by 20 min (95%CI 12-  
280 28) per day (corresponding to 2h:20min per week) after instruction in the activity modification,  
281 compared to before the activity modification. ActiGraph data showed that 87/136 adolescents  
282 reduced MVPA, with 35/136 reducing their MVPA by more than 45 mins per day compared to  
283 baseline. The self-report data showed that 29/141 participated in sports during the activity  
284 modification.

285 In block 1, 51 to 59% of adolescents with available follow-up data were categorised as adherent  
286 (i.e they performed more than 80% of the isometric quadriceps activation and double limbs  
287 bridges). In block 2, 57% performed more than 80% of the exercises and 44% performed more  
288 than 80% of the exercises during block 3.

289

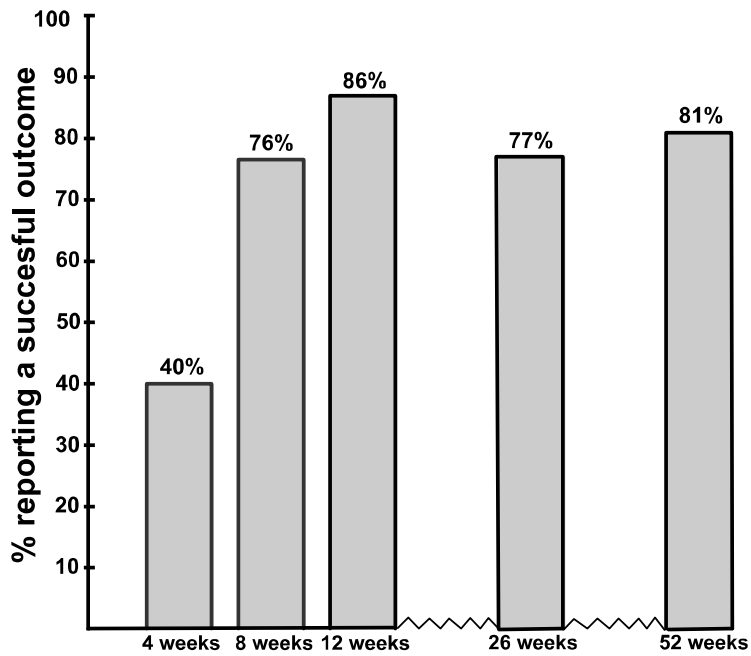
290 **Primary analysis**

291 After the 12-week intervention, 88% (N=132) completed the questionnaire, and of these, 86%  
292 (95%CI: 78-91%) were deemed to have a successful outcome (improved or much improved), with a  
293 slightly lower proportion at 6 months (77%, 95%CI: 68-83%) and 12 months (81%, 95%CI: 73-88%),  
294 Figure 3.

295

296 **Figure 3:** Proportion reporting a successful outcome (success defined as reporting “much

297 improved” or “improved” on the Global Rating of Change Scale).



298

299

300 **Secondary analyses**301 **Physical activity and sports participation**

302 After 12 weeks, 68% of the participants reported that they were back playing sport, with 79% at 6  
 303 months and 81% at 12 months (Table 3).

304

305 Table 3: Sports participation

	Pre-intervention	4 weeks	8 weeks	12 weeks	6 months	12 months
<b>Did you participate in sports the previous month? (% reporting yes)</b>	138/151	29/141	47/131	84/124	93/120	91/115
<b>Current sports participation (training + competition per week)? (frequency per week)*</b>	2 (1-3.15)	1 (1-3)	2.5 (1-4)	2.25 (1-3.75)	3 (2-4)	4 (3-5)
<b>*Presented as median and Interquartile range</b>						

306

307

308

309 **Knee pain**

310 KOOS pain significantly improved over time ((F6,105);P<0.001; Table 5). Worst pain previous week  
 311 on a NRS improved from a median of 7 out of 10 at baseline and down to 3 out of 10 at 12 weeks  
 312 and 2 out of 10 at 12 months. At 12 weeks 92/133 considered themselves to be completely free  
 313 from their previous knee pain, with 81/120 at 12 months.

314

315 **Self-reported knee disability and quality of life**

316 Across the three KOOS domains, ADL, sport and recreation and quality of life, adolescents with  
 317 PFP improved 13-24 points from baseline to primary endpoint (Table 3; P<0.001) and 14-28 points  
 318 to 12 months follow-up, (P<0.001). EQ5D index score increased significantly (F(4,52); P<0.001) by  
 319 0.20 points at 12 weeks and 0.22 points at 12 months (Table 4).

320

321

Table 4: Knee Injury and Osteoarthritis Outcome Score, EuroQoL 5D-3L and pain intensity

X	Pre-intervention Patellofemoral Pain (N=151)	Baseline, mean (SD) N=136	4 weeks, mean (SD) N=138	8 weeks, mean (SD) N=134	12 weeks, mean (SD) N=133	6 months, mean (SD) N=125	12 months, mean (SD) N=120	Change from baseline to 12 weeks, mean (95%CI)	Change from baseline to 12 months, mean (95%CI)
KOOS <sub>pain</sub> [0-100, worst to best]	66 (16)	68 (14)	74 (16)*	80 (15)*	86 (13)*	89 (14)*	88 (15)*	17 (15-20)	21 (18-24)
KOOS <sub>symptoms</sub> [0-100, worst to best]	77 (14)	78 (13)	82 (13)*	87 (12)*	90 (11)*	90 (12)*	90 (13)*	11 (9-14)	12 (9-15)
KOOS <sub>AoL</sub> [0-100, worst to best]	77 (15)	79 (14)	82 (14)*	87 (13)*	92 (10)*	94 (11)*	93 (12)*	13 (10-15)	14 (11-17)
KOOS <sub>sport/recreation</sub> [0-100, worst to best]	54 (23)	55 (21)	63 (28)*	71 (24)*	80 (20)*	82 (22)*	83 (21)*	24 (20-28)	28 (23-33)
KOOS <sub>QoL</sub> [0-100, worst to best]	50 (18)	49 (16)	49 (19)	57 (21)*	66 (22)*	75 (23)*	78 (23)*	16 (12-20)	28 (23-32)
EuroQoL 5D 3L* [index score]		0.72 (0.63-0.78)	0.72 (0.60-0.80)	0.78 (0.71-0.82)*	0.82 (0.78-1.00)*	0.84 (0.78-1.00)*	0.83 (0.78-1.00)*	0.20 (0.16-0.24)	0.22 (0.17-0.27)
Worst pain last week (numeric rating scale), median (IQR)	7 (5-8)	7 (5-8)	5 (3-7)	4 (2-5)	3 (1-5)	2 (1-4)	2 (0-4)	3.5 (3.0-4.1)	4.3 (3.7-5.0)
Proportion considering themselves "free of knee pain"		N/A	52/144	68/135	92/133	87/125	81/120		

322 \*indicates significant changes from baseline

323

324

325 **Hip and knee torque**

326 There was a significant effect of time for hip extension torque (F(2,139); P&lt;0.001), hip abduction

327 torque (F(2,24);P&lt;0.001) and knee extension torque (F(2,64); P&lt;0.001). Post-hoc tests revealed

328 there was a significant increase in torque over time (Table 5) with the largest changes in hip

329 extension torque with an 34% increase during the 12 weeks.

330

331 Table 5: Changes in isometric hip and knee torque from baseline to 12 weeks.

	Baseline (SD)	4 weeks (SD)	12 weeks (SD)	Change from baseline to 12 weeks (95%CI) (% increase)
Hip abduction torque (Nm/kg)	1.23 (0.42)	1.35 (0.48)*	1.49 (0.37)*	0.25 (0.17-0.33) 20.3%
Knee extension (Nm/kg)	1.85 (0.72)	1.96 (0.70)*	2.39 (0.84)*	0.48 (0.40-0.57) 27.9%
Hip extension (Nm/kg)	1.17 (0.44)	1.32 (0.41)*	1.56 (0.41)*	0.38 (0.34-0.43) 32.5%

332 \* indicates significant increase from baseline at P&lt;0.01

333

334 **Satisfaction with treatment**

335 At the primary endpoint (12 weeks), 74% participants reported being very satisfied with the result  
336 of treatment. One adolescent was very unsatisfied with the results of the treatment. 95% would  
337 recommend it to a friend with the same type of knee pain. **Fifty percent were very satisfied to live**  
338 **with their current knee symptoms while 8% were very unsatisfied.**

339

340 At 12 months follow-up 75% were very satisfied with the results of the treatment. 51% would be  
341 very satisfied to live with current level of symptoms, while 8% would be very unsatisfied. **Ninety**  
342 **two percent** would recommend it to a friend with similar knee pain.

343

344 **Use of medication and additional treatments**

345 At 12 weeks follow-up, 7% adolescents reported using painkillers, compared to 24% at baseline  
346 ( $P>0.001$ ). Three percent reported having sought additional treatments at 12 weeks follow-up. Use  
347 of additional treatments, types, and use of pain killers across all time point can be found in  
348 appendix 3.

349

350 **Prognostic factors**

351 **The were no statistically or clinically relevant** differences in clinically measurable patient  
352 characteristics or adherence between those having a successful outcome and adolescents not  
353 having a successful outcome (appendix 4).

354

355 **Discussion**

356 This prospective study showed that 86% of adolescents with PFP were considered to have a

357 successful outcome (based on the GROC) at 12 weeks, with a slightly lower proportion after 6 and  
358 12 months. Adolescents reported large improvements in knee pain and function, and 20-33%  
359 increase in hip and knee torque. This is the first study to test an intervention focussing specifically  
360 on activity modification and load management, where a high proportion of adolescents returned  
361 to sport at follow-up.

362

### 363 **Prognostic factors**

364 Preliminary evidence indicates that certain pain characteristics, as well as quality of life are  
365 associated with outcome in both short term and long term<sup>11</sup>. These findings were not replicated in  
366 the current study. None of the patient characteristics, or adherence to the intervention were  
367 different between those having a successful outcome and those who did not. The clinical  
368 implications of this, is that the large improvements seen may exist across sports active and non-  
369 sports active adolescents and both those with high and low levels of pain intensity.

370

### 371 **Rates of success compared to previous studies on adolescent patellofemoral pain**

372 A previous cluster randomised trial on supervised exercise plus patient education, versus patient  
373 education alone, using similar outcome as the present study, showed much lower success rates  
374 (29%) in both arms<sup>12</sup>. The current study on the other hand had 86% success rate, according to the  
375 same definition of success. Similarly, a pilot study in younger adolescents with PFP showed limited  
376 success on supervised exercise for young adolescents with PFP<sup>10</sup>. The poor results and adherence  
377 resulted in the conclusion that it was impractical to undertake a full clinical trial centered on  
378 exercise alone in young adolescents with PFP.

379 In contrast the current intervention focusing on activity modification and load management,

380 resulted in higher succes rates, and significantly improved KOOS scores, with improvements in  
381 KOOS sport/rec more than double compared to the two previous studies on adolescent PFP<sup>12 10</sup>.

382 There are many potential reason for the greater effect of the current intervention compared to  
383 previous trials on adolescents with PFP<sup>10,12</sup>. Despite the underlying reason cannot be determined  
384 in the current investigation, some plausible explanations include that the current intervention  
385 focussed on modifying the sports/activities that are thought to be associated with the  
386 development of knee pain. Further, the intervention provided a structured approach to expose  
387 and build up tolerance to aggravating activities, helping adolescents be guided back to sports in a  
388 graded manner. This could potentially avoid the 'all or nothing' approach some patients take if  
389 not specifically guided on how to balance this- a balance that may be particulary difficult for  
390 adolescents. Another factor that may play a role in the positive results could be age, as no  
391 previous studies have investigated adolescents with PFP at such a young age. It is however  
392 unknown if these adolescents at 10-14 of age have a better natural history, than those who are  
393 older in previous research. However, these are all postulative and the intervention needs to be  
394 further evaluated and compared to a relevant control to determine its efficacy.

395

396 Despite the positive results, the improvement stagnated after 12 weeks, and after 12 months  
397 average KOOS (Sport/rec) was 83 points, which is still lower than the average 100 points for  
398 controls (blinded reference). Despite reporting improvement on the GROC, the sustained  
399 impairments in sports function and participation indicates this is a long-term condition that needs  
400 ongoing management . As a high proportion of adolescents will stop playing sports due to knee  
401 pain<sup>11</sup>, effective treatments need to consider how to target return to sport, as this is an important  
402 aspect of their life.



403

404 Although 2/3 successfully returned to sport at three months, 1/3 did not, and at 12 months 1/5  
405 were still not back playing sport. The majority of those who had not returned at 12 months had  
406 reported a desire to return, but 4/120 had given up due to knee pain.

407

408 In the present trial self-reported weekly sports participation was overall increased from inclusion  
409 to twelve months. This suggests that despite that participants reported they had reduced  
410 participation at inclusion due to knee pain, quite a large proportion were able to return and  
411 increased their activity after the intervention. This is encouraging, as a previous trial on  
412 adolescents between 15 and 19 years of age with PFP actually reduced their overall sports  
413 participation from inclusion to 12 months<sup>12</sup>.

414

#### 415 **Good adherence and strength improvements**

416 The adherence to refrain from sports participation in block 1 was good (almost 80%). Adherence  
417 to the exercise part was very high (44-57% with more than 80% adherence) compared to previous  
418 trials where almost none participated in more than 80% of the prescribed exercises<sup>12 10</sup>.

419

420 Previously, only minor with-in group strength improvements (between 0 and 10%) have been  
421 reported in adolescents receiving an exercise program<sup>10,13</sup>. One exception is a technology  
422 supported intervention which gave feedback on the execution of exercises and reported a 25%  
423 strength increase<sup>15</sup>. Whether the the 20-33% increased hip and knee torque occurring in the  
424 current study is a result of the large pain reduction or the good adherence to the strengthening  
425 exercises is unknown, and needs further investigation. However, regardless of the underlying

426 mechanism, such an improvement in hip and knee muscle strength could be an important  
427 adaptation as this may reflect an increase in the the load bearing capacity of hip and knee specific  
428 tissues.

429

#### 430 **Satisfaction with results of treatment was high**

431 75% participants were “very satisfied” with the results of treatment, which is higher compared to  
432 two previous studies in adolescents with PFP (50-60% despite pooling “very satisfied” and  
433 “somewhat satisfied”) <sup>10,13 12</sup> . However, only 1 in 2 would be “very satisfied” to live with their  
434 current symptoms at the end of the trial and only 68% considered themselves being free from  
435 knee pain even after 12 months. Based on this, the GROC may paint an overly positive  
436 representation of treatment outcome, and just because they report an improvement in  
437 symptoms, does not mean they do not continue to suffer from pain, and experience deficits in  
438 important domains, such as sport. Therefore, while the current results are better than previous  
439 studies using the same outcome, it is unknown if the the dose and delivery of the intervention  
440 could still be optimised in order to ensure the goal (being pain-free and normal function) is better  
441 attained in subsequent iterations of the intervention.

442

#### 443 **Painkiller usage in adolescents with PFP**

444 In the current study, 24% participants used painkillers at inclusion, which decreased to 7% after 3  
445 months. The reduction in use of painkillers was associated with a drop from 7 to 3 in pain intensity  
446 (NRS) in the same period. This is particularly note-worthy as no advice on painkillers was given in  
447 the education, and indicating a decreased requirement for pain relief. The effect of the  
448 intervention on painkiller use is larger than in previous trials on adolescents with PFP. In particular,

449 in one study 24% adolescents used painkillers at the beginning which decreased to 18 % after 3  
450 months<sup>12</sup> and far greater than a pilot study involving 20 adolescents with PFP between 12 and 16  
451 who found no effect of the intervention on use of painkillers<sup>10</sup>.

452

453

#### 454 **Limitations**

455 The lack of comparator and randomization hinders a direct comparison to previous exercise  
456 therapy focused trials. The long duration of knee pain (on average 18 month) do suggest that  
457 quick recovery is unlikely and suggest a specific effect of the intervention. This trial cannot  
458 disentangle natural recovery versus the specific effects of the intervention. However, due to the  
459 dearth of effective interventions for this specific age group and population, the current  
460 intervention including only four supervised sessions over a 12 week period seems relevant to  
461 adopt in clinical practice, as best available evidence on this particular young age group. The study  
462 was underpowered for the investigation of prognostic factors as we had far higher rates of  
463 successful outcome than anticipated.

464

#### 465 **Future research**

466 Patellofemoral pain in adolescents has been notoriously difficult to treat and highlighted as a  
467 research priority<sup>17</sup>. The current study is the first to provide evidence of an intervention with both  
468 good short and longer term effects (up to 12 months). Despite the intervention was considered a  
469 “success” based on the GROCC, not all considered themselves completely free from knee after 12  
470 months with 20% not returning to sport, which suggests that ongoing management of this  
471 condition is still needed. Future research should investigate how to optimize the treatment of

472 young adolescent with PFP further, including optimal timing of interventions and comparisons to  
473 a control intervention.

474

475 **Conclusion**

476 A treatment strategy focusing on activity modification and load management was associated with  
477 high rates of successful outcomes in adolescents with PFP, at both 12 and 52 weeks. These short  
478 and longer term outcomes were supported by improvements in symptoms, and in objective  
479 measures of hip and knee torque.

480

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