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Lower limb control and strength in runners with and without patellofemoral pain syndrome

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ABSTRACT

Recreational runners with patellofemoral pain syndrome (PFPS) have been shown to present altered movement kinematics, muscle activations, and ground reaction forces (GRF) during running as well as decreased lower limb strength. However, these variables have never been concurrently evaluated in a specific cohort. Therefore, the aim of this study was to compare lower limb control variables during running in recreational runners with and without PFPS. Lower limb control during treadmill running under typical training conditions (usual shoes, foot strike pattern, and speed) was compared between runners with ($n = 21$) and without ($n = 20$) PFPS using lower limb kinematics, electromyographic (EMG) recordings from representative muscles (gluteus medius/maximus, quadriceps and soleus), and vertical GRF. Isometric muscle strength was also evaluated. When comparing all runners from both groups, no between-group differences were found in variables commonly associated with PFPS such as peak hip adduction, hip internal rotation, contralateral pelvic drop, EMG of gluteal and quadriceps muscles, vertical loading rate, or lower limb strength. However, runners with PFPS showed significantly higher hip adduction at toe-off, lower excursion in hip adduction during late-stance, and longer duration of soleus activation. Sub-analyses were performed for females and for rearfoot strikers (RFS), and revealed that these subgroups accounted for most of between-group differences in hip adduction kinematics. Specifically for RFS with PFPS, lower activation of gluteus medius as well as lower GRF were observed. Our results suggest that deficits reported in runners with PFPS may vary depending on gender and on foot strike pattern.

1. Introduction

Overuse injuries are frequent in recreational runners, with a reported annual prevalence of up to 70% [1]. Patellofemoral pain syndrome (PFPS), described as anterior or retropatellar knee pain or pain along the lateral and medial borders of the patella [2], is the most common running injury with 17% of diagnoses [3]. Several factors have been suggested to explain the presence of PFPS including decreased muscle strength and altered mechanical loading, lower limb kinematics, and muscle activation patterns during running.

Mechanical overload is recognized as a risk factor for the development of running-related injuries [4]. Specifically in the patellofemoral joint, running induces repetitive compressive forces of up to 4.5 times the bodyweight [5]. It has been suggested by Davis et al. that runners with PFPS show higher vertical loading rates of ground reaction forces during early stance [6], which have been linked with increased patellofemoral joint forces [7].

Considering the high impact forces during running, it can be hypothesized that impaired lower limb muscle strength, or kinematics and muscle activation patterns during running should facilitate the development of PFPS [8]. Several studies have looked at these factors in runners with PFPS. For muscle strength, various findings have been reported: while cross-sectional studies reported decreased knee extensors [9] or hip abductors strength [10,11], two prospective studies found either no difference [12] or increased abductor/adductor and decreased external/internal rotator strength ratios between runners who would eventually develop PFPS and those who would not [13]. Thus, onset of PFPS in

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runners may not necessarily be causally related to strength deficits.

Regarding running kinematics, different results were found in female and male runners. Female runners with PFPS show increased hip adduction (HADD) and hip internal rotation (HIR) during stance compared to controls [14,15]. In contrast, male runners with PFPS exhibit increased contralateral pelvic drop (CPD) and HADD [16], or even increased hip abduction [17] during stance in comparison to controls. However, most of these studies did not concurrently assess muscle activation patterns to determine the mechanisms underlying such kinematic deficits. The only study to do so found delayed and shorter duration of gluteus medius (GMed) activation during the stance phase in female runners [18]. In addition, increased peak angles of HADD and HIR were correlated with delayed onset of GMed and gluteus maximus (GMax).

To our knowledge, no study has simultaneously looked at muscle strength, lower limb kinematics, muscle activations and ground reaction forces (GRF) during running in this population. The simultaneous study of all of these factors is warranted to enhance our understanding of the mechanisms underlying altered lower limb control during running. Most studies described above have specifically recruited rearfoot strikers, even though PFPS also develops in midfoot and forefoot strikers. Furthermore, standardized cushioned neutral running shoes were used in most of these studies; thus, data were collected in conditions different from the runner's typical training environment. The objective of the present study was to compare lower limb kinematics, muscle activation patterns and GRF during treadmill running, as well as lower limb strength, in recreational runners with or without PFPS regardless of foot strike pattern or footwear. We hypothesized that runners with PFPS would exhibit greater GRF, a combination of increased peak HADD, HIR and/or CPD angles and decreased activation of GMed during the stance phase of running, without concomitant strength deficits.

Table 1
Subjects characteristics, presented as Mean (standard deviation).

	PFPS (n = 21)	Control (n = 20)	P-value
Demographics			
Gender	16 F, 5 M	15 F, 5 M	0.929
Age (years)	34.1 (6.0)	33.2 (6.0)	0.653
Height (cm)	167.8 (6.7)	169.1 (7.1)	0.550
Weight (kg)	67.4 (11.5)	62.8 (9.4)	0.177
Weekly running distance (km)	20.4 (4.4)	24.0 (10.9)	0.169
KOS-ADLS score	71.7 (12.9)	N/E	–
Usual pain (VAS)	2.8 (1.1)	0.0 (0.0)	**<0.001**
Worst pain (VAS)	5.2 (1.6)	0.0 (0.0)	**<0.001**
Pain during running (VAS)	5.0 (1.7)	0.0 (0.0)	**<0.001**
Duration of PFPS (months)	38.1 (45.5)	N/E	–
Running evaluation			
Step frequency (steps/min)	169.6 (10.2)	170.8 (10.2)	0.702
Treadmill speed (km/h)	9.0 (0.8)	9.2 (0.8)	0.444
Footstrike pattern			
Rearfoot	67%	70%	
Midfoot	19%	20%	0.916
Forefoot	14%	10%	
Running shoes*			
Maximalist	86%	75%	0.387
Minimalist	14%	25%	
Muscle strength, in % of bodyweight			
Knee			
Extensors	58.4 (16.0)	62.4 (16.0)	0.433
Hip			
External rotators	13.5 (4.5)	14.8 (4.2)	0.353
Abductors	34.2 (7.4)	33.9 (7.7)	0.885
Extensors	54.4 (13.4)	50.8 (12.1)	0.368

* Maximalist shoes represent traditional cushioned shoes including neutral, stability and motion control. Minimalist shoes represent shoes with low cushioning, low heel to toe drop, high flexibility and low weight. Abbreviations: PFPS = patellofemoral pain syndrome; F = females; M = males; KOS-ADLS = activities of daily living scale of the knee outcome survey, 0–100; VAS = visual analog scale, 0–10; N/E = not evaluated.

2. Methods

2.1. Participants

Twenty-one recreational runners with PFPS (PFPS group) and 20 runners without PFPS (Control group), matched for age, sex and foot strike pattern, were recruited (Table 1). All participants: (1) were aged between 18 and 45, (2) ran at least 15 km per week prior to enrolment, (3) had no history of rheumatoid, inflammatory or neurological disease, surgery to the lower limbs, patellar dislocation or ligamentous injury, and (4) had no other current injury to the lower limbs. Runners with PFPS were included if they had a history of anterior knee pain for a minimum of three months. In addition, they had to report a pain level of at least 3/10 on a visual analog scale during running (0 = no pain) and during at least three activities among: going up/down stairs, kneeling, squatting, resisting knee extension and sitting for a prolonged period [19]. A maximum score of 85/100 on the Activities of Daily Living Scale of the Knee Outcome Survey (KOS-ADLS) [20] was required to ensure a minimum level of symptoms and functional limitations. Exclusion criteria for PFPS group were pain suspected to originate either from meniscus or patellar tendon, or pain following an acute trauma. Control runners were included if they had no history of knee injury. This study was approved by a local ethics committee and all participants signed a detailed consent form.

2.2. Study design

Two evaluation sessions were performed within one week. During the first session, participants completed questionnaires on sociodemographics, symptomatology and running habits. Then, lower limb control was evaluated during treadmill running, with participants wearing their usual running shoes. For the PFPS group, kinematics, kinetics and EMG activity of the affected leg were recorded. When participants reported bilateral symptoms (n = 11), the most painful and limiting limb subjectively reported by participants was assessed. For the control group, the side was chosen to match the proportion of left/right lower limbs of the PFPS group. Isometric muscle strength was assessed during the second evaluation session.

2.3. Lower limb control

2.3.1. EMG recordings

After shaving and cleaning the skin, disposable surface electrodes (Kendall Medi-trace 200, Tyco Healthcare, MA, USA) were placed over the muscle belly, in parallel with the muscle fibers, according to SENIAM recommendations [21]. Muscles recorded from were GMed, GMax, Vastus Medialis Obliquus (VMO), Vastus Lateralis (VL) and Soleus (SOL). A reference electrode was placed over the ipsilateral patella (Fig. 1). EMG data was amplified (gain = 500) and collected (1000 Hz/channel) using a wireless TeleMyo 2400 system (Noraxon, AZ, USA) and custom-made software.

2.3.2. EMG normalization tasks

In populations with musculoskeletal disorders, the maximum voluntary isometric contractions (MVIC) is known to vary from day to day depending on pain level [22]. Therefore, instead of using MVIC, subjects executed three segment weight dynamic tasks [23] against a known load to normalize the amplitude of the recorded muscles: for SOL, they performed ankle plantar flexion during