MISS ZOE YS CHAN (Orcid ID : 0000-0002-8883-1858)
DR. ROY TH CHEUNG (Orcid ID : 0000-0001-7990-3007)

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Effects of deceptive footwear condition on subjective comfort and running biomechanics

Running title

Footwear comfort and running biomechanics

Authors

Zoe Y.S. Chan [1]; Ivan P.H. Au [1]; Janet H. Zhang [1]; Reed Ferber [2,3]; Gary Shum [4]; Winko W. An [1,5]; Roy T.H. Cheung [1]

Institution and affiliations

[1] Gait & Motion Analysis Laboratory, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong

[2] Running Injury Clinic, University of Calgary, Calgary, Canada

[3] Faculties of Kinesiology, Nursing, and Cumming School of Medicine, University of Calgary, Calgary, Canada

[4] School of Sport, Health and Wellbeing, Plymouth Marjon Univerisry

[5] Department of Electrical and Computer Engineering, Carnegie Mellon University, Pittsburgh, United States

Corresponding author:

Zoe Y.S. Chan

Mailing address: Gait & Motion Analysis Laboratory, ST004, G/F, Core S, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

Telephone: 852-2766-4830

Fax: 852-2330-8656

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Email: zoe-ys.chan@connect.polyu.hk

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Conflict of interest

None.

Abstract

Comfort is a major criterion for footwear selection. Previous studies have suggested that physical properties were not enough to predict comfort and psychological factors could also affect the perception. To understand comfort, this study examined the effect of controlled shoe description and price cue on the perception of comfort. Furthermore, this study also examined the running biomechanics in response to footwear conditions of differing comfort. Fifteen runners completed treadmill running tests in two conditions: Shoe A and Shoe B. The same pair of neutral running shoes was used in both conditions, yet, Shoe B was described to be the "latest model designed to maximize comfort" and more expensive than Shoe A. Comfort assessment was conducted after the running trial of each condition. Participants reported significantly greater comfort in Shoe B than Shoe A (p=0.011, Cohen's d=0.70). There were no significant differences found among the temporal-spatial parameters (p>0.916) and the vertical loading rates (p>0.161) when comparing the more and less comfortable conditions. In conclusion, runners exhibited a biased perception of footwear comfort when presented with different shoe description and price information. However, such a difference in perceived comfort alone is not likely to affect running biomechanics.

Keywords

Exercise; Joint; Psychological adaptation; Perception; Kinetics; Kinematics; Trend Symmetry

Abstract word count

195

Introduction

Footwear comfort has been suggested to be related to fatigue, injury development and athletic performance.[1–3] It is considered an important factor for footwear design,[4] and a major selection criterion for athletes.[5] To quantify footwear comfort, a method using a series of visual analog scales (VAS) has been developed.[6] The comfort scale is either 100 or 150 mm in length, with the left-hand side labeled "not comfortable at all", and the right-hand side labeled "most comfortable condition imaginable". This validated comfort measurement tool has been adopted by various research groups to study the relationship between subjective footwear comfort and running biomechanics.[4,7–9] For instance, Dinato *et al*. tested four footwear conditions with different midsole stiffness and cushioning technologies.[7] Interestingly, the results showed that none of the kinetic parameters, material stiffness or pressure distribution, were able to predict the perception of comfort in runners. There is no consensus among researchers on the constituents of comfort.

The constituents of comfort in footwear have rarely been reported in the literature. Hennig *et al*. conducted a study to investigate whether brand information would influence the subjective judgment of shoe comfort and quality.[10] Runners were asked to rate the same pair of shoes both in a blinded situation and also while knowing the brand of the shoes. Significant differences were found between the blinded and non-blinded conditions in five out of six shoe models, suggesting that a runner's judgment of shoe comfort could be affected by factors unrelated to footwear design or materials. Considering that comfort is highly subjective,[11] it is plausible that a runner's comfort perception could be altered by psychological factors. This might explain why physical properties alone are not enough to predict footwear comfort. To further understand footwear comfort, it is important to investigate what information could affect a runner's perception of shoe comfort.

Deceptive messages used in advertisements, especially implied-superiority against other brands, are potentially misleading.[12] A previous study on wine-tasting found that product information, such as price, was able to alter sensory experience not only on the behavioural level, but also on the neural level.[13] Another study that focused on the effects of deceptive advertising and price cues regarding athletic footwear suggested that users could be affected by misleading messages that influence their preference and biomechanics.[14] Therefore, the perception of comfort may be susceptible to misleading shoe description and the marked price of the shoes. Currently, there is limited evidence of how deceptive footwear description could affect subjective comfort. As comfort is often viewed as an essential factor for footwear selection,[5] there is practical value in understanding the effect on comfort perception based on provided information and price cues of a pair of running shoes.

Although the relationships between perceived comfort and a series of running biomechanics have been investigated in previous studies, those studies were not well controlled.[7,9] For instance, Lindorfer *et al*. measured biomechanical variables in response to five shoe models.[9] The biomechanical variables were compared between each participant's most preferred and least preferred model based on comfort. Stride frequency was found to be higher in the less preferred footwear model when compared to the most preferred. However, such difference cannot be interpreted solely based on comfort effect, as there is a potential bias within the analysis due to the difference in mechanical characteristics between the shoe models.

Hence, the objective of this study was two-fold. First, this study sought to use a deceptive study design to investigate the difference in perceived comfort when a pair of running shoes was described differently based on their design and price. It was hypothesized that there would be a within-subject difference in the perception of comfort among the footwear conditions. The second objective was to assess biomechanical differences between a more comfortable footwear condition and a less comfortable footwear condition. The mechanical properties and design were controlled between the two conditions, with the only independent variable being the perceived comfort level. It was hypothesized that there would be no within-subject differences in running biomechanics between the two conditions.

Materials and Methods

Sample size estimation was performed using G∗POWER 3.1 (Universität Kiel, Germany). An effect size of 0.75 was based on the comfort score reported in a previous study on footwear comfort.[10] With alpha set at 0.05, 16 participants were required to obtain a power of 0.8. A total of 18 recreational runners were recruited from local running clubs. All participants had treadmill running experience and weekly mileage of more than 8 km over the past three months. Participants with any lower extremity injuries in the past six months were excluded.

Participants were instructed to complete four running bouts. The first and the third running bouts acted as controlled trials, as recommended for reliable comfort measurement,[6] in which the participants were provided with their usual running shoes and data were not recorded during these two trials. The second and the fourth trials were experimental trials, in which the same pair of neutral running shoes (ARHL002, LiNing, Beijing, China), size-matched to each participant by a Brannock Device (Liverpool, NY, USA), was worn and labeled as 'Shoe A' and 'Shoe B.' The order of the two shoe conditions was randomized. The information of Shoe A and Shoe B was introduced by written descriptions as follows:

Shoe A: USD 50; regular running shoe model; designed for distance running; available in the market; same brand as Shoe B

Shoe B: USD 150; latest shoe model designed to maximize comfort; highly expensive material used; not yet available in the market; same brand as Shoe A

The experimental procedures were reviewed and approved by the Departmental Research Committee, Department of Rehabilitation Sciences, The Hong Kong Polytechnic University and written consent was obtained from each participant before the experiment. The participants were given five minutes of warm-up on a treadmill and selected a testing speed that resembled their usual training speed (2.22±0.13 ms^{-1}). The sequence and description of shoes worn were provided to participants before the first running trial. In order to eliminate the subjective visual perception, participants were blindfolded throughout shoe fitting and running. The test shoes were fit by a single researcher. Sixteen markers were placed over the anatomical landmarks following a validated model to obtain lower limb kinematics.[15] Participants stood in an anatomical position prior to each running trial whilst three-dimensional marker positions were recorded to establish an anatomical frame for joint angle offset. Supported by the overhead safety harness, participants were asked to hold on to a side-rail on the right that was within reachable distance. The treadmill speed was gradually increased upon verbal consent from the participant until the selected testing speed was reached. All participants were instructed to run without the rail support and was monitored by a researcher. Verbal confirmation of a stable running gait was obtained from the participant. For each running trial, a four-minute adaptation period was given[16] before kinetic and kinematic data were collected for one minute. Marker trajectories were sampled at 200 Hz using an 8-camera motion capturing system (VICON, Oxford, UK) positioned around the treadmill. Ground reaction forces (GRF) were sampled at 1,000 Hz by a force-sensing treadmill (AMTI, Watertown, MA, USA). Each trial was separated by a washout period of 15 minutes.[17]

Immediately after each of the experimental running trials, participants were asked to rate the comfort level of the test shoes using the comfort measurement tool. Perception of comfort for each footwear condition was assessed using an electronic version of VAS displayed on a tablet (ThinkPad 8, Lenovo, Beijing, China). A comfort scale of 100 mm in length, validated previously,[6] was displayed on the screen with the left-hand side labeled “not comfortable at all”, and the right-hand side “most comfortable condition imaginable”. The comfort measure consisted of nine domains: “overall comfort” and 8 subcategories, including “forefoot cushioning”, “heel cushioning”, “arch height”, “heel cup fit”, “shoe heel width”, “shoe forefoot width”, “shoe length” and “medio-lateral control”. Each comfort score was converted and presented as a score between 0 and 100, where a score of 100 indicates best comfort level. Upon completion of all running trials and comfort assessments, a debriefing session was set for the participant to report any assumptions made during the whole experiment. The true objective was also revealed to the participant.

The second objective of this study was to identify differences in biomechanical parameters between a more comfortable and a less comfortable footwear condition. The "More comfortable" ($Shoe_{MC}$) and "Less comfortable" ($Shoe_{LC}$) condition were selected for each participant reporting a difference of larger than 9.1 out of 100 between Shoe A and Shoe B, as the clinically meaningful difference in comfort for a 100 mm VAS was previously reported to be 9.1 mm.[18] The footwear conditions with higher and lower comfort rating were considered to be $Shoe_{MC}$ and $Shoe_{LC}$ respectively. Subsequent analysis on running biomechanics was conducted based on the $Shoe_{MC}$ and $Shoe_{LC}$ condition.

The left lower limb was selected as the test limb. Marker trajectories were filtered using a low-pass, fourth-order Butterworth filter with cut-off frequency set at 8 Hz[19] and lower limb joint angles were calculated using a dynamic gait model toolbox (Nexus 1.8, VICON, Oxford, UK). GRF data was filtered and processed using customized MATLAB codes (The MathWorks, Inc, Natick, MA, USA). GRF data were filtered using a low-pass, fourth-order Butterworth filter with cut-off frequency set at 50 Hz.[19] Time of initial foot-ground contact and toe-off were defined by the time the vertical GRF crossed a threshold of 10 N.[20] Percentage stance was calculated as the percentage of time the foot was in contact with the ground relative to the time of one gait cycle. Cadence was measured as the number of steps in one minute. Vertical average loading rate (VALR) and vertical instantaneous loading rate (VILR) were obtained by the method described in a previous study.[20] Vertical loading rate was calculated as the slope of the line through the 20% point and the 80% point of the vertical impact peak (VIP). The VILR was the maximum slope between successive data points, while the VALR was the average slope. The VIP was defined as the local maximum between initial contact and maximum force on the vertical GRF which occurred during the first 50 ms of stance phase. In the case in which no VIP was identified from the force data, the VIP value was defined as the force at 13% stance phase.[21,22] Percentage stance, VALR and VILR were averaged across the last 20 gait cycles of the test limb in each condition.

All dependent variables were tested against a normal distribution by using separate Shapiro-Wilk tests. Differences in comfort score (Shoe A *vs.* Shoe B) and running biomechanics ($Shoe_{MC}$ *vs.* $Shoe_{LC}$) were evaluated by using paired *t*-tests. Cohen's *d* was calculated to evaluate the effect size. All statistical tests were performed by SPSS software (Version 20; SPSS Inc., Chicago, IL, USA), with alpha set as 0.05. In order to control for potential family-wise error, the adjusted *p*-value by Bonferroni correction was also reported for comfort subcategories, with significance at 0.00625 (0.05/8).

An additional measure to describe the intra-subject similarity of joints kinematics between condition $Shoe_{MC}$ and $Shoe_{LC}$ was employed.[23] For participants with a difference in overall comfort larger than 9.1, the lower limb kinematic curves were time-normalized by the gait cycle and compared using the trend symmetry method proposed by Crenshaw and Richards.[23] Four variables, including trend symmetry, range amplitude, range offset and phase offset were calculated for all three planes of motion for the hip, knee and ankle joint. A trend symmetry value of 100% indicates perfect symmetry and the range amplitude value quantifies the difference in the range of motion between two curves, expressed as a ratio of $Shoe_{MC}$ to $Shoe_{LC}$. The range offset was calculated by subtracting the average of $Shoe_{MC}$ from $Shoe_{LC}$. The phase shift was presented in percentage of gait cycle, with a positive phase offset implying that the curve of $Shoe_{MC}$ was shifted forward relative to the $Shoe_{LC}$ curve.

Results

Three participants were excluded from the data analysis. In the debriefing session, two participants reported a suspicion that the shoe models used for Shoe A and Shoe B were the same and another participant reported previous running experience in the test shoe model. The remaining 15 participants (6 females and 9 males; age = 31.9 ± 11.0 years; body mass = 60.2 ± 7.6 kg; body height = 1.7±0.1 m; running experience = 5.9 ± 1.9 years) were included for further analyses.

Participants reported significantly greater overall comfort in Shoe B than Shoe A (p = 0.011). Among the eight subcategories, medio-lateral control (p = 0.001) and arch height (p = 0.014) were reported to be significantly better in Shoe B than Shoe A (Table 1).

Nine participants reported a difference of over 9.1 in overall comfort between Shoe A and Shoe B. Among the nine participants, 89% (8 out of 9) reported Shoe A to be more comfortable than Shoe B. The overall comfort for $Shoe_{MC}$ and $Shoe_{LC}$ were 78.20 ± 10.75 and 59.86 ± 15.91 respectively, with the presence of significant difference in perceived overall comfort confirmed by a paired *t*-test ($p < 0.001$).

Table 2 provides a summary of all biomechanical variables measured. No significant difference was found in percentage of stance (p = 0.955) and cadence (p = 0.916) between $Shoe_{MC}$ and $Shoe_{LC}$. There were also no differences in the kinetic variables of interest, including VALR (p = 0.341) and VILR (p = 0.161), between $Shoe_{MC}$ and $Shoe_{LC}$. The joint kinematic curves were similar between the conditions (Figure 1). The similarity in joint motion between the more and less comfortable shoe conditions was further indicated by the trend symmetry values for all kinematic curves ranging between 96.03% and 99.73% (Table 3). The mean range amplitude was 1.026, and the mean range offset for the curves was 0.233°. The phase offsets were all less than 0.750% of a gait cycle.

Discussion

In reference to the first objective, this study examined the difference in perceived comfort when a pair of running shoes was described differently based on their design and price. In support of our hypothesis, there was a within-subject difference in the perception of comfort among the footwear conditions. The second objective was to determine differences in biomechanical variables between shoes of different comfort levels. No significant difference was found in any of the tested biomechanical variables when comparing the more comfortable to the less comfortable footwear condition.

The overall comfort was perceived to be better in the pair of shoes described to be more expensive and designed using advanced technology. The average difference of 9.8 between Shoe A and Shoe B has reached a clinically meaningful change in comfort, as reported previously.[18] The observed difference suggested that a potential bias could be induced by descriptions and price cues based on the footwear model. In fact, similar bias on subjective judgment has previously been reported. In the study conducted by Hennig *et al.*, runners were blinded to a low-cost running shoe model as well as a known athletic brand, and the branded shoes were rated higher only when branding information was revealed.[10] The results of the current study further supported that perceived comfort can be affected by psychological attributes, as previously suggested by Miller *et al.*[2] The deceptive claims and price information used in this study have induced a bias on runners and significantly altering their perceived comfort. Furthermore, certain comfort-related subcategories may be more sensitive to deceptive messages. Two subcategories were found to be statistically different between the footwear conditions. Both medio-lateral control and arch height were rated higher with a large effect size (Cohen's d = 1.07 and 0.81 respectively) in Shoe B. Researchers should be circumspect when designing studies which target comfort measurement within these domains.

Future studies on footwear should consider the potential bias induced by footwear description, brand and cost. Reduced footwear comfort has been reported to induce a more monotonous running style, defined as reduced variability between strides in the frontal and transverse plane joint angles.[1] It is possible that participants in other footwear tests could perceive comfort differently based on their prior experiences, brand information and knowledge of the footwear model, and such individual differences could affect the validity of the biomechanical evaluations. Based on the findings of the current study, the shoe description would affect comfort perception. In order to minimize such bias on comfort, standard shoe description should be provided in not only psychological, but biomechanical studies on footwear models.

Lindorfer *et al*.[9] measured the difference in biomechanical variables in response to shoe models of various comfort levels. Similar to other studies relating comfort to running biomechanics and economy,[1,3] participants ranked five different shoe models based on their comfort, the most comfortable and least comfortable model were determined for each participant accordingly. Lindorfer *et al*.[9] found a significant difference in stride frequency between the most comfortable model and the least comfortable model. However, the authors reported that the choice of least comfortable model was uneven among the available choices, with 9 out of 15 participants ranking the same footwear model as the least comfortable model. The shoe design and mechanical property could therefore induce potential bias within the analysis. In order to isolate the effect of comfort on running biomechanics, the same pair of neutral running shoes was used for both the most and least comfortable footwear condition within the current study. The more and less comfortable condition were selected based on the perceived overall comfort which exceeded the clinically meaningful difference.[18]

Statistical tests showed no significant difference between condition $Shoe_{MC}$ and $Shoe_{LC}$ in temporal-spatial parameters, however our sample size has limited the statistical power for such variables. The kinematic curves (Figure 1) were averaged across participants for each shoe condition, and all joints in all planes were within one standard deviation of the other condition. The trend symmetry method[23] was used to quantify the within-subject differences in joint kinematics between $Shoe_{MC}$ and $Shoe_{LC}$. Crenshaw and Richards suggested a trend symmetry value of 95% or above indicated similar kinematic curve trend based on a normal population.[23] Values measured in this study were all above 95%, indicating similar running kinematics between the more and less comfortable conditions.

Significant associations have been demonstrated between vertical loading rates and running-related injury.[24] High loading rates were associated with overuse injuries including patellofemoral pain,[25] plantar fasciitis,[26] and tibial stress fractures.[27] Based on our results, the loading rates were similar between the more comfortable and less comfortable condition. Enhanced comfort might not be a valid indicator of reduced impact loading experienced by the runner. Runners should not base their footwear selection solely on comfort. Alternatively, it has been suggested by Shin *et al*. that running assessments which involve the measurement of kinematic and kinetic variables, are better indicators for shoe selection.[28] Future research is therefore necessary to better understand the inter-relationship between shoe selection, self-perceived comfort, gait biomechanics, and injury etiology.

There were several limitations in this study. Firstly, since participants were blindfolded, the tested running style may differ from their usual running pattern. Within-subject comparisons adopted in the current study were less susceptible to such difference, and yet, caution should be taken when comparing results of this study against other conditions. Secondly, for biomechanical parameters, the effect size ranged between 0.01 and 0.12, and the post-hoc power is within the range of 0.05 to 0.06. This study was insufficiently powered to conclude no biomechanical difference between the shoe conditions, yet, the small effect size has suggested low practical significance.[29,30] Thirdly, a short running trial was conducted for each experimental footwear condition. Long-term changes in comfort perceived remains unknown. Finally, the present study was designed to measure perceived comfort and selected biomechanical parameters in a single shoe model. While the selected parameters were conventional measurements of a biomechanical study on footwear, additional information such as plantar pressure could be useful in understanding the potential differences in specific comfort-related aspects.

Perspectives

Information regarding the construction and price of footwear are sufficient to alter the perceived comfort in runners. Runners should be vigilant against these descriptions and claims provided by the footwear manufacturers. Standardized footwear description should be provided to control for subjective bias in footwear comfort evaluations. On the other hand, the differences in comfort alone might not change the running biomechanics.

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Tables

Table 1. Group mean and standard deviation (SD) of comfort level perceived by running in Shoe A and Shoe B

Comfort perception categories	Shoe A		Shoe B		*P*- value	Effect size
	Mean	SD	Mean	SD		
Overall comfort	66.4	16.7	76.2	10.6	0.011*	0.70
Heel cushioning	71.6	13.8	76.0	13.6	0.125	0.32
Forefoot cushioning	67.9	20.9	74.8	13.3	0.107	0.39
Medio-lateral control	61.7	16.5	77.1	12.0	0.001*^	1.07
Arch height	64.0	17.6	76.8	13.9	0.014*	0.81
Heel cup fit	64.3	17.5	71.7	20.4	0.267	0.39
Shoe heel width	68.1	15.8	72.7	16.5	0.310	0.28
Shoe forefoot width	64.9	23.2	73.8	15.1	0.208	0.45
Shoe length	67.5	16.5	75.6	12.4	0.067	0.55

All comfort values were measured as a scale from 0-100, where 100 indicates best comfort level.

* $p < 0.05$

^ $p < 0.00625$ (Bonferroni corrected *p*-value for comfort sub-categories: 0.05/8)

Table 2. Group mean and standard deviation (SD) of temporal-spatial parameters and kinetic variables during running in $Shoe_{MC}$ and $Shoe_{LC}$

Variables	Less comfortable ($Shoe_{MC}$)		More comfortable ($Shoe_{LC}$)		*P*-value	Effect size
	Mean	SD	Mean	SD		
Temporal-spatial parameters						
Percentage stance (%)	38.14	4.39	38.18	4.00	0.955	0.01
Cadence (steps/min)	169.98	12.40	170.19	15.10	0.916	0.02
Kinetics						
VALR (BW/s)	51.34	25.62	49.63	21.44	0.341	0.07
VILR (BW/s)	64.65	26.35	61.73	21.98	0.161	0.12

VALR = vertical average loading rate; VILR = vertical instantaneous loading rate; BW = body weight

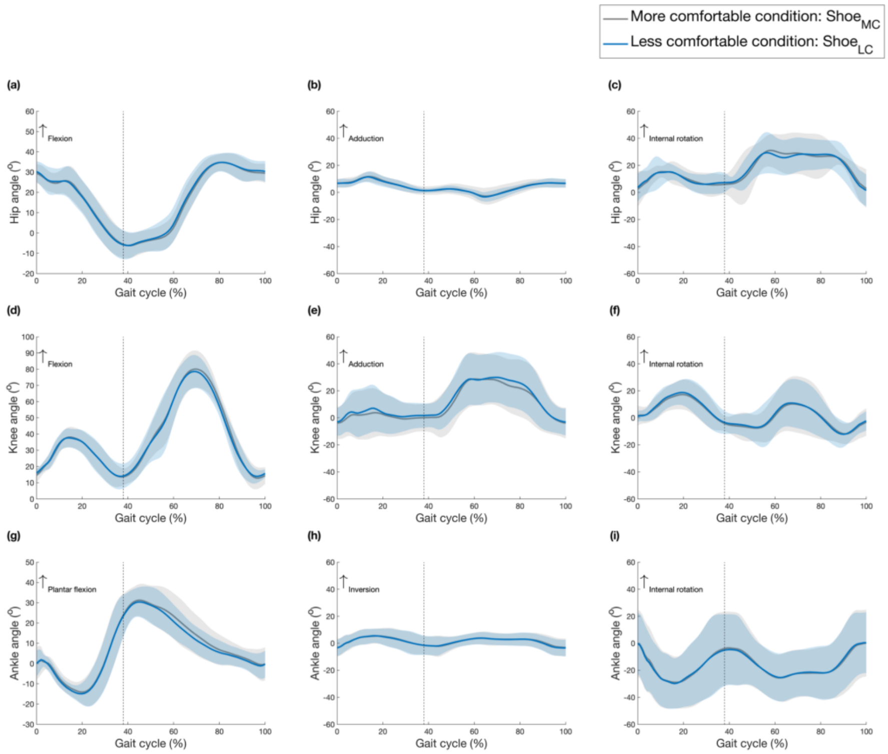
Table 3. Group mean and standard deviation (SD) of trend symmetry measures between $Shoe_{MC}$ and $Shoe_{LC}$ for the hip, knee and ankle joint in the sagittal, frontal and transverse plane

		Trend symmetry (%)		Range amplitude		Range offset (°)		Phase offset (%)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Hip	Sagittal	99.73	0.25	0.991	0.025	0.556	1.172	0.750	0.829
	Frontal	98.96	0.70	1.081	0.190	0.305	0.899	0.250	0.829
	Transverse	96.03	6.14	1.032	0.086	0.090	2.785	0.500	1.118
Knee	Sagittal	99.63	0.28	1.046	0.030	1.792	2.268	0.625	0.696
	Frontal	98.54	1.74	0.998	0.080	-0.987	2.789	0.625	0.696
	Transverse	98.87	0.71	1.028	0.122	-0.644	1.865	0.375	0.857
Ankle	Sagittal	99.62	0.33	1.016	0.070	1.075	1.638	0.250	0.968
	Frontal	99.09	0.59	1.007	0.111	-0.154	0.722	0.375	0.696
	Transverse	99.14	0.57	1.036	0.091	0.067	2.034	0.375	0.696
Average		98.84	1.26	1.026	0.090	0.233	1.797	0.458	0.821

A trend symmetry value of 100% indicates perfect symmetry. A value of range amplitude larger than 1.0 indicates a larger range of motion for $Shoe_{MC}$. A positive range offset value indicates a larger mean value in $Shoe_{MC}$. A positive phase offset indicates the $Shoe_{MC}$ curve was shifted forward relative to the $Shoe_{LC}$ curve.

Figure legends

Figure 1. The angle trajectories (group mean and standard deviation) of the hip, knee, and ankle joint in the sagittal (a, b and c), frontal (d, e and f) and transverse (g, h and i) plane over a running gait cycle



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