Physical Therapy Improves Knee Flexion during Stair Ambulation in Patellofemoral Pain

KAY M. CROSSLEY[1,2], SALLIE M. COWAN[1], JENNY MCCONNELL[1,3], and KIM L. BENNELL[1]

[1]Centre for Health, Exercise and Sports Medicine, School of Physiotherapy, University of Melbourne, AUSTRALIA; [2]Olympic Park Sports Medicine Centre, Melbourne, AUSTRALIA; and [3]McConnell and Clements Physiotherapy, Sydney, AUSTRALIA

ABSTRACT

CROSSLEY, K. M., S. M. COWAN, J. MCCONNELL, and K. L. BENNELL. Physical Therapy Improves Knee Flexion during Stair Ambulation in Patellofemoral Pain. *Med. Sci. Sports Exerc*., Vol. 37, No. 2, pp. 176–183, 2005. **Purpose:** This study aimed to examine whether a physical therapy intervention, designed to reduce pain and improve the neuromotor control resulted in greater improvements in stance-phase knee flexion during stair ambulation in individuals with patellofemoral pain. The relationship between changes in stance-phase knee flexion and changes in pain, disability, and onset timing of individual vasti activity was also examined. **Methods**: Forty participants aged 40 yr or younger diagnosed with patellofemoral pain were randomly allocated to a physical therapy ($N = 21$) or placebo ($N = 19$) treatment group. Stance-phase knee flexion was measured in two dimensions using a PEAK movement analysis system during stair ambulation. Individuals were divided into those with improvements in onset of vastus medialis obliquus (VMO) activity relative to that of the vastus lateralis (VL) of more or less than 10 ms. **Results:** Groups were similar at baseline. After the 6-wk intervention, individuals in the physical therapy group had significantly greater changes in knee flexion at heel strike (mean difference 4°, 95% CI = 2–7°) and peak stance-phase knee flexion (mean difference 9°, 95% CI = 5–12°) than those in the placebo group. No differences were noted during stair ascent. Individuals with greater change in the onset timing of the vasti had greater improvements in stance-phase knee flexion. Changes in usual pain in the week before testing and change in the vasti onset timing were independent predictors of change in stance-phase knee flexion during stair descent, together accounting for 27–40% of the variability in knee motion. **Conclusions**: Physical therapy intervention resulted in significantly greater changes in knee joint motion than a placebo treatment, and these changes in knee motion were partly related to changes in pain and changes in onset timing of the vasti. **Key Words:** REHABILITATION, VASTI, KNEE MOTION, RETRAINING, GAIT, NEUROMOTOR CONTROL

Patellofemoral pain is a musculoskeletal complaint that is common in active and general populations. Recent prospective cohort studies have identified that approximately 10% of active individuals will develop patellofemoral pain (1,31). Currently, the specific pathological process associated with patellofemoral pain is not known (12). However, patellofemoral pain is associated with stereotypical symptoms, namely, anterior or retropatellar pain that is aggravated by activities that repetitively load the patellofemoral joint (PFJ). During weight bearing, activities that involve knee flexion will increase the PFJ reaction force (2,30). Stair ambulation is one activity in which the PFJ reaction force is high (4,23), and thus pain and difficulty with stair ascent and descent are frequently reported in individuals with patellofemoral pain (19).

Reduced stance-phase knee flexion in individuals with patellofemoral pain may be an adaptation to reduce PFJ load or a response to abnormal stimulation of nociceptor and mechanoreceptors. To date, four studies have examined the amount of knee motion in individuals with and without patellofemoral pain, and there are conflicting results. Our research group and one other study found that individuals with patellofemoral pain had less knee flexion during stair descent (11,17). In contrast, no differences between individuals with and without patellofemoral pain in the amount of knee motion were noted by Powers et al. (28) and Heino Brechter and Powers (19), but it is possible that the decreased walking velocity in the patellofemoral pain participants may have contributed to the lack of kinematic differences.

Our previous work has established that the onset of vastus medialis obliquus (VMO) activity was delayed relative to that of vastus lateralis (VL) (8) and that this was associated with less knee flexion during stair descent (11) in a patellofemoral pain cohort compared with a group of healthy controls. It is possible that asynchronous activity of the vasti may be associated with altered patellar tracking, ultimately leading to areas of increased stress in the PFJ (16). There-

Address for correspondence: Dr. Kay Crossley, Centre for Sports Medicine Research and Education, School of Physiotherapy, The University of Melbourne, Victoria 3010, Australia; E-mail: k.crossley@unimelb.edu.au.
Submitted for publication August 2003.
Accepted for publication September 2004.

0195-9131/05/3702-0176
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/01.MSS.0000152676.13197.49

fore, an intervention designed to decrease patellofemoral pain and improve the neuromotor control of the vasti may result in improvements in stance-phase knee flexion during stair ambulation.

Diminution of pain and disability is the most important outcome of treatment. Additionally, if reduced stance-phase knee flexion is observed in individuals with patellofemoral pain, then a valuable aim of an intervention should be to restore normal gait kinematics. To date, there is a paucity of trials that have assessed the effects of intervention on knee joint kinematics during gait in participants with patellofemoral pain. Chesworth and coworkers (3) failed to find any modification in the gait kinematics during downhill treadmill walking in participants with patellofemoral pain after improvement in their clinical symptoms. A number of factors may have contributed to the lack of a treatment effect including the use of a pragmatic intervention that did not specifically address knee function and a sample that may not have had sufficient baseline pain to exhibit reduced stance-phase knee flexion. Although no previous study has demonstrated that a physical therapy intervention can affect knee stance-phase knee flexion during gait, Powers and coauthors (27) found an effect related to patellar tape. They found that the application of patellar tape resulted in a small but significant increase in peak stance-phase knee flexion during the taped condition while participants walked at two speeds, up and down ramps, and up and down stairs.

AIM

We recently conducted a randomized, controlled trial (RCT) that investigated the efficacy of a physical therapy intervention to reduce the pain and disability associated with patellofemoral pain (9). The primary objective of the physical therapy intervention was to improve the neuromotor control of the vasti using a progressive motor retraining program. The aim of the current project was to assess whether individuals who were randomized into the physical therapy group attained a greater increase in stance-phase knee flexion than those in the placebo treatment group. A secondary aim was to evaluate whether changes in stance-phase knee flexion would be partly related to the reductions in patellofemoral pain and disability and improvements in vasti neuromotor function that were noted and have been reported in previous publications (5,9).

METHOD

A randomized, double-blind, placebo control trial was used to investigate the effects of a physical therapy intervention on stance-phase knee flexion during stair ambulation (9).

Participants. The first 40 participants enrolled in a larger RCT (9), for which there were kinematic data available, formed the cohort for this trial. All participants provided written informed consent, and all procedures were undertaken with prior approval from the Human Research and Ethics Committee of The University of Melbourne. Participants were recruited from health professionals, advertisements, and media in Melbourne, Australia. Eligibility criteria were based on those used in previous studies, and an experienced practitioner made the diagnosis of patellofemoral pain on clinical examination. The inclusion criteria were (i) anterior or retropatellar knee pain on at least two of prolonged sitting, stairs, squatting, running, kneeling, and hopping/jumping; (ii) insidious onset of symptoms unrelated to a traumatic incident; (iii) presence of pain on palpation of patellar facets and on step-down from a 25-cm step or double leg squat. Participants were excluded if they had (i) signs or symptoms of other knee pathology; (ii) previous surgery to the PFJ complex; (iii) aged older than 40 yr to reduce the possibility of degenerative joint disease; (iv) previous exposure to patellar taping or known allergy to adhesive tape; (v) inability to attend a physical therapy clinic for a 6-wk treatment program; (vi) currently taking nonsteroidal antiinflammatory (NSAIDs) or corticosteroid medication; and (vii) inability to understand written and spoken English.

Group assignment. Participants were randomly allocated to the physical therapy or placebo treatment groups using simple randomization (in blocks of four), stratified to treatment center, using a computer-generated table of numbers. Treatment allocation was concealed from the outcome assessor at all times and from the physiotherapist until the commencement of treatment. One investigator (K.L.B.) kept the assignment schedule, and the treatment group allocation was provided to the treating physiotherapist in a sealed, opaque envelope.

Interventions. Standardized physical therapy and placebo treatments were implemented, once weekly for 6 wk for similar lengths of time in each group. Ten experienced physiotherapists were trained in the implementation of both interventions. The treatments are described in detail in the published RCT (9) and are summarized below.

Physical therapy treatment. A treatment protocol was developed, based on routine practice in Australia (24,25). Treatment components included (i) patellar taping, corrective taping applied in a standard manner to reduce the participant's symptoms by 50% (Fixomull; Beiersdorf Australia, North Ryde, Australia, and Endura-tape; Endura-Tape Pty., Ltd., Sydney, Australia); (ii) retraining of the vasti, a series of exercises designed to provide progressive load to the PFJ using surface EMG biofeedback (Pathway MR-20; The Prometheus Group, Dover, NH) to maximize that VMO activity; (iii) gluteal strengthening, isometric hip abduction/external rotation in standing; and (v) mobilization of the patella performed in side lying and a home program of stretches to the hamstring and hip rotators. Physiotherapists delivering the intervention were trained in its implementation and were provided with a training manual. Participants were prescribed daily home exercises and provided with standardized home exercise sheets. Compliance with home exercises was monitored via the daily log.

Placebo treatment. The placebo intervention consisted of placebo taping (Endura-tape; Endura-Tape Pty., Ltd.), inoperative ultrasound (custom-made devices), and the light application of a nontherapeutic gel (ultrasonic gel; Parker Laboratories Inc., Fairfield, NJ, and Hospital Skin Care Lotion; Smith & Nephew, Clayton, Australia).

Outcome measures. In all participants, outcome assessment was performed by the investigators (K.M.C. and S.M.C.), blinded to group allocation, at baseline and at the conclusion of the 6-wk treatment program.

Pain and disability scales. A number of self-administered questionnaires were chosen, based on their reliability and validity in this patient population (10). Participant's overall assessment of pain was measured using a 10-cm visual analog scale for usual pain (VASU) in the previous week. Disability was measured on an anterior knee pain–specific, self-administered questionnaire (AKPS) (22). The number of step-ups (25-cm step) and step-downs (25-cm step) that could be performed before the onset of pain was recorded. In addition, the amount of pain recorded during the stair ambulation task was measured on a 10-cm visual analog scale (VASstep). Participants also completed a 5-point scale recording their perceived global rating of change (1 = marked worsening, 2 = moderate worsening, 3 = same, 4 = moderate improvement, 5 = marked improvement).

Stance-phase knee flexion. Stance-phase knee flexion was recorded at baseline and at the conclusion of the 6-wk treatment program in the affected limb (or the more symptomatic limb in case of bilateral symptoms). Stance-phase knee flexion was measured with a PEAK movement analysis system (Peak Performance Technology Inc., Englewood, CO 1991). Reflective markers used to determine sagittal plane motion were attached to the lateral malleolus, neck of the fibula, on the iliotibial band at the level of the superior border of the patella and lateral thigh (junction of the proximal one-third and distal two-thirds) using a standard protocol (29). Custom-made stairs (60-cm platform, two 20-cm high steps) (6) were placed in the center of a 5-m walkway. Movement data of stance-phase (initial foot strike to toe-off) during ascent and descent were recorded by a single camera at a frequency of 50 Hz and then digitized. The obtained raw data representing the spatial location of the four reference markers were then filtered using a robust nonlinear least-squares fourth order (Butterworth) filter. An independent assessor, blinded to group allocation (physical therapy or placebo) digitized the movement data from the videotape. Participants wore their own footwear and were instructed to wear the same footwear on the second test occasion. Each participant completed at least five practice trials, and data were then collected on five trials at a stair-stepping rate of 96 steps per minute.

Stance-phase knee flexion was calculated for both ascending and descending stairs for each trial. Two angular variables were of interest: (i) knee flexion at heel strike and (ii) peak stance-phase knee flexion. The temporal variable of interest was the time to peak stance-phase knee flexion (reported as a percentage of the total stance time). Our previous study determined that the average of three trials was appropriate to obtain a representation of knee joint motion during stair ambulation (11).

EMG recordings of vasti. Recordings of vasti EMG onset are described in full in a previous study (8). Briefly, EMG data were taken during the stance-phase of stair ascent and descent from five consecutive trials. The data were preamplified (ten times) distal to the surface electrodes, band-pass filtered between 20 and 500 Hz, sampled at 1000 Hz, full-wave rectified, and low-pass filtered at 50 Hz. A computer algorithm identified the onset of EMG activity, and the onsets were checked visually from the raw traces. The algorithm identified the point at which the EMG signal deviated by more than three SD, for a minimum of 25 ms, above the baseline level (averaged over 200 ms before the commencement of the trial). The rectified unfiltered EMG data were visually checked to verify the EMG onsets identified by the computer. The onset of EMG activity from each of the individual trials were averaged over the five repetitions and the relative difference in the onset of the vasti was determined by subtracting the time of onset of EMG activity of the VMO from that of the VL. This method is reliable in our laboratory (6). The onsets of the vasti EMG are used in the present study to assess the relationship between changes in VMO EMG onset relative to VL and changes in stance-phase knee flexion after the 6-wk intervention.

Participant details. Age, gender, and duration of symptoms were recorded. Height and weight were measured on each participant when barefoot, and body mass index (BMI) was calculated.

Statistical analyses. All statistics were performed with the Statistical Package for Social Sciences (SPSS; Norusis/SPSS Inc., Chicago, IL), and a two-tailed level of significance was set at 0.05 for all tests. Baseline comparisons between the participants in the physical therapy and placebo treatment groups were performed using independent *t*-tests or chi-square analyses. The effects of treatment were evaluated separately in both the placebo and physical therapy groups using paired *t*-tests. For each gait parameter, the change from baseline to final assessment was calculated. The mean changes were compared between participants in the physical therapy intervention group and those in the placebo group using independent *t*-tests.

To assess the relationship between changes in vasti onset and changes in stance-phase knee flexion, the participants were divided into two groups: those with no change in the onset of VMO relative to VL ($<$10 ms) and those with an earlier onset of VMO relative to VL ($>$10 ms) after the 6-wk intervention. The mean change in stance-phase knee flexion for each group was calculated and then compared using an independent *t*-test. The bivariate relationships between changes in stance-phase knee flexion and the changes in vasti EMG onset, pain, and disability associated with treatment were assessed in the total cohort (physical therapy and placebo treatment groups, $N = 40$) at the completion of the intervention using either a Spearman's or Pearson's correlation coefficient. Pain, disability, and EMG onset vari-

TABLE 1. Description of mean (SD) or frequency characteristics at baseline for the participants in the physical therapy and placebo treatment groups.

	Physical Therapy (*N* = 21)	Placebo (*N* = 19)	Mean Difference (95% CI)	*P*
Participant characteristics				
Age (yr)	31 (6)	26 (8)	5 (0 to 10)	0.038*
Height (m)	1.68 (0.8)	1.71 (0.8)	0.03 (−0.03 to 0.08)	0.335
Weight (kg)	67.7 (14.7)	71.5 (15.6)	3.8 (−5.8 to 13.5)	0.431
BMI (kg·m^{-2})	23.8 (4.1)	24.4 (4.0)	0.57 (−2.0 to 3.2)	0.660
Gender	15 F; 6 M	12 F; 7 M	NA	0.577[a]
Leg dominance	18 R; 3 L	17 R; 2 L	NA	0.720[a]
PFP symptom characteristics				
Total duration of symptoms (mo)	41 (45)	24 (27)	17 (−7 to 41)	0.154
VASW (cm)	7.5 (1.5)	7.0 (1.5)	0.5 (−1.0 to 0.5)	0.381
VASU (cm)	4.5 (1.5)	4.5 (1.5)	0 (−1.0 to 0.5)	0.565
AKPS (100-point scale)	69 (7)	71 (10)	2 (−4 to 8)	0.468
VASstep (cm)	3.0 (1.5)	3.0 (2.0)	0.5 (−0.5 to 2.0)	0.259
No. of step-ups (*N*)	9 (7)	7 (5)	2 (−2 to 6)	0.292
No. of step-downs (*N*)	5 (4)	5 (4)	1 (−2 to 2)	0.950

Leg dominance leg nominated as preferred to kick a football.
BMI, body mass index; VASW, worst pain in the preceding week, measured using a 10-cm visual analog scale; VASU, usual pain in the preceding week, measured using a 10-cm visual analog scale; AKPS, anterior knee pain scale; VASstep, amount of pain during stair stepping task, measured using a 10-cm visual analog scale.
[a] Chi-square analyses; $P < 0.05$.

ables that were significantly correlated with changes in stance-phase knee flexion were then subjected to forward stepwise multiple regression analyses to identify independent predictors.

Sample size of the measurement for stance-phase knee flexion was calculated on a predetermined difference in change in peak stance-phase knee flexion between groups of 5°, based on the results of a previous study (27). Sample size calculations, assuming an SD of 6°, indicate that 38 participants were required to have 80% power to detect the 5° difference. This was increased to 40 to allow for dropouts.

RESULTS

Twenty-one individuals were randomized into the physical therapy group and 19 into the placebo treatment group.

Baseline Comparability

Participant characteristics and patellofemoral pain characteristics of the physical therapy treatment group and placebo treatment group are presented in Table 1. In general, the groups were well matched, but the participants in the physical therapy group were older than those in the placebo group. The amounts of patellofemoral pain and disability were equivalent between the two groups. At baseline, the amount of knee flexion during stair ambulation was similar to that in our previous (larger) cohort of individuals with patellofemoral pain and less than that described in the healthy cohort (stair ascent: knee flexion at heel strike 72°, peak knee flexion 74°; stair descent: knee flexion at heel strike 16°, peak knee flexion 36°) (11). In the present study, there were no differences in the amount or timing of knee flexion ($P > 0.05$) during stair ascent or descent between the two treatment groups at baseline (Table 2).

Effect of Physical Therapy Intervention on Pain and Disability

The results of the main RCT on pain and disability are presented in full in a prior publication (9). Briefly, significantly greater improvements in pain were noted in the present study by the individuals in the physical therapy group (mean change 3.5 ± 1.5 cm) than those in the placebo group (mean change 2.0 ± 1.5 cm).

Effect of Physical Therapy Intervention on Stance-Phase Knee Flexion

After the 6-wk intervention, participants in the placebo treatment group were essentially unchanged (Table 2 and Fig. 1). In contrast, individuals in the physical therapy group had significant improvements in the amount of knee flexion at heel strike and peak stance-phase knee flexion. Analyses of the mean changes in knee flexion between the two treatment groups revealed similar results, with significantly greater improvements in knee motion in those individuals in the physical therapy treatment group. The mean (SD) for the

TABLE 2. Stance-phase knee flexion of participants in physical therapy and placebo treatment groups at baseline, final assessment, and mean change.

	Baseline		Final		Mean change			
	Physical Therapy (*N* = 21) Mean (SD)	Placebo (*N* = 19) Mean (SD)	Physical Therapy (*N* = 21) Mean (SD)	Placebo (*N* = 19) Mean (SD)	Physical Therapy (*N* = 21) Mean (SD)	Placebo (*N* = 19) Mean (SD)	Mean Difference (95% CI)	*P*
Ascending stairs								
Knee flexion at heel strike (°)	65 (11)	64 (12)	69 (8)	66 (9)	4 (12)	2 (12)	2 (−6 to 10)	0.624
Peak knee flexion (°)	68 (9)	67 (11)	71 (7)	67 (8)	3 (11)	1 (10)	2 (−5 to 9)	0.527
Time to peak (%)	9 (5)	9 (4)	9 (5)	10 (5)	−1 (4)	1 (4)	1 (−2 to 4)	0.432
Descending stairs								
Knee flexion at heel strike (°)	13 (5)	13 (4)	17 (5)	13 (4)	4 (4)	−1 (3)	5 (2 to 7)	0.000
Peak knee flexion (°)	31 (7)	34 (7)	39 (6)	32 (5)	7 (6)	−2 (4)	9 (5 to 12)	0.000
Time to peak (%)	24 (4)	26 (6)	30 (4)	26 (4)	6 (19)	0 (5)	6 (1 to 12)	0.082

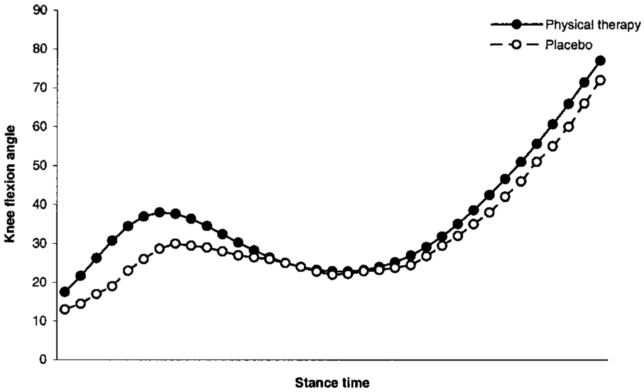

FIGURE 1—Representative trace of stance-phase knee flexion for the physical therapy and placebo treatment groups.

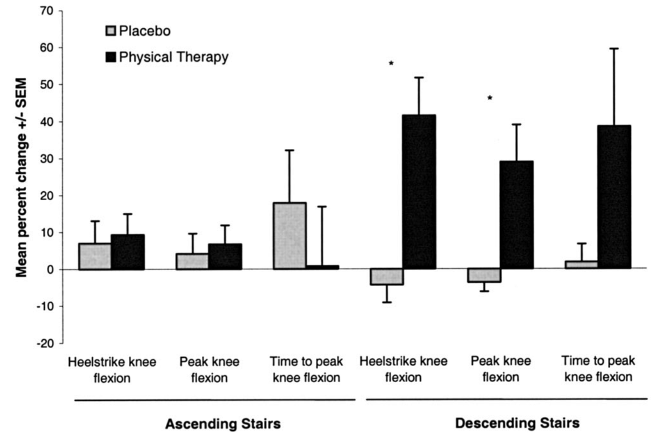

FIGURE 2—Mean percentage of change from baseline in stance-phase knee flexion of the physical therapy and placebo treatment groups.

baseline, final, and mean change scores are presented in Table 2 and the percentage of changes (final − baseline score/baseline score) are presented in Figure 2.

Relationship between Changes in Stance-Phase Knee Flexion and Changes in Timing of Vasti EMG Onset

At baseline, the mean onset of VMO EMG activity was delayed relative to that of the VL, and these data are presented in a previous publication (8). Participants were divided into two groups: those whose change in VMO onset relative to VL onset was ≤10 ms ($N = 18$) and those whose change in VMO relative to VL onset was >10 ms ($N = 22$). The amount and timing of stance-phase knee flexion in these groups were comparable at baseline ($P > 0.05$) (Table 3). At the conclusion of the 6-wk intervention, individuals whose VMO onset timing relative to VL had improved by more than 10 ms had significantly greater improvements in stance-phase knee flexion during stair descent (Table 3). There were no significant differences in knee joint motion during stair ascent.

During stair descent, bivariate correlations revealed similar results with significant but moderate correlations noted between changes in VMO EMG onset relative to VL with increases in knee flexion at heel strike (r = 0.39, $P = 0.015$) and peak stance-phase knee flexion (r = 0.38, $P = 0.019$). No correlations were observed during stair ascent.

Relationship between Changes in Stance-Phase Knee Flexion and Patellofemoral Pain and Function

There were few correlations with baseline participant characteristics or patellofemoral pain and disability. During stair descent, greater improvements in knee flexion were associated with longer total duration of symptoms (r = 0.44; $P = 0.004$) and greater pain, as measured by the VASU (r = 0.36; $P = 0.022$). There were no correlations observed with changes in knee motion during stair ascent.

The changes in pain and disability associated with patellofemoral pain were correlated with changes in stance-phase knee flexion and the correlation coefficients are provided in Table 4. Greater change in peak knee flexion during stair descent was associated with greater improvement in VASU, with an increase in the number of step-ups and step-downs that could be performed and with a decrease in the amount of pain noted during the stair ambulation task. These correlations were moderate, accounting for between 10 and 33% of the variability in the knee flexion. During stair ascent, there were no significant correlations.

Independent Predictors of Change in Stance-Phase Knee Flexion during Stair Descent

The variables that were significantly correlated with changes in the amount of knee flexion during stair descent

TABLE 3. Stance-phase knee flexion of participants at baseline, final assessment, and mean change of those who had no change in the onset of VMO relative to VL and those who had an earlier onset of VMO relative to VL after physiotherapy.

	Baseline		Final		Mean Change			
	<10-ms Change ($N = 18$) Mean (SD)	>10-ms Change ($N = 20$) Mean (SD)	<10-ms Change ($N = 18$) Mean (SD)	>10-ms Change ($N = 20$) Mean (SD)	<10-ms Change ($N = 18$) Mean (SD)	>10-ms Change ($N = 20$) Mean (SD)	Mean Difference (95% CI)	P
Ascending stairs								
Knee flexion at heel-strike (°)	63 (13)	66 (10)	67 (10)	68 (7)	4 (14)	2 (11)	2 (−10 to 5)	0.586
Peak knee flexion (°)	65 (12)	69 (8)	69 (9)	69 (7)	3 (13)	0 (9)	3 (−10 to 4)	0.431
Time to peak (%)			9 (6)	9 (4)	0 (4)	0 (4)	1 (−4 to 2)	0.565
Descending stairs								
Knee flexion at heel-strike (°)	14 (4)	12 (5)	13 (5)	17 (5)	−1 (3)	5 (3)	6 (3 to 8)	0.000
Peak knee flexion (°)	32 (6)	33 (8)	33 (6)	38 (6)	0 (5)	6 (7)	6 (2 to 10)	0.008
Time to peak (%)	25 (7)	25 (4)	26 (4)	27 (4)	2 (7)	1 (4)	0 (−4 to 4)	0.961

TABLE 4. Correlations of changes in stance-phase knee flexion with changes in patellofemoral pain and disability.

Changes in Variables (Final–Baseline Scores)	Ascending Stairs: Knee Flexion at Heel-strike (°)	Ascending Stairs: Peak Knee Flexion (°)	Ascending Stairs: Time to Peak (%)	Descending Stairs: Knee Flexion at Heel-strike (°)	Descending Stairs: Peak Knee Flexion (°)	Descending Stairs: Time to Peak (%)
VASU (cm)						
r	−0.235	−0.205	0.379	−0.402	−0.572	−0.284
P	0.144	0.204	0.016	0.010	0.000	0.076
AKPS						
r	0.050	−0.015	−0.425	0.223	0.309	0.231
P	0.758	0.927	0.006	0.167	0.053	0.152
No. of step-ups (*N*)						
r	0.171	0.177	−0.211	0.284	0.364	0.154
P	0.291	0.273	0.191	0.076	0.021	0.342
No. of step-downs (*N*)						
r	0.204	0.189	−0.257	0.259	0.317	0.085
P	0.206	0.242	0.110	0.107	0.046	0.604
VASstep (cm)						
r	0.030	0.048	0.134	−0.289	−0.317	−0.041
P	0.854	0.768	0.409	0.070	0.046	0.803

VASU, usual pain in the preceding week, measured using a 10-cm visual analog scale; AKPS, anterior knee pain scale; VASstep, amount of pain during stair stepping task, measured using a 10-cm visual analog scale.

were subjected to a multiple regression analysis (Table 5). Forward stepwise regression identified that change in onset timing of VMO relative to VL and improvements in VASU were independent predictors of change in the amount of knee flexion at heel strike and together accounted for 27% of the variability in the data. The same variables were related to improvements in peak knee flexion, accounting for 40% of the variability in knee motion. The other variables that were identified as being associated with changes in knee motion (number of step-ups, number of step-downs, and pain on stair ambulation) through bivariate correlations did not independently predict changes in peak knee flexion.

DISCUSSION

The assessment of gait impairments is a novel inclusion in the evaluation of a physical therapy intervention for patellofemoral pain. Although restoration of normal function is a desirable outcome of a successful treatment, this has not been measured previously in a controlled clinical trial. The physical therapy treatment was designed to reduce the pain associated with patellofemoral pain and improve the function of the PFJ. The treatment regimen focused on retraining the function of the vasti in general and the VMO in particular. At baseline, participants in the physical therapy group demonstrated a significantly greater improvement in peak stance-phase knee flexion and in knee flexion at heel strike during stair descent than those participants who received placebo treatment. At heel strike, knee flexion improved by an average of 4° (31%), whereas peak stance-phase knee flexion improved by 7° (22%) during stair descent. The mean amount of stance-phase knee flexion at the completion of the 6-wk trial was similar to that observed in healthy control participants in our previous study (11).

In contrast, no differences between the physical therapy and placebo groups were found for change in any gait parameter during stair ascent. Although there was a trend for the physical therapy group to show greater improvements than the placebo group (mean difference in the physical therapy group of 3–4°), the stance-phase knee flexion in this active treatment group did not reach the values of those noted in healthy participants (11), indicating maintenance of the original deficit. Because the physical therapy treatment in this study emphasized vasti retraining during eccentric activities (squats and step-downs), it is possible that improvements in vasti neuromotor control were greater in the eccentric quadriceps activity associated with stair descent rather than the concentric quadriceps activity associated with stair ascent. Similarly, changes in time to peak stance-phase knee flexion were not evident with treatment. This may reflect the fact that deficits were not present initially, when compared with results obtained from healthy individuals (11). The timing of the peak stance-phase knee flexion appears to be a fairy stable measure within an individual.

There are a number of possible explanations for the greater reduction in stance-phase knee flexion during stair descent seen in participants in the physical therapy treatment group in the current trial. Improvements in the neuromotor control of the vasti may affect patellar tracking, and thus function, during gait. Alternatively, the gait adaptations may be reversed in association with pain reduction. It is not possible to comment on whether the changes in kinematics

TABLE 5. Forward stepwise regressions of changes in knee flexion with predictors of change.

	r^2	β	SE	*P*
Change in knee flexion at heel-strike (descending stairs)				
Change in onset timing of VMO-VL (descending stairs)	0.164	0.042	0.019	0.032
Change in usual pain in preceding week	0.268	−0.838	0.374	0.032
Change in peak knee flexion (descending stairs)				
Change in usual pain in preceding week	0.327	−1.980	0.520	0.001
Change in onset timing of VMO-VL (descending stairs)	0.403	0.056	0.026	0.041

observed in this study resulted from or contributed to the changes seen in vasti neuromotor control or pain and disability.

Changes in Stance-Phase Knee Flexion Are Associated with Improvements in Neuromotor Control of the Vasti

Neuromotor control of the vasti is one of the factors thought to influence patellar tracking (15). Therefore, although the physical therapy intervention in this study contained a number of components, it focused on the retraining of motor control of the vasti. As previously discussed, our research team established that the participants in this RCT exhibited an imbalance in the activation of VMO and VL at baseline (8) and that the physical therapy intervention resulted in greater improvements in the onset timing of VMO relative to VL than the placebo treatment (5). Thus, in addition to reducing pain, this physical therapy intervention program restored the neuromotor control of the vasti, potentially enhancing quadriceps function and leading to an improved ability to withstand the greater PFJ loads associated with increases in knee flexion during stance-phase.

Changes in Stance-Phase Knee Flexion Are Related to Improvements in Pain and Disability

The physical therapy intervention in this study produced a significantly greater reduction in pain than the placebo treatment. It is possible that the greater pain relief experienced by participants in the physical therapy group resulted in a heightened ability to tolerate the greater load associated with an increase in stance-phase knee flexion or expand the envelope of function as described by Dye (12). Although kinetic analyses were not performed in this study, the increased range of knee flexion used by those in the physical therapy intervention may suggest an improvement in shock attenuation and tolerance of the increased PFJ reaction force.

Further evidence to support the association between changes in gait kinematics and improvements in pain can be found from the correlations between changes in sagittal plane knee motion and pain reduction. During stair descent, greater improvements in peak stance-phase knee flexion correlated moderately with improvements in worst pain, usual pain, and pain during stair descent in the preceding week. In addition, the increases in peak stance-phase knee flexion were correlated with the improvements in the number of step-ups and step-downs that could be performed and with the amount of pain experienced during the testing procedure. Although significant, these correlations were not strong. Therefore, although pain reduction probably accounts for some of the improvements in knee flexion during stance-phase of stair descent, other factors must be considered. These may include improvements in quadriceps function and vasti neuromotor control.

The two previous studies that examined gait impairment as an outcome reported mixed results (3,27). One case series failed to find changes in the amount of stance-phase knee flexion after an effective intervention that resulted in pain reduction (3). The difference in knee flexion at the completion of the physical therapy intervention was approximately 2°. The most obvious difference between the current study and that of Chesworth and coworkers (3) is the physical therapy intervention. Chesworth et al. (3) used a nonstandardized treatment that included icing, stretching, and strengthening but not specific functional retraining of the quadriceps. It is possible that the treatment had little effect on quadriceps function and thus no improvements were observed in stance-phase knee flexion.

In contrast, Powers and coworkers (27) found that patellar taping resulted in pain reduction and a significant short-term change in stance-phase knee flexion during stair ambulation of 4.6°. Although the magnitude of this change was small (average 3.4°), the authors suggested that the participants demonstrated a greater ability to load the knee joint with confidence during all gait conditions. In addition, patellar tape has been associated with short-term improvements in neuromotor control of the vasti (7,15) and quadriceps function (13,18,20). Therefore, it is possible that the improvements in gait associated with tape were a function of improved neuromotor control in addition to reductions in pain.

Clinical Implications

Although it is not known what the specific effects of small changes in knee joint motion are, ambulating with reduced knee flexion may reduce quadriceps activity, decrease active shock attenuation (21,26), and increase loading (14). Therefore, although pain reduction is the primary treatment aim, it also desirable to reverse any gait abnormalities associated with patellofemoral pain. The current project demonstrated that such an effect can be attained with a physical therapy program, but for the clinician, these changes in knee flexion are unlikely to be able to be assessed using visual examination. However, the data collection system is quite simple (video assessment) and it is possible that clinicians may be able to incorporate a more objective measure of knee joint function during gait into their clinical evaluation of treatment outcome. Interestingly, this physical therapy intervention was able to affect a change in gait kinematics without any specific gait retraining.

CONCLUSION

In our previous study (11), individuals with patellofemoral pain were found to walk up and down stairs with less knee flexion than healthy individuals. The current study identified that a physical therapy intervention aimed at reducing pain and disability through improving the neuromotor control of the vasti successfully increased the amount of stance-phase knee flexion in individuals with patellofemoral pain. In addition, these changes in stance-phase knee flexion were partly related to reductions in pain and disability and to improvements in the vasti neuromotor function. This study used an objective measure of impairment to provide further evidence of a beneficial effect of physical therapy treatment.

The authors thank the following people for implementing the interventions: Simon Boag, Craig Bosworth, Bruce Connor, Tony Davis, David Francis, Steve Hawkins, Kate Hunt, Mark Raberger, Mark Summers, and Paul Wise. We also acknowledge the assistance of the following individuals for data processing: Ben Metcalf and Bernadette Matthews. The authors acknowledge the technical assistance of Dr. Trevor Allen and Gavin Walsh.

This project was supported by a grant from the Physiotherapy Research Foundation (Australia).

Dr. Crossley holds a National Health and Medical Research Council (Australia) Health Professional Training Fellowship (Regkey no. 209168). Dr. Cowan holds a National Health and Medical Research Council (Australia) Research Training Fellowship (Regkey no. 251762).

Product for this study was provided by Electromed Sales and Rental, Smith and Nephew Pty. Ltd., Endura-tape Pty. Ltd., and Beiersdorf Australia Pty. Ltd. J. McConnell receives a royalty from the sale of Endura-Tape (Sydney, Australia). Endura-Tape was not used exclusively in this study.

The other authors have no conflicts of interest relevant to this study.

REFERENCES

1. Almeida, S. A., K. M. Williams, R. A. Shaffer, and S. K. Brodine. Epidemiological patterns of musculoskeletal injuries and physical training. *Med. Sci. Sports Exerc.* 31:1176–1182, 1999.
2. Buff, H., L. C. Jones, and D. S. Hungerford. Experimental determination of forces transmitted through the patellofemoral joint. *J. Biomech.* 35:17–23, 1988.
3. Chesworth, B. M., E. G. Culham, G. E. Tata, and M. Peat. Validation of outcome measures in patients with patellofemoral syndrome. *J. Orthop. Sports Phys. Ther.* 17:302–308, 1989.
4. Costigan, P. A., K. J. Deluzio, and U. P. Wyss. Knee and hip kinetics during normal stair climbing. *Gait Posture.* 16:31–37, 2002.
5. Cowan, S. M., K. L. Bennell, K. M. Crossley, P. W. Hodges, and J. McConnell. Physiotherapy treatment alters the recruitment of the vasti in patellofemoral pain syndrome. *Med. Sci. Sports Exerc.* 34:1879–1885, 2002.
6. Cowan, S. M., K. L. Bennell, and P. Hodges. The test retest reliability of the onset of concentric and eccentric vastus medialis obliquus and vastus lateralis electromyographic activity in a stair stepping task. *Phys. Ther. Sports.* 1:129–136, 2000.
7. Cowan, S. M., K. L. Bennell, and P. W. Hodges. Therapeutic patellar taping changes the timing of vastii muscle activation in people with patellofemoral pain syndrome. *Clin. J. Sports Med.* 12:339–347, 2002.
8. Cowan, S. M., K. L. Bennell, P. W. Hodges, K. M. Crossley, and J. McConnell. Delayed onset of electromyographic activity of vastus medialis obliquus relative to vastus lateralis in subjects with patellofemoral pain syndrome. *Arch. Phys. Med. Rehabil.* 82:183–189, 2001.
9. Crossley, K., K. Bennell, S. Green, S. Cowan, and J. McConnell. Physical therapy for patellofemoral pain: a randomised, double-blind, placebo controlled trial. *Am. J. Sports Med.* 30:857–865, 2002.
10. Crossley, K. M., K. L. Bennell, S. Green, and S. M. Cowan. Analysis of outcome measures for persons with patellofemoral pain: which are reliable and valid? *Arch. Phys. Med. Rehabil.* 85:815–822, 2004.
11. Crossley, K. M., S. M. Cowan, K. L. Bennell, and J. McConnell. Knee flexion during stair ambulation is altered in individuals with patellofemoral pain. *J. Orthop. Res.* 22:267–274, 2004.
12. Dye, S. F. Patellofemoral pain current concepts: an overview. *Sports Medicine and Arthroscopy Review* 9:264–272, 2001.
13. Gerritson, K. G. M., A. J. van den Bogert, and B. M. Nigg. Direct dynamics simulation of the impact phase in heel-toes running. *J. Biomech.* 28:661–668, 1995.
14. Dye, S. F. Patellofemoral pain current concepts: an overview. *Sports Med. Arthrosc. Rev.* 9:264–272, 2001.
15. Gilleard, W., J. McConnell, and D. Parsons. The effect of patellar taping on the onset of vastus medialis obliquus and vastus lateralis muscle activity in persons with patellofemoral pain. *Phys. Ther.* 78:25–32, 1998.
16. Grabiner, M. D., T. J. Koh, and L. F. Draganich. Neuromechanics of the patellofemoral joint. *Med. Sci. Sports Exerc.* 26:10–21, 1994.
17. Greenwald, A. E., A. M. Bagley, E. P. France, L. E. Paulos, and R. M. Greenwald. A biomechanical and clinical evaluation of a patellofemoral knee brace. *Clin. Orthop.* 324:187–195, 1996.
18. Handfield, T., and J. Kramer. Effect of McConnell taping on perceived pain and knee extensor torques during isokinetic exercise performed by patients with patellofemoral pain syndrome. *Physiother. Can.* Winter:39–44, 2000.
19. Heino, Brechter J., and C. M. Powers. Patellofemoral joint stress during stair ascent and descent in persons with and without patellofemoral pain. *Gait Posture.* 16:115–123, 2002.
20. Herrington, L., and C. J. Payton. Effects of corrective taping of the patella on patients with patellofemoral pain. *Physiotherapy.* 83:566–572, 1997.
21. Hsu, A. T., J. Perry, J. K. Gronley, and H. J. Hislop. Quadriceps force and myoelectric activity during flexed knee stance. *Clin. Orthop.* 288:254–262, 1993.
22. Kujala, U. M., L. H. Jaakola, S. K. Koskinen, S. Taimela, M. Hurme, and O. Nelimarkka. Scoring of patellofemoral disorders. *Arthroscopy.* 9:159–163, 1993.
23. Matthews, L. S., D. A. Sonstegard, and J. A. Henke. Load bearing characteristics of the patellofemoral joint. *Acta Orthop. Scand.* 18:511–516, 1977.
24. McConnell, J. The management of chondromalacia patellae: a long term solution. *Aust. J. Physiother.* 32:215–223, 1986.
25. McConnell, J. Management of patellofemoral problems. *Man. Ther.* 1:60–66, 1996.
26. Perry, J., D. Antonelli, and W. Ford. Analysis of knee joint forces during flexed knee stance. *J. Bone Joint. Surg. Am.* 57:961–967, 1975.
27. Powers, C. M., R. Landel, T. Sosnick, et al. The effects of patellar taping on stride characteristics and joint motion in subjects with patellofemoral pain. *J. Orthop. Sports Phys.* 26:286–291, 1997.
28. Powers, C. M., J. Perry, A. Hsu, and H. J. Hislop. Are patellofemoral pain and quadriceps femoris muscle torque associated with locomotor function? *Phys. Ther.* 77:1063–1075, 1997.
29. Tully, E. A., and B. C. Stillman. Computer aided video analysis of vertebrofemoral motion during toe touching in healthy subjects. *Arch. Phys. Med. Rehabil.* 78:759–766, 1997.
30. van Eijden T. M. G., E. Kouwenhoven, J. Verburg, and W. A. Weijs. A mathematical model of the patellofemoral joint. *J. Biomech.* 19:219–229, 1986.
31. Witvrouw, E., R. Lysens, J. Bellemans, and K. Peers. Intrinsic risk factors for the development of anterior knee pain in an athletic population. A two year prospective study. *Am. J. Sports Med.* 28:480–489, 2000.