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**Immediate effects of semi-custom insoles and structured knee sleeves on lower
extremity kinetics and kinematics in recreational male athletes with patellofemoral
pain.**

Jonathan Kenneth Sinclair & Bobbie Butters

Keywords: Patellofemoral pain, kinetics, knee, biomechanics, musculoskeletal.

1. Abstract.

The aim of this experiment was to provide insight into the immediate influence of both semi-custom insoles and knee sleeves in recreational male runners/ athletes suffering from patellofemoral pain and also to explore the association between the extent of patellofemoral pain and psychological wellbeing. Experiment 1 examined 17 male recreational runners with patellofemoral pain, in semi-custom insole and no-insole conditions. Experiment 2 examined 13 male recreational athletes with patellofemoral pain, undertaking run, 45° cut and single leg hop movements in knee sleeve and no-sleeve conditions. In both experiments, motion capture and ground reaction forces were collected, allowing kinetics and three-dimensional kinematics to be calculated alongside patellofemoral joint loading quantified using musculoskeletal modelling. In both experiments, patellofemoral pain symptoms were examined using the KOOS Patellofemoral pain subscale and psychological wellbeing using the COOP-WONCA questionnaire. The findings from both experiments showed that pain symptoms significantly predicted psychological wellbeing ($R^2 = 0.29$ in experiment 1 and $R^2 = 0.33$ in experiment 2). Experiment 1 showed that orthoses significantly reduced tibial internal rotation range of motion (no-insole = 7.59° & insole = 6.87°) whilst also increasing the peak knee adduction moment (no-insole = 1.00Nm/kg & insole = 1.09Nm/kg). The findings from experiment 2 revealed that

the knee sleeve reduced the peak patellofemoral force (no-sleeve = 3.40BW & sleeve = 3.10BW) in the run movement and the patellofemoral load rate in the cut movement (no-sleeve = 135.18BW/s & sleeve = 111.24BW/s). Overall, the findings confirm that pain symptoms are predictive of psychological-wellbeing in recreational male athletes with patellofemoral pain. Furthermore, the findings suggest that both insoles and knee sleeves may provide immediate biomechanical benefits in recreationally active individuals with patellofemoral pain, although when wearing insoles this may be at the expense of an increased knee adduction moment during running.

2. Introduction

Engagement in physical activity and sport is a prevalent recreational pass time, that has been shown to mediate a range of physical and psychological advantages¹. However, in spite of the physiological benefits produced through regular physical activity, it is connected to a high frequency of chronic injuries². Anterior knee pain more commonly referred to as patellofemoral pain, is renowned as the most commonly occurring overuse injury³. This condition characteristically presents via retropatellar or diffuse peripatellar pain and inflammation, exaggerated by actions that commonly and excessive load the joint itself⁴. This pathology has an extremely high overall prevalence of 15-45% in the general population⁵, with 25% of individuals reporting to physiotherapy clinics presenting with patellofemoral pain⁶.

Concerningly, patellofemoral pain is associated with a very poor long-term prognosis, with as many as 91% of patients still experiencing ongoing symptoms 20 years after diagnosis⁷. Overall, females are regarded as being at a 3-fold increased risk from experiencing

patellofemoral pain compared to age matched males⁸. However, Selfe et al.,⁹ identified three clinical sub-groups of patellofemoral pain patients (strong, weak & tight and pronated foot), in order to improve patient outcomes using bespoke targeted treatments. Importantly, the strong group typified by enhanced physical activity levels, was comprised of 54% of male participants, highlighting a lack of sex dominance in recreationally active patellofemoral pain patients. Significantly, individuals suffering from patellofemoral pain habitually experience osteoarthritic degeneration at this joint in later life¹⁰, making early treatment essential to alter the course of disease progression. Importantly, many individuals are forced by their pain symptoms to reduce or even cease their participation in sport and physical activity¹¹, meaning that those experiencing this condition, forego the physiological and psychosocial benefits of regular exercise as a result. Furthermore, previous analyses have shown that those with patellofemoral pain exhibit significantly lower levels of psychological wellbeing compared to healthy controls^{12,13}, although the extent of the association between pain symptoms and indices of psychological wellbeing is not fully established, particularly in recreationally active individuals.

Despite the prevalence of patellofemoral pain, the mechanisms responsible for the initiation and progression of pain symptoms are not well understood. Epidemiological analyses have shown that individuals suffering from patellofemoral pain are associated with higher levels of physical activity¹⁴. Furthermore, it is recognized that there are multiple factors linked to the aetiology of this pathology. Patellofemoral pain itself is a manifestation of several pathophysiological progressions¹⁵ and both extrinsic and intrinsic factors have been cited as causative factors¹⁶. Commonly cited extrinsic mechanisms include excessive training volumes, training errors and suboptimal training equipment¹⁶. Typically outlined intrinsic modalities include, lower extremity muscle imbalances, mal-alignment, and knee joint laxity¹⁷. From a

biomechanical perspective, elevated loading at the patellofemoral joint itself is regarded as an important factor in the progression of symptoms at the patellofemoral joint ¹⁸, alongside enhanced levels of eversion/ tibial internal rotation ^{19,20}, hip adduction ²¹, hip internal rotation ^{22,23}, knee valgus ²⁴ and vertical loading rates/ tibial accelerations ²⁵.

Taking into account the prevalence of patellofemoral pain in physically active individuals, several conservative treatment/ prophylactic modalities have been adopted ²⁶. Selfe et al., ⁹ advocated proprioceptive training, knee-bracing and taping for the strong subgroup of patellofemoral pain patients. Similarly, orthoses/ insoles are a recognized treatment and a longstanding aspect of the 'Best Practice Guide' for the mediation and prevention of patellofemoral pain symptoms. However, the effects of the aforementioned modalities in recreationally active individuals is not yet fully explored. Insoles typically possess a contoured silhouette that follows the shape of the medial arch and are designed to influence lower extremity joint alignment in the coronal and transverse planes ²⁷. Previous analyses concerning the influence of insoles on the three-dimensional kinetics and kinematics of running that are linked to the aetiology of patellofemoral pain in healthy individuals have shown firstly that loading rates/ tibial accelerations were significantly reduced when using insoles ^{27, 28}. Furthermore, ankle eversion and internal rotation of the tibia have not been shown to be significantly affected ^{28, 29}, whereas peak knee abduction and hip adduction angles have been shown to be greater when wearing insoles ²⁷. Patellofemoral joint kinetics examined in insole and no-insole conditions have shown an inconsistent pattern, with Sinclair et al., ³⁰ indicating that in males, insoles significantly reduced loading at this joint, Sinclair et al., ³¹ showing that in females, patellofemoral joint loads were statistically increased in the presence of insoles and Sinclair et al., ²⁷ in a factorial investigation examining both males and females showed that there was no effect of orthoses on patellofemoral loads.

Similarly, knee sleeves are designed to attenuate the biomechanical factors linked with knee joint pathologies and also to improve proprioception at this joint ³². Knee sleeves are a relatively low-cost modality, that are designed to be minimally restrictive during athletic movements ³³. Several investigations have been undertaken exploring the influence of knee sleeves on the kinetic and kinematic parameters pertinent to the aetiology of patellofemoral pain in healthy individuals. Valldecabres et al., ³⁴ showed that the knee sleeve significantly attenuated the maximum knee adduction moment during a badminton lunge, yet Sinclair et al., ³³ revealed that a knee sleeve did not mediate any statistical differences in joint moments during run, 45° cut and vertical jump tasks. Sinclair et al., ³³ also revealed that patellofemoral loading was not significantly influenced by the knee sleeve, yet the internal rotation range of motion at the knee joint was significantly reduced. Finally, Sinclair et al., ³⁴ found that the knee sleeve did not mediate any statistical alterations during single and double limb netball deceleration movements.

At the current time however there have been no investigations concerning the biomechanical effects of either knee sleeves or insoles during functional athletic movements in recreational athletes with patellofemoral pain. Therefore, the aims-of-the current investigation using a two-experiment-approach were to investigate: 1) Across both experiments, the extent to which patellofemoral pain predicts psychological wellbeing, 2) For experiment 1, using musculoskeletal modelling, the immediate influence of semi-custom insoles on lower extremity kinetics and kinematics in runners with patellofemoral pain and 3) For experiment 2, using musculoskeletal modelling, the immediate influence of a knee sleeve on lower extremity kinetics and kinematics in recreational athletes with patellofemoral pain. The current

study tests the hypotheses that patellofemoral pain symptoms will predict psychological wellbeing and that both semi-custom insoles and knee sleeves will attenuate the risk factors associated with patellofemoral pain.

3. Methods

Ethical approval

Informed consent was obtained in written form from each participant prior to the commencement of data collection. The procedures for both experiments were approved by an institutional ethics panel, with the reference STEMH 424 for experiment 1 and STEMH 295 for experiment 2.

Participants

Seventeen male recreational runners (Table 1) took part in experiment 1 and thirteen male recreational athletes (Table 1) volunteered for experiment 2. Those in experiment 1 were required to have undergone at least 2 years of running training, at least 3 training sessions per week and completing at least 35 km per week. Similarly, those in experiment 2 were all recreational athletes who came from squash, netball, basketball, and soccer athletic backgrounds, trained at least 3 times per week with at least 2 years of experience in their chosen athletic discipline. All participants completed the KOOS patellofemoral-pain subscale (KOOS-PF)³⁶ and COOP WONCA questionnaires¹² upon arrival. The diagnosis of patellofemoral pain was undertaken according to the guidelines of Crossley et al.³⁷, and volunteers were precluded from the investigation if they were over the age of 50, exhibited symptoms of another knee injury or had previously undergone surgery at this joint. Furthermore, all volunteers were

required to have experienced patellofemoral symptoms for a minimum of 3 months prior to data collection.

@@@ TABLE 1 APPROX HERE @@@

Experimental insoles and knee sleeve

The insoles examined in experiment 1 (Sole Control, UK), were constructed from EVA and had a Shore A 30 rating and a depth measured at the heel of 0.6 cm. These insoles were selected due to being identical to those utilized previously within the scientific literature³³. The insoles were moulded in the laboratory in full accordance with the manufacturer's guidelines using previously outlined procedures³³. The knee brace utilized in experiment 2, (Trizone, DJO USA), was positioned onto the dominant (right) limb in all participants. This knee sleeve was selected due to being identical to the devices adopted previously within the scientific literature³¹. The same experimental footwear was used in both experiments (Asics, Patriot 6), and had an average mass of 265 g, heel midsole depth of 2.2 cm and heel to toe drop of 1.0 cm and a score of 22 on the minimalist footwear index³⁸.

Procedure

In both experiments' retroreflective marker trajectories and ground reaction forces were obtained simultaneously. Marker data was collected using a capture rate of 250 Hz via an optoelectric motion analysis system comprised of eight cameras (Qualisys AB, Sweden). Ground reaction forces were collected using a piezoelectric force plate (Kistler, UK) embedded into the laboratory floor, that captured data at 1000 Hz. Calibration of the three-dimensional

motion capture space was undertaken dynamically in both experiments preceding the commencement of data.

In both experiments retroreflective markers were positioned in order to delineate the trunk, pelvis, foot, shank and thigh segments. To accomplish this, markers and tracking clusters were positioned according to a previously outlined experimental marker set ²⁷ (Figure 1a). Each participant underwent a static calibration trial, whereby they were stood in the anatomical position and were captured by the motion capture system, allowing the locations of the anatomical markers to be established in relation to those utilized for tracking (Figure 1b). The anatomical co-ordinate axes of each segment were delineated using previously described procedures ²⁷.

- FIGURE 1 NEAR HERE -

In experiment 1, participants completed five running trials with and without the experimental insoles and participants were tested in each insole condition in a counterbalanced manner. In experiment 2 participants undertook five repeats of three functional athletic tasks; run, 45° cut and single leg hop, with and without the experimental knee sleeve. Once again, participants were tested in the sleeve and movement conditions in a counterbalanced manner.

In both experiments data were collected during run, 45° cut and single leg hop conditions using the protocol outlined below:

Run

Participants undertook run movements across a 20 m biomechanics laboratory at 4.0 m/s ($\pm 5\%$), making contact with the force plate using their right (dominant) foot. Running velocity was observed with an infrared timing gate system (SmartSpeed, FusionSports, UK). The stance phase was delineated as the period in which >20 N of vertical ground reaction force was measured by the force plate ³⁹. A running trial was considered successful if it was within the aforementioned velocity range with no evidence of targeting.

Cut

Participants undertook 45° cutting movements with an approach velocity of 4.0 m/s ($\pm 5\%$), striking the force plate with their right foot. Approach running velocity was again monitored using a timing gate system. Cut angles were delineated using tape applied onto the laboratory floor at the desired angle, to ensure that it was clearly outlined ⁴⁰. The stance phase was defined in the same manner as during running ³⁹.

Hop

Participants stood initially on their dominant limb, and then on instruction, hopped forwards maximally, landing with same leg on the force plate without needing to touch their opposite limb to the ground to maintain balance. This movement was defined from the point of foot contact (>20 N of vertical ground reaction force on the force plate), until the instance of peak sagittal plane knee flexion ³³.

In experiment 1 only, vertical tibial accelerations were quantified with a tri-axial accelerometer (Biometrics ACL, UK) with an acquisition rate of 1000 Hz. The accelerometer itself was mounted to the distal tibia according to the procedures outlined in detail elsewhere ⁴¹.

215 *Processing*

216 Across both experiments' marker trajectories were auto-digitized within Qualisys Track
217 Manager software and then exported in C3D format to Visual 3D (C-Motion, USA). All
218 dynamic data were time-normalized according to the start and end points described above.
219 Ground reaction force, marker trajectories and tibial acceleration data were smoothed within
220 Visual 3D software at 50, 12 and 60 Hz respectively using a Butterworth 4th order low-pass
221 filter. Three-dimensional kinematics were quantified with an X (sagittal-plane), Y (coronal-
222 plane) and Z (transverse-plane) cardan sequence. In experiment 1 knee, ankle and tibial internal
223 rotation angles were examined and in experiment 2 only knee joint kinematics were explored.
224 Three-dimensional joint angle indices from the knee, ankle and tibia that were extracted for
225 further analysis were 1) maximum angle and 2) range of motion (ROM) from footstrike to
226 maximum angle, 3) maximum angular velocity and 4) minimum angular velocity. Lower
227 extremity joint torques were undertaken using standard inverse-dynamics within Visual 3D and
228 normalized as a function of body mass (N/kg). The peak knee adduction moment, knee
229 adduction moment loading rate (N/kg/s - maximum increase between neighboring data points
230 using a first derivative function within Visual 3D) and knee adduction moment integral (N/kg·s
231 - using an integral function within Visual 3D) were extracted.

232

233 Across both experiments patellofemoral joint loading was calculating by adapting an early
234 model developed by van Eijden et al.,⁴² to account for knee flexor co-contraction⁴³. The
235 process for calculating patellofemoral loading using the aforementioned modeling approach is
236 described in detail elsewhere⁴. The peak patellofemoral force (BW), peak patellofemoral stress
237 (KPa/BW), patellofemoral force loading rate (BW/s - maximum increase between neighboring
238 data points quantified using a first derivative function within Visual 3D), patellofemoral stress
239 loading rate (KPa/BW/s - maximum increase between neighboring data points quantified using

a first derivative function within Visual 3D), patellofemoral force integral (BW·s – using a trapezoidal function) and patellofemoral stress integral (KPa/BW·s – using the integral function within Visual 3D) during the each movement/ experimental condition were extracted.

For both experiments' knee joint and limb stiffness indices were quantified. Normalized limb stiffness was calculated via a spring-mass modelling approach ⁴⁴. Limb stiffness (BW/m) was obtained by dividing the peak vertical ground reaction force by the maximum compression of the leg spring, which was determined by calculating the alteration in limb length from the instance of footstrike to minimum limb length during each movement ⁴⁵. In addition, normalized knee joint stiffness (Nm/kg/°) was quantified by dividing the change in sagittal plane knee flexion moment quantified using inverse dynamics by the knee joint angular ROM in the sagittal plane from footstrike to maximum knee flexion ⁴⁵.

In experiment 1 only, the loading rate, peak tibial acceleration and effective mass were examined. Loading rate (BW/s) was obtained by determining the maximum increase in vertical ground reaction force between neighboring data points using a first derivative function within Visual 3D, and the peak tibial acceleration (g) was obtained as by extracting the maximum vertical acceleration peak from the stance phase. To calculate effective mass (% BW), an impulse-momentum model was adopted developed by Addison & Lieberman, ⁴⁶. The process for quantifying effective mass during running has been described in detail elsewhere ⁴⁷, but the vertical foot velocity in this manuscript was calculated using the foot segment centre of mass in Visual 3D ⁴⁸.

Data analysis

Means and standard deviations were calculated for each experimental variable described in the processing section. Differences in biomechanical parameters between the insole and no-insole conditions for experiment 1 and between sleeve and no-sleeve conditions in experiment 2 were examined using within subjects linear mixed models, with condition (i.e. orthoses and no-orthoses or sleeve and no-sleeve) modelled as a fixed factor and random intercepts by participants. The mean difference (b), t-value and 95% confidence intervals of this difference were obtained. In addition, to examine the extent to which patellofemoral pain symptoms influence psychological wellbeing, linear regression analyses were undertaken for both experiments, with the COOP WONCA score as the dependent and the KOOS PF score as the predictor variable. For linear regression the R^2 , its 95% confidence intervals as well as the gradient (β) and y-axis intercept (α) of the regression line were presented. Significance for all analyses was taken at the $P \leq 0.05$ level. All of the above analyses were undertaken using SPSS v27.0 (IBM, USA).

4. Results

Regression analyses

In both experiments linear regression analyses showed that KOOS PF significantly predicted COOP WONCA scores (Experiment 1: $R^2 = 0.29$, (95% CI = 0.01 – 0.65), $\beta = -0.0112$, $\alpha = 2.6374$, $P < 0.05$ and Experiment 2: $R^2 = 0.33$, (95% CI = 0.03 – 0.85), $\beta = -0.0121$, $\alpha = 2.6477$, $P < 0.05$).

Knee and external kinetics

286 - FIGURE 2 APPROX HERE -

287 - FIGURE 3 APPROX HERE -

288 - TABLE 3 APPROX HERE -

289 - TABLE 4 APPROX HERE -

290 - TABLE 5 APPROX HERE -

291 - TABLE 6 APPROX HERE -

292

293 In experiment 1, the peak knee adduction moment and knee adduction moment integral were
294 significantly larger in the insole condition (Table 2; Figure 2a). In experiment 2, both peak
295 patellofemoral force and patellofemoral force integral were significantly greater in the no-
296 sleeve condition during the run movement, whereas limb stiffness was greater in the knee
297 sleeve (Table 4; Figure 3ab). Again, during experiment 2, patellofemoral load rate was
298 significantly larger in the no-sleeve condition in the cut movement (Table 6; Figure 3d).

299

300 Kinematics

301 In experiment 1, peak dorsiflexion velocity was significantly greater in the insole condition
302 and tibial internal rotation ROM greater in the no-insole condition (Table 3; Figure 2bc). In
303 experiment 2, peak knee flexion was significantly greater in the no-sleeve condition in the run
304 movement (Table 4; Figure 3c).

305

306 5. Discussion

307 This represents the first study to investigate: the extent to which patellofemoral pain predicts
308 psychological wellbeing, the immediate effects of semi-custom insoles on lower extremity

kinetics and kinematics in runners with patellofemoral pain as well as the immediate effects of a knee sleeve on lower extremity kinetics and three-dimensional kinematics in recreational athletes with patellofemoral pain. This therefore yields additional insight into the strength of the association between patellofemoral pain and psychological wellbeing in recreationally active individuals. Furthermore, additional clinically meaningful information is also provided regarding the efficacy of both insoles and knee sleeves in recreationally active individuals suffering from patellofemoral pain.

Previous analyses have confirmed that patients with patellofemoral pain are associated with statistically lower levels of psychological wellbeing¹². This investigation expands on previous work by examining the magnitude of the association between pain symptoms and indices of psychological wellbeing in recreationally active individuals. Importantly, the findings from both experiments support both our original hypothesis and those of previous analyses¹³, in that patellofemoral pain symptoms quantified using the KOOS PF significantly predicted psychological wellbeing measured via the COOP WONCA chart. However, whilst it appears logical that a pathology associated with long term pain symptoms would result in reduced levels of psychological wellbeing, like previous investigations the current study is not able to determine whether knee pain symptoms cause individuals to be disposed to reduced psychological wellbeing or vice versa. Therefore, prospective investigations of patellofemoral pain patients taking into account the effects of psychosocial as well as biomechanical and demographic indices are clearly warranted. Furthermore, exploring the R^2 values from both investigations shows that whilst pain magnitude appears to mediate reductions in psychological wellbeing, the amount of unexplained variance in the regression models remains relatively high. Therefore, future investigations are necessary using multiple regression models to

determine the additional factors that contribute to overall psychological wellbeing in recreationally active individuals suffering from patellofemoral pain.

In relation to patellofemoral joint kinetics, the observations from experiment 1 showed that foot orthoses had no statistical effect on patellofemoral forces during running. This observation opposes our original hypothesis and also those of Sinclair et al.,³⁰ who found that in healthy males patellofemoral kinetics were significantly attenuated in the presence of foot insoles, yet agrees with those of Sinclair et al.,²⁷ indicating that insoles had no statistical influence on patellofemoral loading. However, in support of our hypothesis, the findings from experiment 2 importantly showed that patellofemoral joint kinetics were significantly attenuated by the knee sleeve in both the run and cut movements. This opposes those from Sinclair et al.,³³ and Sinclair et al.,³⁵ in healthy individuals, whereby no alterations in patellofemoral joint loading were observed when knee sleeves were utilized. Excessive and frequent patellofemoral joint loading is recognized as the predominant biomechanical causative mechanism for the commencement and progression of pain symptoms in physical active individuals¹⁸, therefore the observations from this investigation indicate that knee sleeve may be an valuable conservative therapeutic modality for active individuals with patellofemoral pain.

In addition, further examination of knee joint kinetics showed that in experiment 1, the maximum knee adduction moment and also the integral of the knee adduction moment were significantly larger in the insole condition. This finding agrees with those of Franz et al.,⁴⁹, who revealed in healthy individuals that insoles increased the magnitude of the maximum knee adduction moment during running. Despite not featuring any specific medially orientated posting, the medial arch support of the insoles examined in experiment 1 was likely sufficient

to position the centre of pressure laterally and move the ground reaction force vector medially in relation to the knee joint ⁵⁰. The knee adduction moment is a pseudo measure of medial tibiofemoral loading ⁵¹, and the peak moment ⁵², its integral ⁵³ and the loading rate of the knee adduction moment ⁵⁴ are recognized as important predictors of medial knee osteoarthritis. Importantly, despite the prevalence of patellofemoral pain as the most frequently occurring musculoskeletal pathology in active individuals, tibiofemoral pathologies still account for as many as 17 % of all knee pathologies ³. Therefore, the increased knee adduction moment indices in the insole condition indicates that they may ultimately enhance the risk for medial tibiofemoral compartment osteoarthritis.

However, whilst experiment 1 revealed that knee adduction moment parameters were larger in the insole condition, in support of our hypothesis this experiment also revealed that peak tibial internal rotation was statistically attenuated when wearing insoles. Increased internal rotation of the tibia is a commonly observed in those suffering from patellofemoral pain in relation to healthy controls ²⁰, and indeed is commonly targeted in conservative treatment plans for this condition ⁵⁵. Once again, it is likely that this alteration in tibial internal rotation was mediated via the medial arch support in the experimental orthoses ²⁷. Therefore, significant reductions in tibial internal rotation mediated via the insoles may be clinically important and indicate that insoles may be a successful treatment modality for runners' individuals with patellofemoral pain.

Furthermore, the findings in relation to the spring mass-based indices, showed that although no statistical alterations were found in experiment 1, limb stiffness was significantly larger in the knee sleeve condition during running in experiment 2. The findings from experiment 1

oppose those of Taylor et al.,⁵⁶ showing that insoles significantly enhanced knee stiffness, although experiment 2 is the first to explore the influence of knee sleeves on limb and joint stiffness indices. It is likely that the reductions in peak knee flexion that were observed in the sleeve condition, were responsible for the corresponding increase in limb stiffness as previous investigations have shown that knee flexion is negatively associated with limb stiffness⁵⁷. Increased limb stiffness has been postulated to be a with risk factor for chronic lower extremity running injuries, although the evidence base remains controversial⁵⁸. As such, the implications of this observation for runners with patellofemoral pain is not currently known. Therefore, future aetiological analyses are important to clarify the association between limb stiffness and patellofemoral pain.

A downside to this study is that it examined male runners/ athletes only. As females are known to be more susceptible to patellofemoral pain¹⁶ and exhibit distinct patellofemoral joint kinetics⁵⁹ in relation to age matched males, it is therefore unknown as to whether the findings from this study would differ had female runners/ athletes been examined. Future, research should seek to establish the effectiveness of both insoles and knee sleeves in recreational runners/ athletes of both sexes. In addition, that patellofemoral loading was explored using musculoskeletal modelling may also serve as a shortcoming to the current study. This approach was necessary taking into account the impracticalities of obtaining direct indices of joint kinetics and represents an extension of traditional patellofemoral joint modelling approaches, as knee flexor co-contraction was incorporated into the biomechanical model. However, additional research and development analyses remain necessary, in order to develop bespoke subject specific knee joint models that improve patellofemoral joint loading indices and allow the effects of different treatment modalities to be examined more readily.

405

406 In conclusion, this investigation augments the existing literature in clinical biomechanics by
407 examining the extent to which pain symptoms predict psychological wellbeing as well as giving
408 a comprehensive comparative examination concerning the influence of insoles and knee
409 sleeves on lower extremity biomechanics in those with patellofemoral pain. The findings from
410 both experiments show that pain symptoms were predictive of psychological wellbeing.
411 Experiment 1 importantly revealed that whilst insoles significantly increased the knee
412 adduction moment, they were able to reduce the magnitude of tibial internal rotation and
413 experiment 2 showed that the knee sleeve attenuated patellofemoral joint kinetics in both the
414 run and cut movements. The findings therefore suggest that both insoles and knee sleeves may
415 provide immediate biomechanical benefits in recreationally active individuals with
416 patellofemoral pain, although when wearing insoles this may be at the expense of an increased
417 knee adduction moment during running.

418

419 **List of figures**

420 Figure 1: a. Experimental marker locations and b. trunk, pelvis, foot, shank and thigh segments,
421 with segment axes (R = right & L = left), (TR=trunk, P=Pelvis, F=foot, S =shank & T=thigh),
422 (X=sagittal, Y=coronal & Z=transverse planes).

423 Figure 2: Kinetics and kinematics from experiment 1 (a = knee adduction moment, b = tibial
424 internal rotation & c = dorsiflexion velocity).

425 Figure 3: Kinetics and kinematics from experiment 2 (a = patellofemoral force during running,
426 b = limb stiffness during running, c = knee flexion during running & d. patellofemoral force
427 during the cut movement).

428

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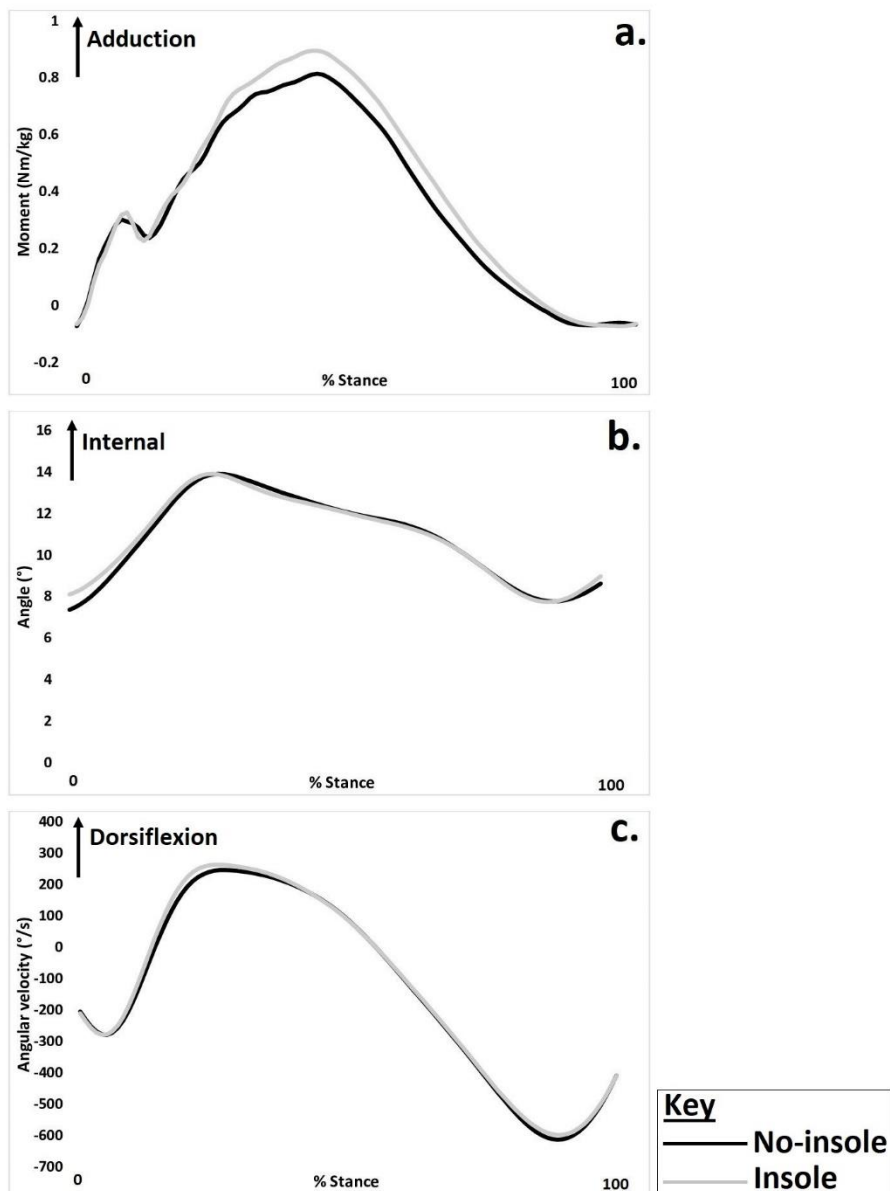
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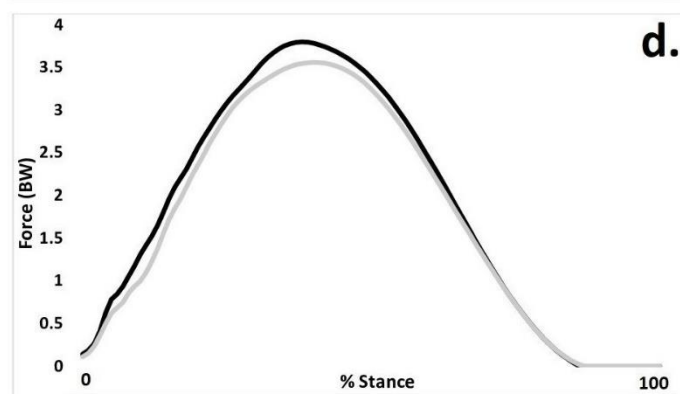
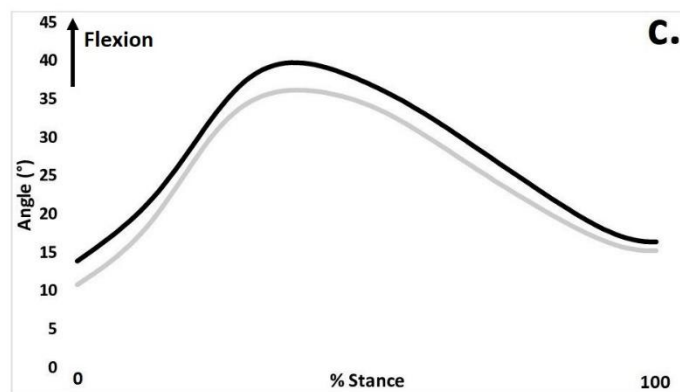
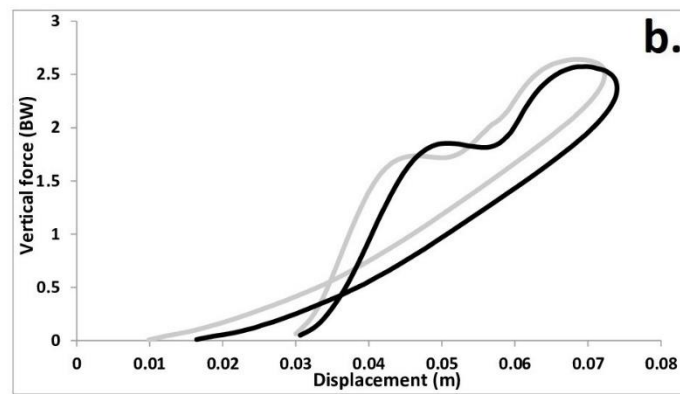
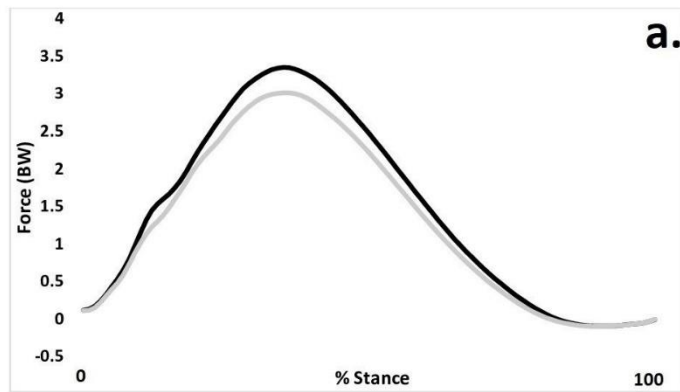
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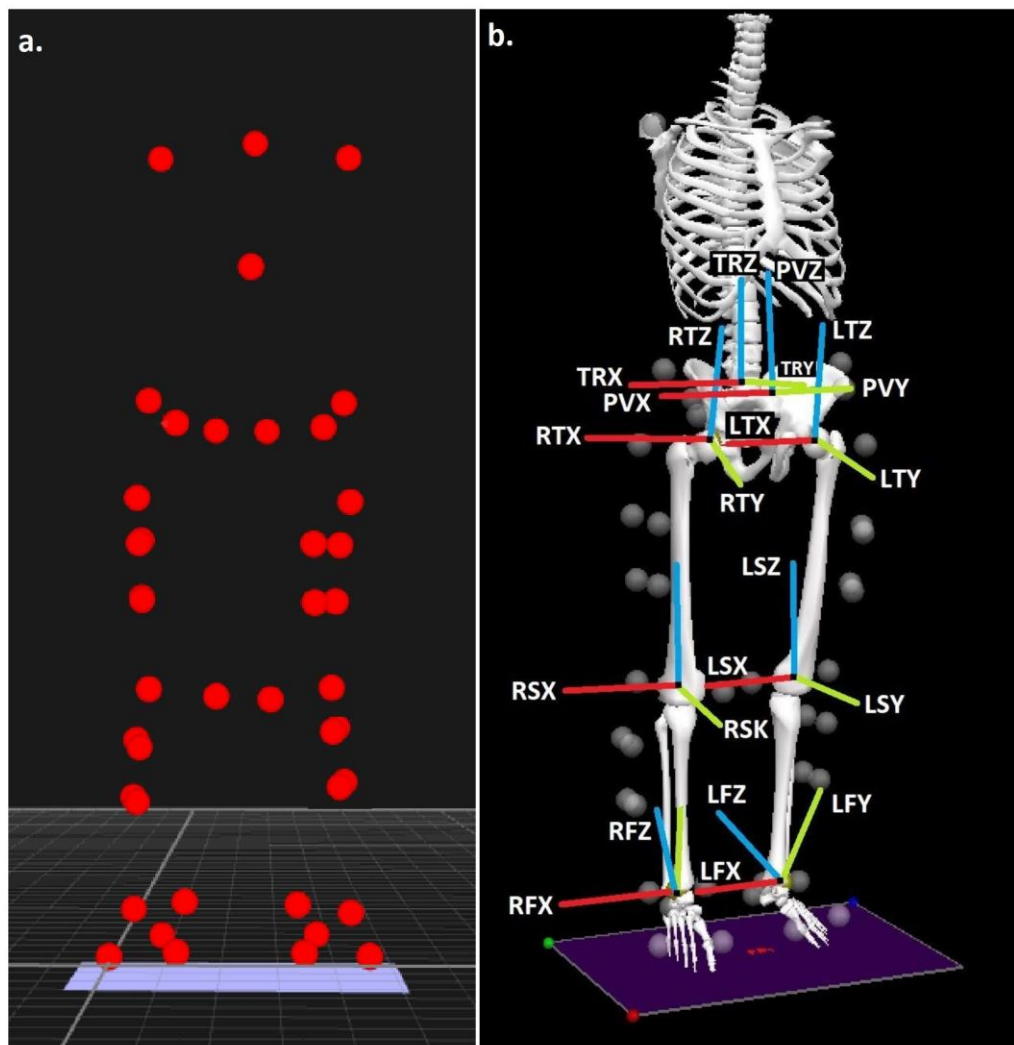




Key

— No-sleeve

— Sleeve



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611 Table 1: Participant characteristics from both experiments.

Experiment 1			Experiment 2		
	Mean	SD		Mean	SD
Age	33.12	8.4	Age	27.15	7.48
Body mass (kg)	72.28	13.02	Body mass (kg)	69.15	6.49
Stature (m)	1.74	0.08	Stature (m)	1.72	0.06
BMI (kg/m ²)	23.8	2.44	BMI (kg/m ²)	22.8	2.01
KOOS-PF	59.44	13.3	KOOS-PF	59.83	14.84
COOP WONCA	1.97	0.28	COOP WONCA	1.92	0.38

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Table 2: Knee and external kinetics from experiment 1, from the insole and no-insole conditions.

	No-insole		Insole		<i>b</i>	t	p	95% CI	
	Mean	SD	Mean	SD				Lower	Upper
Knee adduction moment (Nm/kg)	1.00	0.28	1.09	0.34	-0.10	-2.23	0.04	-0.19	0.00
Knee adduction moment load rate (Nm/kg/s)	62.34	19.14	69.13	21.13	-6.79	-1.65	0.12	-15.49	1.91
Knee adduction moment integral (Nm/kg·s)	0.08	0.03	0.09	0.04	-0.01	-2.40	0.03	-0.02	0.00
Peak patellofemoral force (BW)	3.55	0.94	3.59	0.95	-0.04	-0.29	0.77	-0.34	0.25
Patellofemoral load rate (BW/s)	94.59	22.82	99.49	26.56	-4.90	-1.89	0.08	-10.41	0.61
Patellofemoral force integral (BW·s)	0.31	0.10	0.32	0.10	-0.01	-0.54	0.59	-0.05	0.03
Peak patellofemoral stress (KPa/BW)	6.48	1.42	6.55	1.42	-0.07	-0.34	0.74	-0.51	0.37
Patellofemoral stress load rate (KPa/BW/s)	188.29	33.46	194.73	37.54	-0.02	-0.59	0.57	-0.08	0.04
Patellofemoral stress integral (KPa/BW·s)	0.59	0.16	0.60	0.16	-6.45	-1.15	0.27	-18.34	5.45
Limb stiffness (BW/m)	61.64	22.77	59.20	20.76	2.44	0.95	0.36	-2.99	7.87
Peak tibial acceleration (g)	7.64	1.70	7.80	2.02	-0.16	-0.41	0.69	-0.97	0.65
Tibial acceleration load rate (g/s)	610.27	117.70	653.39	172.26	-43.13	-1.13	0.28	-124.05	37.80
Load rate (BW/s)	145.80	36.27	147.39	36.47	-1.58	-0.27	0.79	-14.00	10.83
Effective mass (%BW)	10.26	2.16	10.45	1.95	-0.19	-0.56	0.58	-0.92	0.54
Knee stiffness (Nm/kg/°)	0.10	0.02	0.09	0.02	0.00	0.51	0.62	0.00	0.01

Key: Bold text = statistical significance

Table 3: Knee and ankle kinematics from experiment 1, from the insole and no-insole conditions.

	No-insole		Insole		<i>b</i>	t	p	95% CI	
	Mean	SD	Mean	SD				Lower	Upper
	<i>Knee</i>								
Peak flexion (°)	40.05	6.96	40.32	7.24	-0.27	-0.41	0.69	-1.68	1.14
Peak abduction (°)	-9.06	4.76	-9.05	5.08	-0.01	-0.02	0.99	-0.98	0.97
Peak internal rotation (°)	11.00	6.85	9.71	7.08	1.29	1.57	0.14	-0.45	3.03
Sagittal plane ROM (°)	26.40	4.79	26.63	3.65	-0.23	-0.36	0.73	-1.59	1.13
Coronal plane ROM (°)	5.72	3.37	5.32	3.54	0.39	0.99	0.34	-0.45	1.23
Transverse plane ROM (°)	15.92	7.37	14.82	7.84	1.09	1.53	0.15	-0.42	2.61
Peak flexion velocity (°/s)	481.68	77.23	500.64	78.68	-18.96	-1.33	0.20	-49.09	11.17
Peak adduction velocity (°/s)	133.49	46.94	135.87	55.06	-2.37	-0.21	0.84	-26.32	21.57
Peak internal rotation velocity (°/s)	329.22	102.70	305.61	112.81	23.61	1.38	0.19	-12.56	59.78
Peak extension velocity (°/s)	-282.75	78.05	-284.35	81.35	1.60	0.21	0.84	-14.57	17.76
Peak abduction velocity (°/s)	-283.21	67.95	-281.69	71.81	4.60	0.50	0.62	-14.92	24.12
Peak external rotation velocity (°/s)	-292.69	82.70	-286.90	81.68	-5.78	-0.49	0.63	-30.83	19.26
	<i>Ankle</i>								
Peak dorsiflexion (°)	18.74	4.50	18.90	5.19	-0.16	-0.42	0.68	-0.96	0.64
Peak eversion (°)	-7.77	3.41	-7.80	3.98	0.03	0.05	0.96	-1.08	1.13
Peak external rotation (°)	-6.92	3.80	-7.01	4.15	0.09	0.20	0.84	-0.84	1.01
Sagittal plane ROM (°)	10.16	4.18	11.44	3.83	-1.28	-1.57	0.14	-3.01	0.44
Coronal plane ROM (°)	12.13	2.88	11.87	2.95	0.26	0.83	0.42	-0.40	0.92
Transverse plane ROM (°)	6.46	3.53	6.03	3.69	0.43	1.40	0.18	-0.22	1.08
Peak dorsiflexion velocity (°/s)	300.01	63.16	317.07	64.45	-17.06	-2.34	0.03	-32.50	-1.62
Peak inversion velocity (°/s)	153.76	62.12	151.52	60.45	2.23	0.38	0.71	-10.15	14.61
Peak external rotation velocity (°/s)	175.64	48.39	175.19	58.26	0.44	0.05	0.96	-18.89	19.78
Peak plantarflexion velocity (°/s)	-631.52	107.93	-617.54	114.29	-13.98	-1.26	0.23	-37.58	9.62
Peak eversion velocity (°/s)	-283.21	67.95	-281.69	71.81	-1.52	-0.15	0.88	-22.49	19.45
Peak internal rotation velocity (°/s)	-201.67	77.05	-195.56	88.72	-6.11	-0.68	0.51	-25.16	12.94
Peak tibial internal rotation (°/s)	14.95	8.01	14.97	8.02	-0.02	-0.04	0.97	-0.95	0.92
Tibial internal rotation ROM (°/s)	7.59	3.42	6.87	4.07	0.72	2.14	0.05	0.01	1.43
Peak tibial internal rotation velocity (°/s)	209.58	63.04	208.93	90.53	0.65	0.06	0.95	-22.31	23.62

Key: Bold text = statistical significance

Table 4: Kinetics and kinematics for the run movement in experiment 2.

	No-sleeve		Sleeve		<i>b</i>	<i>t</i>	<i>p</i>	95% CI	
	Mean	SD	Mean	SD				Lower	Upper
Knee adduction moment (Nm/kg)	1.05	0.29	1.08	0.50	-0.03	-0.37	0.71	-0.21	0.14
Knee adduction moment integral (Nm/kg·s)	0.08	0.03	0.09	0.04	-0.01	-0.36	0.73	-0.02	0.01
Knee adduction moment load rate (Nm/kg/s)	76.52	28.58	80.97	42.68	-4.46	-0.69	0.50	-18.51	9.60
Peak patellofemoral force (BW)	3.40	0.79	3.10	0.67	0.30	2.13	0.04	0.02	0.63
Patellofemoral load rate (BW/s)	109.13	34.96	95.46	27.21	13.67	1.91	0.08	-1.91	29.25
Patellofemoral force integral (BW·s)	0.35	0.10	0.32	0.08	0.03	2.00	0.04	0.01	0.07
Peak patellofemoral stress (KPa/BW)	6.16	1.26	5.84	1.16	0.33	1.39	0.19	-0.19	0.84
Patellofemoral stress integral (KPa/BW·s)	236.26	75.06	218.96	60.40	17.30	1.25	0.24	-12.89	47.49
Patellofemoral stress load rate (KPa/BW/s)	0.67	0.17	0.62	0.14	0.04	1.64	0.13	-0.01	0.10
Limb stiffness (BW/m)	51.77	12.76	58.43	18.15	-6.66	-2.76	0.02	-11.92	-1.39
Knee stiffness (Nm/kg/°)	0.12	0.03	0.11	0.03	0.01	0.59	0.57	-0.01	0.02
Peak flexion (°)	39.95	4.77	36.56	3.74	3.38	3.51	0.00	1.29	5.48
Peak abduction (°)	-6.37	4.13	-4.93	4.14	-1.43	-1.27	0.23	-3.90	1.03
Peak internal rotation (°)	8.32	4.11	8.40	4.48	-0.08	-0.06	0.95	-2.77	2.62
Sagittal plane ROM (°)	26.08	4.16	25.65	3.92	0.43	0.40	0.70	-1.94	2.80
Coronal plane ROM (°)	4.07	3.00	4.05	3.38	0.01	0.02	0.98	-1.47	1.50
Transverse plane ROM (°)	10.61	4.77	10.88	4.80	-0.28	-0.30	0.77	-2.26	1.71
Peak flexion velocity (°)	468.32	85.62	484.84	99.88	-16.52	-0.93	0.37	-55.30	22.27
Peak adduction velocity (°)	99.08	32.03	102.81	32.76	-3.73	-0.39	0.71	-24.68	17.23
Peak internal rotation velocity (°)	264.79	74.07	273.32	75.38	-8.53	-0.44	0.67	-50.77	33.70
Peak extension velocity (°)	-259.31	69.67	-244.61	40.94	-14.70	-0.95	0.36	-48.37	18.98
Peak abduction velocity (°)	-124.77	46.02	-135.71	55.54	10.94	0.74	0.47	-21.31	43.19
Peak external rotation velocity (°)	-233.77	78.51	-220.67	59.55	-13.09	-0.76	0.46	-50.73	24.55

Key: Bold text = statistical significance

Table 5: Kinetics and kinematics for the cut movement in experiment 2.

	No-sleeve		Sleeve		<i>b</i>	<i>t</i>	<i>p</i>	95% CI	
	Mean	SD	Mean	SD				Lower	Upper
Knee adduction moment (Nm/kg)	1.15	0.25	1.15	0.41	0.00	0.07	0.95	-0.15	0.16
Knee adduction moment integral (Nm/kg·s)	0.10	0.05	0.11	0.08	-0.01	-0.82	0.43	-0.04	0.02
Knee adduction moment load rate (Nm/kg/s)	105.48	40.61	96.30	47.73	9.18	1.46	0.17	-4.52	22.88
Peak patellofemoral force (BW)	3.94	1.11	3.75	1.13	0.19	1.46	0.17	-0.09	0.47
Patellofemoral load rate (BW/s)	135.18	61.30	111.24	43.09	23.94	2.12	0.04	4.06	51.93
Patellofemoral force integral (BW·s)	0.49	0.19	0.50	0.19	-0.01	-0.50	0.63	-0.05	0.03
Peak patellofemoral stress (KPa/BW)	6.83	1.78	6.51	1.74	0.32	1.52	0.15	-0.14	0.79
Patellofemoral stress load rate (KPa/BW/s)	286.44	123.54	241.70	97.10	44.73	1.57	0.14	-17.44	106.91
Patellofemoral stress integral (KPa/BW·s)	0.90	0.31	0.92	0.31	-0.02	-0.75	0.47	-0.09	0.05
Limb stiffness (BW/m)	48.20	17.05	49.80	18.43	-1.60	-0.35	0.73	-11.50	8.30
Knee stiffness (Nm/kg/°)	0.10	0.03	0.09	0.02	0.01	1.43	0.18	-0.01	0.03
Peak flexion (°)	44.75	4.36	44.35	4.28	0.41	0.46	0.65	-1.51	2.33
Peak abduction (°)	-6.96	4.39	-6.77	4.79	-0.19	-0.14	0.89	-3.18	2.79
Peak internal rotation (°)	8.05	4.26	8.43	4.48	-0.39	-0.33	0.75	-2.94	2.16
Sagittal plane ROM (°)	30.48	6.09	32.86	5.17	-2.38	-2.06	0.06	-4.90	0.14
Coronal plane ROM (°)	5.40	3.18	5.61	3.74	-0.21	-0.23	0.82	-2.20	1.78
Transverse plane ROM (°)	11.99	4.91	11.31	4.54	0.68	0.78	0.45	-1.22	2.58
Peak flexion velocity (°)	534.87	102.66	569.22	109.24	-34.35	-1.78	0.10	-76.45	7.75
Peak adduction velocity (°)	150.10	67.34	137.27	65.62	12.83	1.13	0.28	-11.85	37.51
Peak internal rotation velocity (°)	287.99	106.19	284.90	80.21	3.09	0.19	0.85	-31.79	37.97
Peak extension velocity (°)	-306.10	101.59	-302.58	109.33	-3.52	-0.33	0.75	-27.07	20.04
Peak abduction velocity (°)	-176.62	62.59	-185.86	71.79	9.25	0.68	0.51	-20.44	38.93
Peak external rotation velocity (°)	-244.51	87.24	-228.60	80.55	-15.91	-1.06	0.31	-48.61	16.80

Key: Bold text = statistical significance

Table 6: Kinetics and kinematics for the hop movement in experiment 2.

	No-sleeve		Sleeve		<i>b</i>	<i>t</i>	<i>p</i>	95% CI	
	Mean	SD	Mean	SD				Lower	Upper
Knee adduction moment (Nm/kg)	1.37	0.46	1.31	0.28	0.06	0.58	0.57	-0.16	0.27
Knee adduction moment integral (Nm/kg·s)	0.11	0.05	0.12	0.06	-0.01	-0.41	0.69	-0.03	0.02
Knee adduction moment load rate (Nm/kg/s)	130.33	71.73	125.23	49.39	5.11	0.42	0.68	-21.51	31.73
Peak patellofemoral force (BW)	4.40	1.20	4.17	1.10	0.22	0.76	0.46	-0.42	0.87
Patellofemoral load rate (BW/s)	151.25	71.71	118.42	36.17	32.82	1.81	0.10	-6.65	72.30
Patellofemoral force integral (BW·s)	0.58	0.34	0.59	0.42	-0.01	-0.09	0.93	-0.20	0.18
Peak patellofemoral stress (KPa/BW)	7.49	1.50	7.23	1.57	0.26	0.68	0.51	-0.58	1.10
Patellofemoral stress load rate (KPa/BW/s)	340.61	158.35	282.26	103.57	58.35	1.32	0.21	-37.94	154.64
Patellofemoral stress integral (KPa/BW·s)	1.01	0.49	1.03	0.64	-0.03	-0.19	0.85	-0.33	0.28
Limb stiffness (BW/m)	39.66	13.21	38.30	10.59	1.36	0.27	0.79	-9.54	12.26
Knee stiffness (Nm/kg/°)	0.09	0.03	0.09	0.03	0.00	0.59	0.56	-0.01	0.02
Peak flexion (°)	49.13	10.84	47.85	9.18	1.28	0.49	0.63	-4.43	7.00
Peak abduction (°)	-3.55	4.78	-3.00	3.98	-0.55	-0.42	0.68	-3.39	2.30
Peak internal rotation (°)	4.57	4.50	4.49	2.69	0.08	0.09	0.93	-2.00	2.16
Sagittal plane ROM (°)	33.94	8.47	35.52	8.99	-1.58	-0.57	0.58	-7.56	4.41
Coronal plane ROM (°)	1.40	1.69	1.35	1.86	0.05	0.07	0.94	-1.45	1.55
Transverse plane ROM (°)	4.99	2.85	5.13	2.05	-0.14	-0.16	0.87	-1.98	1.71
Peak flexion velocity (°)	565.30	117.61	547.91	114.53	17.39	0.88	0.40	-25.82	60.59
Peak adduction velocity (°)	146.58	51.91	142.90	41.87	3.68	0.38	0.71	-17.68	25.05
Peak internal rotation velocity (°)	221.34	70.13	210.13	58.95	11.22	0.82	0.43	-18.67	41.11
Peak extension velocity (°)	-30.97	48.55	-27.93	42.94	-3.04	-0.32	0.75	-23.56	17.49
Peak abduction velocity (°)	-125.73	33.49	-117.13	25.39	-8.59	-0.79	0.45	-32.44	15.25
Peak external rotation velocity (°)	-183.18	82.93	-181.03	67.26	-2.15	-0.10	0.92	-47.72	43.42