

Knee flexion during stair ambulation is altered in individuals with patellofemoral pain [☆]

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Received 10 March 2003; accepted 20 August 2003

Abstract

Reduced knee flexion is a logical gait adaptation for individuals with patellofemoral pain (PFP) to lessen the patellofemoral joint reaction force and minimise pain during stair ambulation. This gait adaptation may be related to the co-ordination of individual vasti components.

Purpose: This study investigated the amount of stance-phase knee flexion in individuals with ($n = 48$) and without ($n = 18$) PFP using a cross-sectional design. The relationship between stance-phase knee flexion and onset timing of individual vasti activity was also examined.

Method: Stance-phase knee flexion was measured in 2-dimensions using a PEAK movement analysis system during stair ascent and descent. Individuals with PFP were separated into those with synchronous onset of the EMG activity of vastus medialis obliquus (VMO) and vastus lateralis (VL), and those where the onset of VMO EMG activity was delayed relative to the VL.

Results: The amount of knee flexion at heel-strike and peak was less in the individuals with PFP compared with the healthy controls. In addition, there were trends towards individuals with PFP who had a delayed EMG onset of VL having reduced knee flexion during stair descent compared with PFP individuals with simultaneous vasti onsets and the control participants.

Conclusion: These results indicate that the amount of stance-phase knee flexion is lower in individuals with PFP and that this may be related to onset timing of the vasti.

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Keywords: Patellofemoral pain; Anterior knee pain; Vasti; Sagittal plane; Knee motion; Gait

Introduction

Patellofemoral pain (PFP) is characterised by pain that is perceived as occurring in the anterior aspect of the knee for which there is no specific or definitive diagnosis [6,15,23,38]. The pain is typically aggravated by activities that load the patellofemoral joint (PFJ) such as squatting, stair ascending and descending [21,22,53]. While the exact incidence of PFP is not well docu-

mented, prospective cohort studies report incidence rates of 7–15% in young active adults and military populations [1,2,27,33,35,39,50,52,58].

The structures involved in PFP have not clearly been established, but a number of causative mechanisms for this disorder have been postulated. Central to these is repetitive submaximal load on the PFJ [16, 43]. During weight-bearing activities, an increase in knee flexion will heighten the PFJ reaction force [4,31, 55]. Thus, individuals with PFP may reduce the amount of knee flexion during ambulation in an attempt to lessen the PFJ reaction force and patellofemoral pain. However, the evidence supporting a reduction in stance-phase knee flexion in individuals with PFP is conflicting. Some studies have shown that knee flexion during walking is reduced in participants

[☆] This project was supported by a grant from the Physiotherapy Research Foundation.

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with PFP compared with healthy individuals [14,40] while other trials have failed to demonstrate a difference [20,26,45,47,48].

It is possible that walking does not sufficiently load the PFJ to observe consistent alterations in knee flexion and that stair ambulation may be a more appropriate task to observe such gait changes, since it results in greater PFJ loading [7] and is frequently associated with PFP symptoms. However, studies that have examined knee joint motion during stair climbing are also inconclusive. One study reported decreased knee flexion at initial step contact and mid-stance during stair descent [20] while Powers et al. [48] and Heino Brechter and Powers [25] found no significant differences in sagittal plane knee joint motion between participants with PFP and controls during ascending or descending ramps or stairs. Thus it is unclear whether limited stance-phase knee flexion is a consistent gait adaptation to PFP.

One factor that may influence the amount of stance-phase knee flexion is the neuro-motor control of the PFJ. The precise co-ordination of muscle activities around the PFJ is important to maintain optimal patellar tracking within the femoral trochlea. Dysfunction of the PFJ neuro-motor control resulting in an imbalance in the magnitude or timing of the vastus medialis obliquus (VMO) and vastus lateralis (VL) activity may lead to abnormal patellar tracking and subsequent areas of heightened contact pressures [19]. Therefore, individuals with altered co-ordination of their vasti may be more likely to adapt their stance-phase knee flexion in an attempt to minimise further patellofemoral pain and joint stress. Our research group demonstrated that, in a group of individuals with PFP, the onset of VMO EMG was later than that of VL, while the onset of the two vasti occurred simultaneously in a group without pain [9,10]. This confirms that neuro-motor control of the vasti during stair ambulation was disrupted in participants with PFP. The alteration in onset timing of the vasti could contribute to reduced stance-phase knee flexion in individuals with PFP.

The purpose of this investigation was to compare sagittal knee kinematics during stair ambulation in a group of individuals with PFP, compared to healthy controls. The secondary aim of this study was to examine the relationship between stance-phase knee flexion during stair ambulation and parameters measured on the PFP cohort and described in previous studies, namely onset timing of the vasti [9] and participant characteristics, knee pain, disability and function [11]. We hypothesised that individuals with PFP would have reduced knee flexion when ambulating over stairs, compared with their healthy counterparts, and that decreased knee joint flexion would be related to increased pain and disability associated with PFP and to delayed onset of the VMO.

Method

A cross-sectional design was used to determine whether stance-phase knee flexion during stair ambulation was different in individuals with and without PFP.

Participants

Forty-eight individuals with PFP and 18 asymptomatic individuals with no present or previous knee pain or injury participated in this study. 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. Those with PFP were recruited as part of a larger trial investigating the effect of conservative treatment for PFP [11].

Participants with PFP were recruited from health professionals, advertisements and media in Melbourne, Australia. They were included if they exhibited signs and symptoms of patellofemoral pain, with no evidence of any other specific pathology. 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 (iv) 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; and (iii) aged >40 years to reduce the possibility of degenerative joint disease.

A control group of 18 healthy individuals served as a comparison group. Participants were recruited from advertisements placed at The University of Melbourne. To be eligible for inclusion in the study, the participants had to be aged less than 41 years of age and have no history of knee pain or pathology and no current lower limb pain or pathology. In addition, they were to have no other limitations that would affect their gait.

Procedures

Pain and disability scales

Worst pain in the previous week was recorded on a 10-cm visual analogue scale (VASW). Disability was measured on an anterior knee pain specific self-administered questionnaire (AKPS) [36]. In addition, the amount of pain recorded during the stair ambulation task was measured on a 10-cm visual analogue scale (VASstep).

Stair-stepping protocol

Stairs were custom made, based on the dimensions used in a previous study [18] and consisted of two steps of 20-cm height leading to a 60-cm long platform. No handrail was provided or needed. The stairs were placed in the centre of a 5 m walkway. Participants wore their own footwear for the stair-stepping task. A metronome (Alans Music, Bourke St., Melbourne) was used at 96 steps per minute in an attempt to increase the repeatability of the stair-walking task. The stair-stepping rate was based on previous research [8]. Each participant completed at least five practice trials (each trial involved a single ascent and descent of the stair apparatus) to ensure that they were able to step in time with the metronome and were able to contact the middle step with the leg to be tested. Following practice trials, data were collected from five consecutive trials.

Stance-phase knee flexion

The affected limb (or most symptomatic in case of bilateral symptoms) of the PFP group was tested, whilst in controls, the left or right limb was randomly tested. Stance-phase knee flexion was measured with a PEAK movement analysis system (Peak Performance Technology Inc., Englewood, CO, 1991). Reflective markers were used to determine sagittal plane motion and were attached to the lateral malleolus, neck of fibular, on the iliotibial band at the level of the superior border of the patella and lateral thigh (junction of the proximal 1/3 and distal 2/3) using a standard protocol [54]. 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 digitised. The obtained raw data representing the spatial location of the four reference markers were then filtered using a robust non-linear

least-squares fourth order (Butterworth) filter (4 Hz). An independent assessor, unaware of the participant group (PFP or control), digitised the movement data from the video tape.

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). Prior to statistical analysis, a preliminary analysis was performed on the data of 22 participants (11 PFP and 11 controls) to determine the number of trials required to provide an average result that was representative of knee joint motion. For the angular variables, the averages of five trials, four trials and three trials were generated for each participant for both ascending and descending stairs. The average values were then compared using a repeated measures ANOVA and an ICC (3,4) [51]. The analyses indicated no significant differences between the average of three, four and five trials, and visual inspection revealed no discernible difference. Therefore the average of three trials was used for further analyses to minimise digitisation time.

EMG recordings of vasti

EMG recordings of vasti onset are described in full in a previous study [9]. Briefly, EMG data were taken during stance-phase of five consecutive trials of stair ascent and descent. The data were preamplified (10 times) distal to the surface electrodes, band-pass filtered between 20 and 500 Hz, sampled at 1000 Hz and full-wave rectified and low-pass filtered at 50 Hz. A computer algorithm identified the onset of EMG activity (3 SD/50 ms) and the onsets were checked visually from the raw traces. 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 [8]. The onsets of the vasti EMG are used in present study only to divide the participants into those with a similar onset of the two vasti (VMO=VL) and those with a later onset of VMO than VL (delayed VMO). Based on our previous work, individuals were placed into the delayed VMO group if the onset of VMO was more than 10 ms later than that of VL [9].

Other measures

Age and gender were recorded. Height and weight were measured on each participant when barefoot and body mass index (BMI) was calculated. Participants with PFP were asked to describe the duration of their current symptoms (in months).

Statistical analyses

All statistics were performed with the Statistical Package for Social Sciences (SPSS—Norusis/SPSS Inc., Chicago, IL, USA) and a two-tailed level of significance was set at 0.05 for all tests unless otherwise specified. Participant characteristics were compared between the PFP and control groups to ensure that the two groups were similar using independent *t*-tests or χ^2 analyses. To determine whether a difference in sagittal plane knee joint motion existed between the participants with PFP and the healthy controls, comparison of independent means were performed using an independent *t*-test. The relationship between participant characteristics, pain and disability associated with PFP and the amount of stance-phase knee flexion in the PFP group was assessed using a Spearman's correlation coefficient. Group differences between those with delayed VMO onset, synchronous vasti onset and the control group were determined using one-way analyses of variance for the knee angles at both heel-strike and peak knee flexion. When differences were detected, Scheffe *f* tests were used to locate the source of differences using a Bonferroni adjusted alpha of 0.017.

Results

Participant characteristics

The participant characteristics were similar between the PFP and control groups (Table 1). In the PFP group,

Table 1

Participant characteristics for patellofemoral pain cohort and control group

Variable	PFP group (<i>N</i> = 48) Mean (SD)	Control group (<i>N</i> = 18) Mean (SD)
Age (years)	28 (8)	35 (5)
Gender	31 female; 17 male	9 female; 9 male
Leg dominance	43 right; 5 left	16 right; 2 left
Height (m)	1.70 (0.09)	1.72 (0.12)
Weight (kg)	69.5 (14.6)	66.3 (12.6)
BMI (kg m ⁻²)	23.9 (4.0)	22.2 (2.7)

BMI: body mass index.

the mean (SD) for the duration of current symptoms was 8 (8) months, of the worst pain in the previous week was 7.5/10 (1.5) cm, the AKPS score was 70/100 (8) and the amount of pain recorded during the stair ambulation task was 2.5/10 (2.0) cm.

Stance-phase knee flexion

Participants with PFP had significantly less knee flexion at heel-strike during stair ascent and descent than the control participants. The magnitude of the mean difference in knee flexion between the two groups was 6.8° (95%CI: 0.8; 12.9°) during stair ascent and 2.5° (95%CI: 0.2; 4.9°) during descent. In addition, the peak stance-phase knee flexion was significantly less in the participants with PFP. During stair ascent and descent, the PFP group had a mean difference of 6.0° (95%CI: 0.6; 11.4°) and 5.5° (95%CI: 1.7; 9.4°) less peak stance-phase knee flexion respectively, than the controls. There were no differences in temporal variables between the two groups (*p* > 0.05). Fig. 1 is a representative trace of the kinematic curves during stair descent.

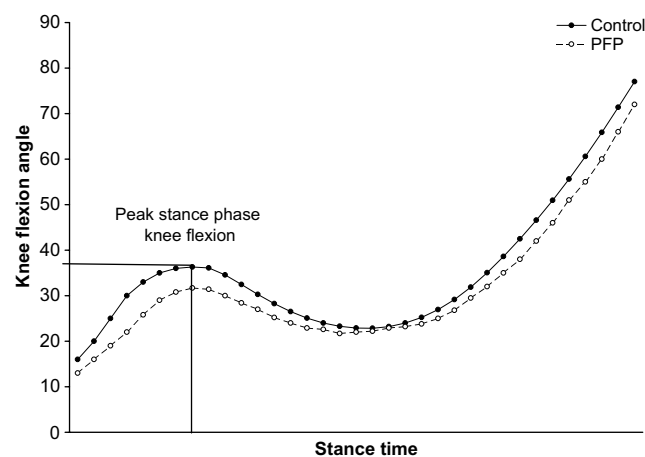


Fig. 1. Representative kinematic trace of stance-phase knee flexion during stair descent.

Inspection of the data revealed that while the means of the PFP and healthy groups were significantly different for the knee flexion angles during stair ascent and descent, there was considerable variability in the data. A number of participants in each group had scores that were within the range of the other.

Relationship between stance-phase knee flexion and participant characteristics

There were no significant correlations between age or BMI and any of the stance-phase knee flexion variables. Longer duration of current symptoms was significantly correlated with less peak knee flexion during stair descent. Of the pain and disability scales, only greater worst pain in the preceding week was correlated with less peak knee flexion during stair descent. There were no correlations between any of the gait parameters and the AKPS or the amount of pain described during stair ambulation (Table 2).

Relationship between stance-phase knee flexion and onset of VMO and VL EMG

For the PFP participants the mean onset of VMO EMG activity was delayed, relative that of the VL [9]. These participants were divided into two groups: those with a delay in the onset of VMO relative to VL (delayed VMO), and those with synchronous onset of the

two vasti components (VMO = VL). During stair ascent, the mean (SD) timing difference (VMO – VL) of the delayed VMO group was –36.54 (19.68) ms and the VMO = VL group was 4.09 (14.06) ms. The control group had a timing difference of 2.06 (1.55) ms. During stair descent the mean (SD) timing difference (VMO – VL) of the delayed VMO group was –38.47 (14.59) ms, the VMO = VL group was –0.48 (18.95) ms and the control group was 0.37 (5.70) ms.

The means (SD) for the groups with the delayed VMO, VMO = VL and control group are presented in Table 3. During stair ascent, although both groups of individuals with PFP had lower values of knee flexion at heel-strike and peak knee flexion, these differences were not significant. During stair descent, there was a significant difference between the amount of knee flexion in the three groups. Post hoc tests revealed no significant differences, but there were trends towards less knee flexion in the group of individuals with the delayed VMO, compared with the healthy control group.

Discussion

Individuals with PFP frequently report pain and difficulty with stair ambulation. In this study, knee flexion at heel-strike and peak stance-phase knee flexion were reduced in participants with PFP compared with asymptomatic individuals. This is a logical adaptation

Table 2
Correlations between participant characteristics and stance-phase knee flexion

		Ascending stairs			Descending stairs		
		Knee flexion at heel-strike	Peak stance-phase knee flexion	Time to peak stance-phase knee flexion	Knee flexion at heel-strike	Peak stance-phase knee flexion	Time to peak stance-phase knee flexion
<i>All participants (N = 66)</i>							
Age (years)	<i>r</i>	–0.001	–0.027	–0.078	0.022	0.043	–0.226
	<i>p</i>	0.995	0.832	0.533	0.863	0.734	0.069
BMI (kg m ^{–2})	<i>r</i>	0.056	0.038	–0.136	–0.215	0.049	–0.074
	<i>p</i>	0.655	0.760	0.277	0.084	0.695	0.557
<i>Patellofemoral pain participants (N = 48)</i>							
Duration of current symptoms (years)	<i>r</i>	–0.171	–0.181	0.073	–0.085	–0.365	–0.047
	<i>p</i>	0.246	0.218	0.623	0.566	0.011	0.752
Worst pain in preceding week (VAS) (cm)	<i>r</i>	–0.218	–0.178	0.253	–0.135	–0.301	–0.001
	<i>p</i>	0.136	0.226	0.083	0.361	0.038	0.992
Anterior knee pain scale (0–100)	<i>r</i>	0.094	0.098	0.069	–0.090	0.198	0.036
	<i>p</i>	0.525	0.508	0.643	0.542	0.178	0.810
Pain during stair ambulation (VAS) (cm)	<i>r</i>	0.027	0.053	0.180	0.104	–0.082	0.273
	<i>p</i>	0.856	0.718	0.222	0.481	0.578	0.061

Table 3
Stance-phase knee flexion for the control participants and PFP participants with a greater and lesser difference in vasti onset timing

	Delayed VMO Mean (SD)	VMO = VL Mean (SD)	Control group Mean (SD)	ANOVA <i>p</i> value
Ascending stairs	<i>N</i> = 24	<i>N</i> = 23	<i>N</i> = 18	
Knee flexion at heel-strike (°)	65.5 (12.1)	63.4 (11.1)	71.1 (9.3)	0.082
Peak knee flexion (°)	68.2 (10.7)	65.9 (10.1)	72.9 (8.1)	0.955
Descending stairs	<i>N</i> = 23	<i>N</i> = 24	<i>N</i> = 18	
Knee flexion at heel-strike (°)	12.2 (3.6) ^a	14.4 (4.7)	15.8 (4.4) ^a	0.032*
Peak knee flexion (°)	31.9 (8.2) ^b	33.1 (5.1)	37.4 (5.0) ^b	0.019*

Delayed VMO: onset of VMO was later than that of VL.

VMO = VL: onset of VMO and VL occurred simultaneously.

* *p* < 0.05.

^a *p* = 0.037.

^b *p* = 0.027.

for participants with PFP in order to decrease the PFJ reaction force and perhaps reduce their pain during this activity. While the cross-sectional study design does not allow the temporal relationship between this gait alteration and PFP to be established, it is more likely that the gait adaptation results from the condition rather than causes it. Evidence for the adaptation theory can be found in studies utilising pain induction models at other anatomical sites [37,42], which demonstrated immediate gait compensations in response to pain that were reversed with pain relief [42]. Therefore, it is possible that PFP may result in compensatory gait adaptations.

The results of the current study are similar to those of Greenwald et al. [20] who found that participants with PFP demonstrated reduced knee flexion at initial step contact and mid-stance during stair descent compared with their healthy counterparts. In contrast, two other studies [25,48] failed to find differences in sagittal plane knee joint motion. The PFP participants in these two studies walked slower than the healthy participants and Heino Brechter and Powers [25] reported that the decreased walking velocity might have contributed to the reduced PFJ reaction force in the PFP group. Thus, the participants may not have needed to limit their knee flexion in order to decrease the PFJ reaction force.

The reduced stance-phase knee flexion in this PFP cohort may be associated with pain and disability from the PFJ or neuro-motor dysfunction of the PFJ. These possibilities are discussed below.

Is reduced stance-phase knee flexion associated with patellofemoral pain?

While the reduced knee flexion observed in this PFP cohort is believed to be an adaptation to PFP and thus an attempt to reduce PFJ loading, there was a lack of correlation with the measures of pain, disability or function. There are several possible explanations for this lack of association. The poor correlations may reflect the variability in the kinematic variables. Participants

with PFP may utilise different strategies to minimise their PFJ reaction force, including modifications to the hip and ankle kinematics [23,57], or decreasing gait velocity [45,56]. Although studies of other knee pathologies are not directly comparable to individuals with PFP, kinematic data also reveal discrepancies in gait kinematic patterns [3,5,12,13,28,34,49], indicating that individuals with knee pain utilise varied gait adaptations. It is possible that individuals with PFP do the same. In addition, the stair-stepping task may not provoke sufficient pain in some individuals to require gait compensation. The pain during testing was low (mean 3.0; SD 2.0). Also, some participants who have pain may not adapt their gait. Any gait compensation may only be evident after the symptoms have been present for some time or if the symptoms worsen.

Interestingly, there was a weak correlation between a longer duration of PFP symptoms and reduced peak stance-phase knee flexion. While it is logical that symptom duration would not fully account for the reduced range of motion, the relationship warrants discussion. A study that investigated gait compensations at multiple time points in individuals who underwent anterior cruciate ligament reconstruction concluded that gait adaptations take a relatively long time to develop [13]. Furthermore, it has been shown that patients with persistent symptoms have abnormal gait kinematics [3,5]. In the present study, gait adaptations during stair descent were more likely to occur when the current symptoms had been present for longer. This may reflect a response to an ongoing effect of reduced quadriceps activity or neuro-motor control. Studies have shown that quadriceps inhibition does not spontaneously recover over time [32]. Therefore, failure to address decreased quadriceps activation may perpetuate the gait adaptations. In addition if deficient neuro-motor control is not addressed then altered patellar tracking may result [41], which may reduce patellofemoral contact area [24,30] and thus perpetuate gait adaptations in an attempt to lower the patellofemoral joint stress.

Is reduced stance-phase knee flexion associated with dysfunction of the neuro-motor control of the PFJ?

Dysfunction of the neuro-motor control systems may result in an imbalance in the magnitude or timing of the vasti activation, thus impacting on patellar tracking. Our research group identified a later onset of VMO EMG activity than VL in this PFP cohort, confirming that neuro-motor control of the vasti during stair ambulation was disrupted in participants with PFP [9]. Additionally, we found in the present study that during stair descent, the individuals with the greatest deficit in VMO onset relative to VL had a greater reduction in peak stance-phase knee flexion. One hypothesis is that this altered onset timing of the vasti may have resulted in increased PFJ stress due to altered patellar tracking. Two recent studies by Heino Brechter and Powers [25,26] investigated PFJ stress during level walking and stair ambulation in individuals with and without PFP. They reported that the individuals with PFP had significantly reduced PFJ contact area, as measured by non-weight-bearing MRI, which may be associated with altered patellar tracking. Vasti neuro-motor control dysfunction is one factor that may contribute to altered patellar tracking and may account for the altered stance-phase knee flexion in some individuals.

What are the consequences of reduced stance-phase knee flexion?

Knee flexion reduction appears to be a logical mechanism to reduce the PFJ reaction force. However, such a mechanism results in reduced quadriceps activity [29,44] and consequently decreased active shock attenuation from the eccentric quadriceps contraction. Therefore, patients with PFP may be subjected to increased vertical ground reaction forces as well as greater loading rates experienced by the lower extremity [17]. There is insufficient evidence to support or refute the hypothesis that reduced stance-phase knee flexion can have further deleterious effects on the PFJ or knee joint. However it appears logical that restoration of asymptomatic stance-phase knee flexion may reduce the likelihood of developing long-term joint damage.

What are the clinical implications?

The differences in knee flexion between those with and without patellofemoral pain, whilst statistically significant are small; mean differences of 2.5–6.8°. While it is unknown whether difference of this magnitude could be detected clinically, it is likely that even small differences in knee flexion may impact on patellofemoral joint stress. Based on the current study, it will be useful to assess whether interventions designed to treat patellofemoral pain could affect knee joint motion. One

previous study by Powers et al. [46] found small but significant improvements in knee joint motion following an intervention. Our research group is planning to assess the impact of a physiotherapy intervention on sagittal plane knee motion.

Summary

Individuals with PFP frequently report pain and difficulty with stair ambulation, an activity that loads the PFJ. This study confirms that individuals with PFP reduce the amount of knee flexion used during stair ascent and descent, presumably a reversible compensation to their knee condition. However, there is also considerable variability in the amount of stance-phase knee flexion in the participants with PFP. Worst pain in the preceding week, symptom duration and disrupted onset timing of the vasti may be responsible for some of the adaptation during stair ambulation.

Acknowledgements

The authors would like to thank the following people in the assistance of data processing: Mr. Ben Metcalf, Ms. Bernadette Matthews. The authors would also like to acknowledge the technical assistance of Dr. Trevor Allen and Mr. Gavin Walsh. Dr. K.M. Crossley holds a National Health and Medical Research Council (Australia) Health Professional Training Fellowship (Regkey no. 209168). Dr. S.M. Cowan holds a National Health and Medical Research Council (Australia) Research Training Fellowship (Regkey no. 251762). The authors have no conflicts of interest relevant to this study.

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