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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 advantages [1]. However, in spite of the physiological benefits produced through regular physical activity, it is connected to a high frequency of chronic injuries [2]. Anterior knee pain more commonly referred to as patellofemoral pain, is renowned as the most commonly occurring overuse injury [3]. This condition characteristically presents via retropatellar or diffuse peripatellar pain and inflammation, exaggerated by actions that commonly and excessive load the joint itself [4]. This pathology has an extremely high overall prevalence of 15-45% in the general population [5], with 25% of individuals reporting to physiotherapy clinics presenting with patellofemoral pain [6].

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 diagnosis [7]. Overall, females are regarded as being at a 3-fold increased risk from experiencing patellofemoral pain compared to age matched males [8]. 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 life [10], 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 activity [11], 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 activity [14]. 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 progressions [15] and both extrinsic and intrinsic factors have been cited as causative factors [16]. Commonly cited extrinsic mechanisms include excessive training volumes, training errors and suboptimal training equipment [16]. Typically outlined intrinsic modalities include, lower extremity muscle imbalances, mal-alignment, and knee joint laxity [17]. 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 questionnaires [12] 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 literature [33]. The insoles were moulded in the laboratory in full accordance with the manufacturer's guidelines using previously outlined procedures [33]. 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 literature [31]. 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 index [38].

*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 (±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 (±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].

*Processing*

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

Across both experiments patellofemoral joint loading was calculating by adapting an early model developed by van Eijden et al., [42] to account for knee flexor co-contraction [43]. The process for calculating patellofemoral loading using the aforementioned modeling approach is described in detail elsewhere [4]. The peak patellofemoral force (BW), peak patellofemoral stress (KPa/BW), patellofemoral force loading rate (BW/s - maximum increase between neighboring data points quantified using a first derivative function within Visual 3D), patellofemoral stress 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 $R^2$, it's 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*

**- FIGURE 2 APPROX HERE -**

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

*Kinematics*

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

## 5. Discussion

This represents the first study to investigate: the extent to which patellofemoral pain predicts 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 wellbeing [12]. 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 analyses [13], 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 individuals [18], 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 tibiofmeoral 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 stiffness [57]. Increased limb stiffness has been postulated to be a with risk factor for chronic lower extremity running injuries, although the evidence base remains controversial [58]. 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 pain [16] and exhibit distinct patellofemoral joint kinetics [59] 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.

In conclusion, this investigation augments the existing literature in clinical biomechanics by examining the extent to which pain symptoms predict psychological wellbeing as well as giving a comprehensive comparative examination concerning the influence of insoles and knee sleeves on lower extremity biomechanics in those with patellofemoral pain. The findings from both experiments show that pain symptoms were predictive of psychological wellbeing. Experiment 1 importantly revealed that whilst insoles significantly increased the knee adduction moment, they were able to reduce the magnitude of tibial internal rotation and experiment 2 showed that the knee sleeve attenuated patellofemoral joint kinetics in both the run and cut movements. The findings therefore 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.

**List of figures**

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

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

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

## References

1. Lee, D. C., Pate, R. R., Lavie, C. J., Sui, X., Church, T. S., & Blair, S. N. (2014). Leisure-time running reduces all-cause and cardiovascular mortality risk. Journal of the American College of Cardiology, 64(5), 472-481.
2. Lauersen, J. B., Bertelsen, D. M., & Andersen, L. B. (2014). The effectiveness of exercise interventions to prevent sports injuries: a systematic review and meta-analysis of randomised controlled trials. British Journal of Sports Medicine, 48(11), 871-877.
3. Taunton, J. E., Ryan, M. B., Clement, D. B., McKenzie, D. C., Lloyd-Smith, D. R., & Zumbo, B. D. (2002). A retrospective case-control analysis of 2002 running injuries. British Journal of Sports Medicine, 36(2), 95-101.
4. Sinclair, J., Janssen, J., Richards, J. D., Butters, B., Taylor, P. J., & Hobbs, S. J. (2018). Effects of a 4-week intervention using semi-custom insoles on perceived pain and patellofemoral loading in targeted subgroups of recreational runners with patellofemoral pain. Physical Therapy in Sport, 34, 21-27.
5. Clijsen, R., Fuchs, J., & Taeymans, J. (2014). Effectiveness of exercise therapy in treatment of patients with patellofemoral pain syndrome: systematic review and meta-analysis. Physical Therapy, 94(12), 1697-1708.
6. Dixit, S., Difiori, J. P., Burton, M., & Mines, B. (2007). Management of patellofemoral pain syndrome. American family physician, 75(2), 194-202.
7. Nimon, G., Murray, D., Sandow, M., & Goodfellow, J. (1998). Natural history of anterior knee pain: a 14-to 20-year follow-up of nonoperative management. Journal of Pediatric Orthopaedics, 18(1), 118-122.
8. Robinson, R. L., & Nee, R. J. (2007). Analysis of hip strength in females seeking physical therapy treatment for unilateral patellofemoral pain syndrome. Journal of orthopaedic & sports physical therapy, 37(5), 232-238.

9. Selfe, J., Janssen, J., Callaghan, M., Witvrouw, E., Sutton, C., Richards, J., & Dey, P. (2016). Are there three main subgroups within the patellofemoral pain population? A detailed characterisation study of 127 patients to help develop targeted intervention (TIPPs). British journal of sports medicine, 50(14), 873-880.
10. Thomas, M. J., Wood, L., Selfe, J., & Peat, G. (2010). Anterior knee pain in younger adults as a precursor to subsequent patellofemoral osteoarthritis: a systematic review. BMC Musculoskeletal Disorders, 11(1), 1-8.
11. Blond, L., & Hansen, L. (1998). Patellofemoral pain syndrome in athletes: a 5.7-year retrospective follow-up study of 250 athletes. Acta Orthop Belg, 64(4), 393-400.
12. Jensen, R., Hystad, T., & Baerheim, A. (2005). Knee function and pain related to psychological variables in patients with long-term patellofemoral pain syndrome. Journal of Orthopaedic & Sports Physical Therapy, 35(9), 594-600.
13. Maclachlan, L. R., Matthews, M., Hodges, P. W., Collins, N. J., & Vicenzino, B. (2018). The psychological features of patellofemoral pain: a cross-sectional study. Scandinavian journal of pain, 18(2), 261-271.
14. Fulkerson, J. P. (2002). Diagnosis and treatment of patients with patellofemoral pain. The American journal of sports medicine, 30(3), 447-456.
15. Witvrouw, E., Callaghan, M. J., Stefanik, J. J., Noehren, B., Bazett-Jones, D. M., Willson, J. D., & Crossley, K. M. (2014). Patellofemoral pain: consensus statement from the 3rd International Patellofemoral Pain Research Retreat held in Vancouver, September 2013. British journal of sports medicine, 48(6), 411-414.
16. Hryvniak, D., Magrum, E., & Wilder, R. (2014). Patellofemoral pain syndrome: an update. Current Physical Medicine and Rehabilitation Reports, 2(1), 16-24.
17. Tumia, N., & Maffulli, N. (2002). Patellofemoral pain in female athletes. Sports Medicine and Arthroscopy Review, 10(1), 69-75.

18. Farrokhi, S., Keyak, J. H., & Powers, C. M. (2011). Individuals with patellofemoral pain exhibit greater patellofemoral joint stress: a finite element analysis study. Osteoarthritis and Cartilage, 19(3), 287-294.

19. Hetsroni, I., Finestone, A., Milgrom, C., Sira, D. B., Nyska, M., Radeva-Petrova, D., & Ayalon, M. (2006). A prospective biomechanical study of the association between foot pronation and the incidence of anterior knee pain among military recruits. The Journal of bone and joint surgery. British volume, 88(7), 905-908.

20. Levinger, P., & Gilleard, W. (2007). Tibia and rearfoot motion and ground reaction forces in subjects with patellofemoral pain syndrome during walking. Gait & posture, 25(1), 2-8.

21. Willson, J. D., & Davis, I. S. (2008). Lower extremity mechanics of females with and without patellofemoral pain across activities with progressively greater task demands. Clinical biomechanics, 23(2), 203-211.

22. Souza, R. B., & Powers, C. M. (2009). Differences in hip kinematics, muscle strength, and muscle activation between subjects with and without patellofemoral pain. journal of orthopaedic & sports physical therapy, 39(1), 12-19.

23. Boling, M. C., Padua, D. A., Marshall, S. W., Guskiewicz, K., Pyne, S., & Beutler, A. (2009). A prospective investigation of biomechanical risk factors for patellofemoral pain syndrome: the Joint Undertaking to Monitor and Prevent ACL Injury (JUMP-ACL) cohort. The American journal of sports medicine, 37(11), 2108-2116.

24. Nakagawa, T. H., Moriya, É. T., Maciel, C. D., & Serrao, A. F. (2012). Frontal plane biomechanics in males and females with and without patellofemoral pain. Medicine and science in sports and exercise, 44(9), 1747-1755.

25. Davis, I. S., Bowser, B. J., & Hamill, J. (2010). Vertical Impact Loading in Runners with a History of Patellofemoral Pain Syndrome. Medicine & Science in Sports & Exercise, 42(5), 682-685.

26. Smith, B. E., Hendrick, P., Bateman, M., Moffatt, F., Rathleff, M. S., Selfe, J., & Logan, P. (2019). A loaded self-managed exercise programme for patellofemoral pain: a mixed methods feasibility study. BMC musculoskeletal disorders, 20(1), 1-13.

27. Sinclair, J., Ingram, J., Taylor, P. J., & Chockalingam, N. (2019). Acute effects of different orthoses on lower extremity kinetics and kinematics during running; a musculoskeletal simulation analysis. Acta of bioengineering and biomechanics, 21(4), 13-25.

28. Sinclair, J., Isherwood, J., & Taylor, P. J. (2014). Effects of foot orthoses on kinetics and tibiocalcaneal kinematics in recreational runners. FAOJ, 7, 3-11.

29. Laughton, C. A., Davis, I. M., & Hamill, J. (2003). Effect of strike pattern and orthotic intervention on tibial shock during running. Journal of applied biomechanics, 19(2), 153-168.

30. Sinclair, J. K., Vincent, H., Selfe, J., Atkins, S., Taylor, P. J., & Richards, J. (2015). Effects of foot orthoses on patellofemoral load in recreational runners. FAOJ, 8(2), 5-10.

31. Sinclair, J. K., Shore, H., & Richards, J. (2016). Effects of semi-custom and off-the-shelf orthoses on Achilles tendon and patellofemoral kinetics in female runners. Baltic Journal of Health and Physical Activity, 8(4), 7-15.

32. Uboldi, F. M., Ferrua, P., Tradati, D., Zedde, P., Richards, J., Manunta, A., & Berruto, M. (2018). Use of an elastomeric knee brace in patellofemoral pain syndrome: short-term results. Joints, 6(2), 85-89.

33. Sinclair, J. K., Vincent, H., & Richards, J. D. (2017). Effects of prophylactic knee bracing on knee joint kinetics and kinematics during netball specific movements. Physical Therapy in Sport, 23, 93-98.
34. Valldecabres, R., de Benito, A. M., Littler, G., & Richards, J. (2018). An exploration of the effect of proprioceptive knee bracing on biomechanics during a badminton lunge to the net, and the implications to injury mechanisms. PeerJ, 6, e6033.
35. Sinclair, J., Taylor, P. J., & Foxcroft, H. (2019). Effects of prophylactic knee bracing on knee joint kinetics and kinematics during single-and double-limb post-catch deceleration strategies in university netballers. Sport Sciences for Health, 15(1), 215-222.
36. Crossley, K. M., Macri, E. M., Cowan, S. M., Collins, N. J., & Roos, E. M. (2018). The patellofemoral pain and osteoarthritis subscale of the KOOS (KOOS-PF): development and validation using the COSMIN checklist. British journal of sports medicine, 52(17), 1130-1136.
37. Crossley, K., Bennell, K., Green, S., Cowan, S., & McConnell, J. (2002). Physical therapy for patellofemoral pain: a randomized, double-blinded, placebo-controlled trial. The American journal of sports medicine, 30(6), 857-865.
38. Esculier, J. F., Dubois, B., Dionne, C. E., Leblond, J., & Roy, J. S. (2015). A consensus definition and rating scale for minimalist shoes. Journal of Foot and Ankle Research, 8(1), 1-9.
39. Sinclair, J. K., Edmundson, C. J., Brooks, D., & Hobbs, S. J. (2011). Evaluation of kinematic methods of identifying gait Events during running. International Journal of Sports Science and Engineering, 5(3), 188-192.

40. Sinclair, J., Chockalingam, N., Naemi, R., & Vincent, H. (2015). The effects of sport-specific and minimalist footwear on the kinetics and kinematics of three netball-specific movements. Footwear Science, 7(1), 31-36.

41. Sinclair, J., Bottoms, L., Taylor, K., & Greenhalgh, A. (2010). Tibial shock measured during the fencing lunge: the influence of footwear. Sports Biomechanics, 9(2), 65-71.

42. Van Eijden, T. M. G. J., Kouwenhoven, E., Verburg, J., & Weijs, W. A. (1986). A mathematical model of the patellofemoral joint. Journal of biomechanics, 19(3), 219-229.

43. Willson, J. D., Ratcliff, O. M., Meardon, S. A., & Willy, R. W. (2015). Influence of step length and landing pattern on patellofemoral joint kinetics during running. Scandinavian journal of medicine & science in sports, 25(6), 736-743.

44. Blickhan, R. (1989). The spring-mass model for running and hopping. Journal of biomechanics, 22(11-12), 1217-1227.

45. Sinclair, J., Atkins, S., & Taylor, P. J. (2016). The effects of barefoot and shod running on limb and joint stiffness characteristics in recreational runners. Journal of Motor Behavior, 48(1), 79-85.

46. Addison, B. J., & Lieberman, D. E. (2015). Tradeoffs between impact loading rate, vertical impulse and effective mass for walkers and heel strike runners wearing footwear of varying stiffness. Journal of Biomechanics, 48(7), 1318-1324.

47. Chi, K. J., & Schmitt, D. (2005). Mechanical energy and effective foot mass during impact loading of walking and running. Journal of Biomechanics, 38(7), 1387-1395.

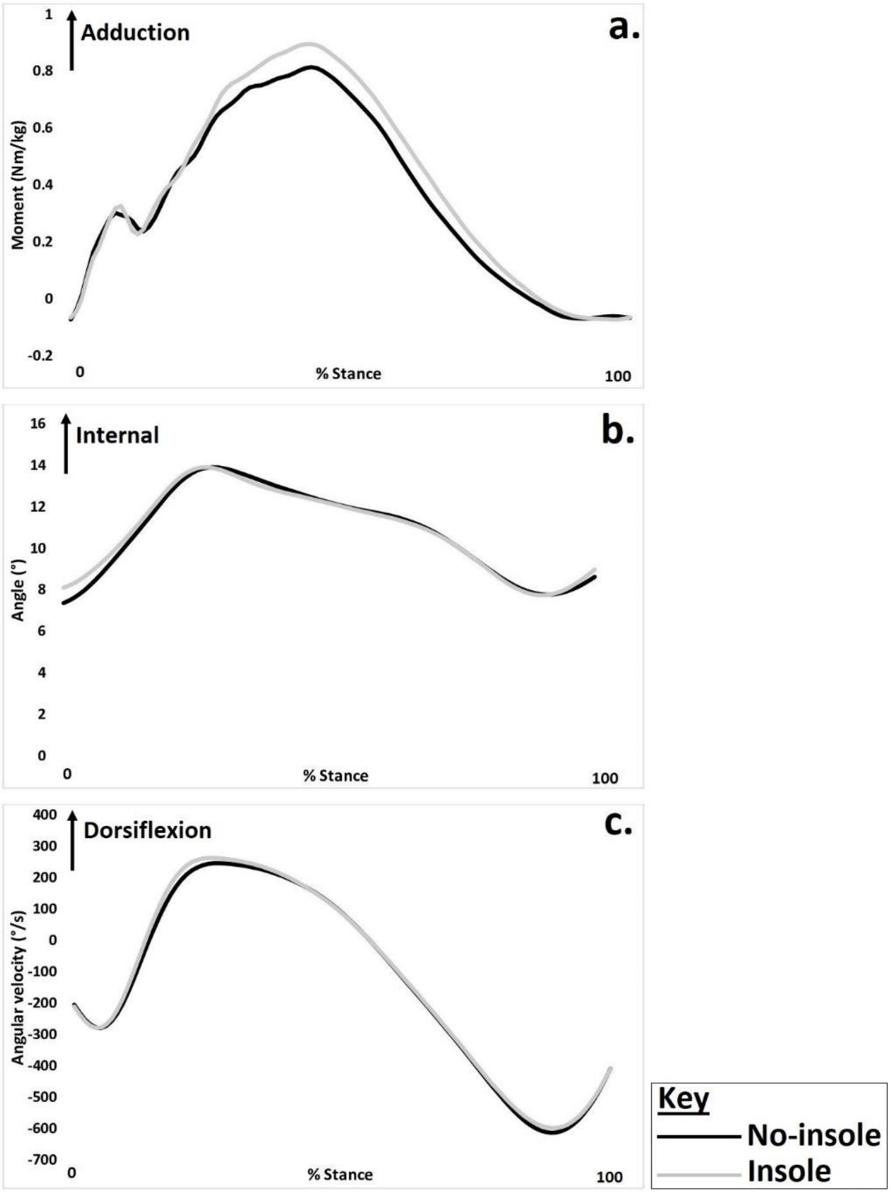
48. Sinclair, J., Stainton, P., & Hobbs, S. J. (2018). Effects of barefoot and minimally shod footwear on effective mass–Implications for transient musculoskeletal loading. Kinesiology, 50(2), 165-171.

49. Franz, J. R., Dicharry, J., Riley, P. O., Jackson, K., Wilder, R. P., & Kerrigan, D. C. (2008). The influence of arch supports on knee torques relevant to knee osteoarthritis. Medicine and Science in Sports and Exercise, 40(5), 913-917.
50. Sinclair, J. (2018). Mechanical effects of medial and lateral wedged orthoses during running. Physical Therapy in Sport, 32, 48-53.
51. Birmingham, T. B., Hunt, M. A., Jones, I. C., Jenkyn, T. R., & Giffin, J. R. (2007). Test–retest reliability of the peak knee adduction moment during walking in patients with medial compartment knee osteoarthritis. Arthritis Care & Research, 57(6), 1012-1017.
52. Miyazaki, T., Wada, M., Kawahara, H., Sato, M., Baba, H., & Shimada, S. (2002). Dynamic load at baseline can predict radiographic disease progression in medial compartment knee osteoarthritis. Annals of the Rheumatic Diseases, 61(7), 617-622.
53. Kito, N., Shinkoda, K., Yamasaki, T., Kanemura, N., Anan, M., Okanishi, N., & Moriyama, H. (2010). Contribution of knee adduction moment impulse to pain and disability in Japanese women with medial knee osteoarthritis. Clinical Biomechanics, 25(9), 914-919.
54. Morgenroth, D. C., Medverd, J. R., Seyedali, M., & Czerniecki, J. M. (2014). The relationship between knee joint loading rate during walking and degenerative changes on magnetic resonance imaging. Clinical biomechanics, 29(6), 664-670.
55. Clifford, A. M., Dillon, S., Hartigan, K., O'Leary, H., & Constantinou, M. (2020). The effects of McConnell patellofemoral joint and tibial internal rotation limitation taping techniques in people with Patellofemoral pain syndrome. Gait & Posture, 82, 266-272.
56. Taylor, P. J., Vincent, H., Atkins, S., & Sinclair, J. (2015). Acute exposure to foot orthoses affects joint stiffness characteristics in recreational male runners. Comparative Exercise Physiology, 11(3), 183-190.

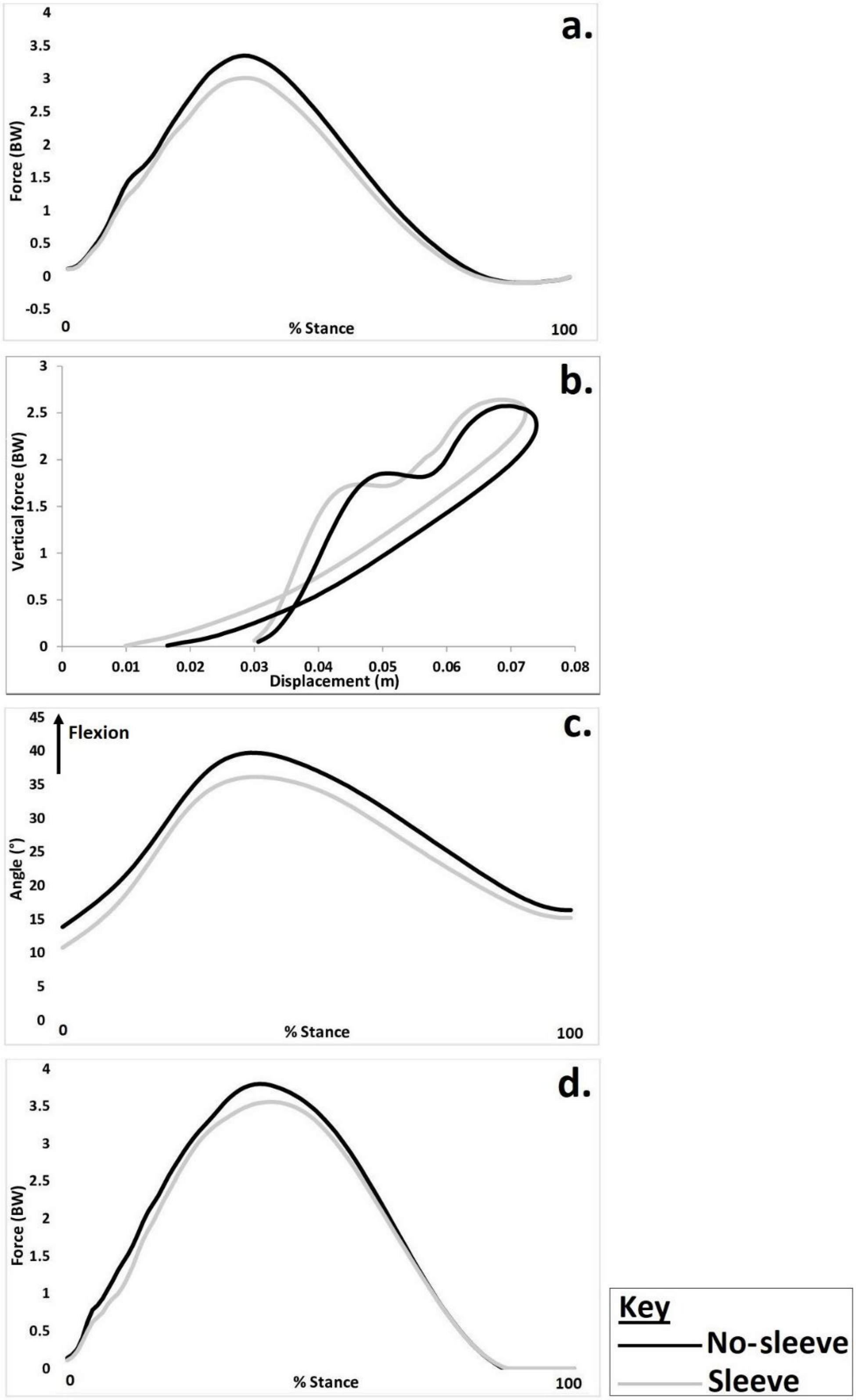
57. Farley, C. T., & Morgenroth, D. C. (1999). Leg stiffness primarily depends on ankle stiffness during human hopping. Journal of biomechanics, 32(3), 267-273.

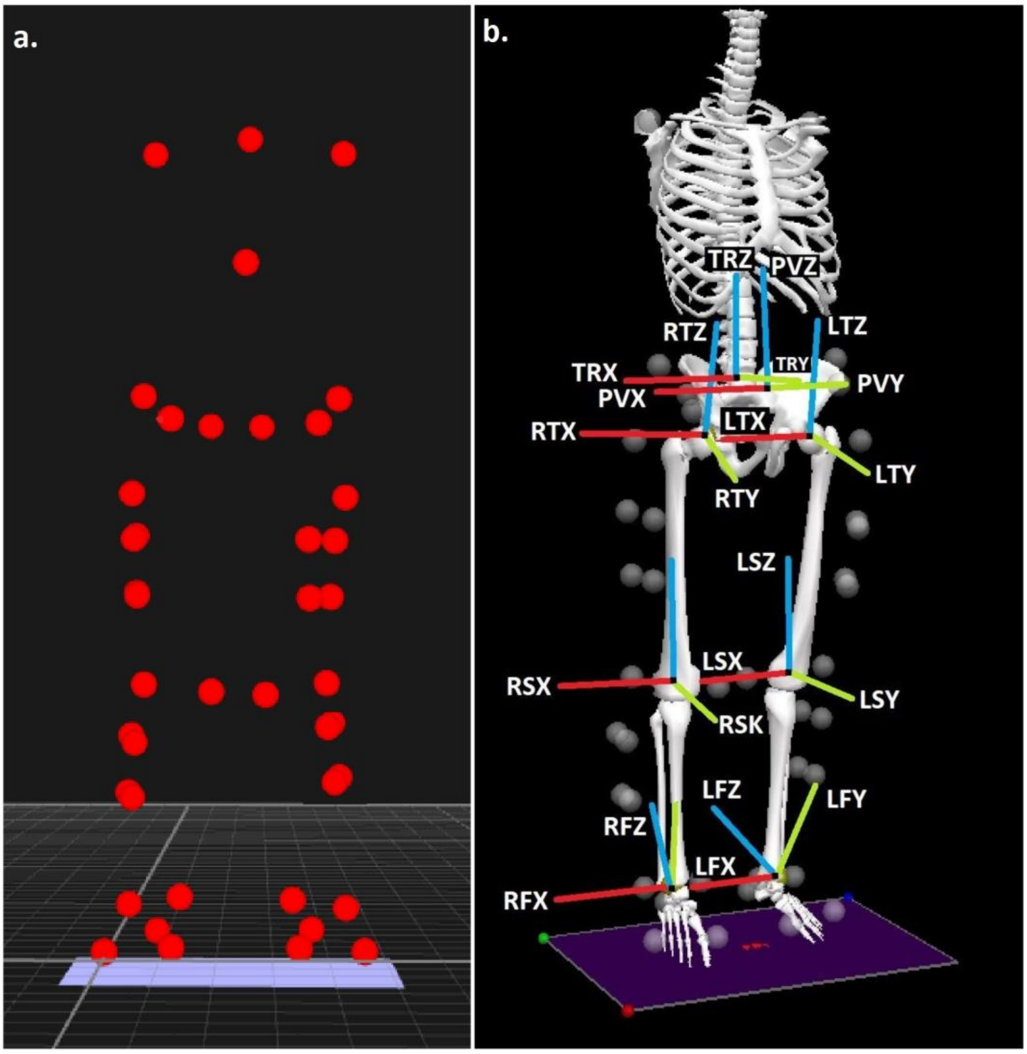
58. Lorimer, A. V., Keogh, J. W., & Hume, P. A. (2018). Using stiffness to assess injury risk: comparison of methods for quantifying stiffness and their reliability in triathletes. PeerJ, 6, e5845.

59. Sinclair, J., & Selfe, J. (2015). Sex differences in knee loading in recreational runners. Journal of biomechanics, 48(10), 2171-2175.


a.
Adduction
Moment (Nm/kg)
1
0.8
0.6
0.4
0.2
0
-0.2
0
% Stance
100
b.
Internal
Angle (°)
16
14
12
10
8
6
4
2
0
0
% Stance
100
c.
Dorsiflexion
Angular velocity (°/s)
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
0
% Stance
100
Key
No-insole
Insole

605


a.
Force (BW)
% Stance
0
100
b.
Vertical force (BW)
Displacement (m)
c.
Flexion
Angle (°)
% Stance
0
100
d.
Force (BW)
% Stance
0
100
Key
No-sleeve
Sleeve


a.
b.
TRZ
PVZ
RTZ
LTZ
TRY
TRX
PVY
PVX
LTX
RTX
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RTY
LSZ
LSX
RSX
LSY
RSK
LFZ
LFY
RFZ
LFX
RFX

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 |

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

| | No-insole | | Insole | | *b* | 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 | | *b* | t | p | 95% CI | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | | | | Lower | Upper |
| | ***Knee*** | | | | | | | | |
| 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 |
| | ***Ankle*** | | | | | | | | |
| 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 | | *b* | t | p | 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 | | *b* | t | p | 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 | | *b* | t | p | 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 |