

Middlesex University Research Repository

An open access repository of

Middlesex University research

<http://eprints.mdx.ac.uk>

Greenhalgh, Andrew, Taylor, P. J. and Sinclair, J. (2014) The influence of different force and pressure measuring transducers on lower extremity kinematics measured during walking. *Gait & Posture*, 40 (3). pp. 476-479. ISSN 0966-6362

Final accepted version (with author's formatting)

This version is available at: <http://eprints.mdx.ac.uk/14300/>

Copyright:

Middlesex University Research Repository makes the University's research available electronically.

Copyright and moral rights to this work are retained by the author and/or other copyright owners unless otherwise stated. The work is supplied on the understanding that any use for commercial gain is strictly forbidden. A copy may be downloaded for personal, non-commercial, research or study without prior permission and without charge.

Works, including theses and research projects, may not be reproduced in any format or medium, or extensive quotations taken from them, or their content changed in any way, without first obtaining permission in writing from the copyright holder(s). They may not be sold or exploited commercially in any format or medium without the prior written permission of the copyright holder(s).

Full bibliographic details must be given when referring to, or quoting from full items including the author's name, the title of the work, publication details where relevant (place, publisher, date), pagination, and for theses or dissertations the awarding institution, the degree type awarded, and the date of the award.

If you believe that any material held in the repository infringes copyright law, please contact the Repository Team at Middlesex University via the following email address:

eprints@mdx.ac.uk

The item will be removed from the repository while any claim is being investigated.

See also repository copyright: re-use policy: <http://eprints.mdx.ac.uk/policies.html#copy>

**The influence of different force and pressure measuring transducers on lower extremity
kinematics measured during walking**

Greenhalgh, A.¹, Taylor, P. J.² and Sinclair, J.³

¹London Sport Institute, Middlesex University

²School of Psychology, University of Central Lancashire

³Division of Sport Exercise and Nutritional Sciences, University of Central Lancashire

Corresponding Author:

Dr. Andrew Greenhalgh

London Sport Institute

University of Middlesex,

London

NW4 4BT.

e-mail: a.greenhalgh@mdx.ac.uk

Keywords: Walking, Gait, Pressure, Kinematics, Force plate

Abstract

The examination of synchronous three dimensional (3-D) kinetics and kinematics of walking in laboratory based analyses typically requires participants/patients to make foot contact with a force or pressure measuring device. However it has been proposed that this may lead to targeting whereby participants modify their natural gait pattern in order to ensure contact with the device. This study aimed to determine the extent to which an embedded force plate(EFP) and two different pressure mats PMs affect natural gait kinematics. Male participants (n=12, age 24.23 SD 4.22 y, height 1.74 m SD 0.10, mass 75.78 SD 6.90 kg) walked at a velocity of 1.25 m.s⁻¹ along a 22 m walkway in four different conditions. 1. EFP, 2. FootScan (FS) PM, 3.Matscan (MS) PM, 4.No device (ND).3-D angular kinematic parameters were collected using an eight camera motion analysis system.Differences in kinematics were examined using repeated measures ANOVAs. Significant differences were observed in hip abduction, knee flexion/extension and knee abduction between various conditions and may warrant consideration in future research. No significant differences were reported at the ankle joint in any conditions. Comparing the PMs no significant differences were observed, however significant differences between the MS and the EFP and ND conditions were identified. The research supports the efficacy of collecting gait kinematics at the ankle joint and in most variables measured at the knee and hip joints.

Introduction

The examination of synchronous kinetics and kinematics of walking gait in laboratory based analyses typically requires participants/patients to make foot contact with a force or pressure measuring device^{1,2}. However it has been proposed that this may lead to targeting whereby participants modify their natural gait pattern in order to ensure contact with the device³.If

participants have to alter their habitual gait pattern in order to accomplish this then the efficacy of the clinical interpretation may be compromised.

There are currently numerous commercially available force plates (FP) and pressure mats (PM). FPs are typically embedded into the laboratory surface, whereas PMs are traditionally positioned on top of the laboratory surface and may present a more conspicuous visual target due to the small increase in height of the target. When examining the three dimensional (3-D) kinematics of gait it is important to know how different underfoot measuring devices influence the extent to which targeting occurs.

This study aimed to determine the extent to which an embedded FP and two different PMs affected natural gait patterns by contrasting the 3-D lower extremity kinematics obtained when walking in these conditions compared to walking uninhibited, without concern for striking an underfoot transducer.

Method

Participants

Twelve healthy male participants (age 24.23 SD 4.22 y, height 1.74 m SD 0.10, mass 75.78 SD 6.90 kg) were recruited for this study. All were free from musculoskeletal pathology at the time of data collection. Ethical approval was obtained from a University ethical committee in accordance with the declaration of Helsinki.

Data collection

Participants walked at a velocity of $1.25 \text{ m}\cdot\text{s}^{-1}$ along a 22 m walkway in four different conditions. 1. embedded piezoelectric FP (EFP) (Kistler, Kistler Instruments Ltd, Alton, UK) (length, width, height =60 x 40 x 0 cm) , 2. FootScan (FS) (RSscan International, Olen, Belgium) PM (length, width, height =60 x 40 x 0.8cm) overlaying the EFP, 3. Matscan (MS) (Tekscan Inc. Boston, USA) PM (length, width, height =70 x 40 x 0.5cm) overlaying the EFP and 4. No device (ND), uninhibited to the side of the EFP without concern for striking a transducer. Walking velocity was quantified using timing gates and a maximum deviation of 5% was allowed. The order in which participants walked in each condition was randomised. Participants dictated their own starting point for their walking trials which was maintained throughout; no instructions were given other than to maintain their normal gait pattern.

Surface retroreflective markers and technical tracking clusters were positioned in accordance with previous research^{4,5} allowing the pelvis, right thigh, shank and foot to be defined and tracked. All participants defined themselves as right limb dominant. Marker trajectories were captured using an eight camera optoelectric motion capture system (Qualisys Gothenburg, Sweden) operating at 100 Hz. All participants indicated their perceived comfort after walking in each condition using a 10 point likert scale with 10 being totally comfortable and zero being totally uncomfortable. All data was collected in a single session on the same day.

Data processing

Data were digitized using Qualisys track manager and exported to Visual 3D (C-motion, Germantown USA). Marker information was filtered at a cut-off frequency of 6 Hz using a Butterworth low pass 4th order filter. Hip, knee and ankle joint kinematics from the stance (right) limb were quantified using an XYZ sequence of rotations. The stance phase was

delineated using kinematic information⁶. Only trials in which a clean footstrike onto the measuring transducer was recorded were examined.

Statistical analyses

Descriptive statistics for walking velocity, perceived comfort and 3-D stance phase angular kinematic parameters at footstrike, toe-off, peak angle and range of motion (ROM) which was representative of the angular displacement from footstrike to toe-off were calculated. Differences in these parameters were examined between walking conditions using repeated measures ANOVA with the alpha criterion adjusted to $p \leq 0.0014$ to control type I error. Post-hoc pairwise comparisons were utilized to examine significant main effects. Statistical procedures were undertaken using SPSS v20.

Results

Walking velocity

Walking velocity was shown not to differ significantly ($p=0.771$) between conditions with an overall mean of 1.24 ± 0.10 m/sec.

Perceived comfort

An overall main effect was observed for perceived comfort tests $p < 0.0014$, $\eta^2 = 0.67$. Significant differences were found between walking over the EFP (8.55 ± 0.81) and both pressure mats (MS= 7.55 ± 0.97 and FS= 6.55 ± 1.07).

Lower extremity kinematics

The overall patterns of the resultant 3-D kinematic waveforms were qualitatively similar (Figure 1, Supplemental file), although statistical differences were observed at the hip and knee (Tables 1-3).

@@@ **Tables 1-3 near here** @@@

Discussion and Conclusions

Kinematics at the hip identified no significant differences between the PMs and the ND condition and only a small significant difference of an increased hip abduction (2.32 degrees) at footstrike in the EFP condition compared to the ND condition. This would appear to suggest that clinical gait assessment of the hip joint is reasonable whilst participants are walking over the PM devices. However, minor caution regarding the clinical interpretation of kinematics in the frontal plane whilst walking over an EFP such as the one used in this study.

Subjective responses from participant showed that the EFP allowed participants to utilize a significantly more natural walking pattern in contrast to the FS and MS settings. This observation although subjective is important conceptually and may raise concerns regarding the effects of elevated transducers on the efficacy of gait kinematics. Additional work may be required to examine the perceptual influence of raised transducers on gait parameters.

The largest significant difference reported for the knee joint ROM (4.83 degrees in the sagittal plane) in the MS compared to the ND condition may appear to be attributable to the slightly raised surface (0.5cm) of the pressure mat. Previous research has identified that changes in surface height can influence kinetics during gait⁷ which may be linked to the

changes in kinematics measured at the knee in this study. However the thicker pressure mat (MS) (0.8cm) did not report any significant differences, suggesting that small changes in height may not be the cause of the observed differences. The influences of such small changes in height (≤ 1 cm) during walking may warrant further investigation.

With no significant differences identified between any of the conditions when considering the ankle joint, this research suggests that devices used in this paper are appropriate for clinical assessments and research focussed data collection of ankle joint kinematics.

When considering all of the kinematic differences identified for all lower extremity joints, significant differences were observed between the MS and both the EFP and ND conditions. However no differences were found between the FS and any of the other conditions. Furthermore, no significant differences were identified between the two PM conditions. This makes an overall conclusion about the superiority of one PM system to another regards minimising the unwanted influence on gait somewhat inconclusive, but due to a lack of any differences between the FS and ND conditions it could be hypothesised that the FS system would be preferential.

This study focussed on a non-pathological young adult population. The results may not be generalizable to a pathological population or an elderly population due to already observed differences in gait kinematics⁸. With longer versions of the pressure mats used in this research available, further research may be required to investigate the effects of larger pressure or force measuring devices.

In conclusion, this research supports the efficacy of collecting gait kinematics at the ankle joint whilst walking over devices used in this study. Most variables measured at the knee and hip also appear to be suitable for such research or clinical use. The differences observed in

hip abduction, knee flexion/extension and knee abduction may warrant consideration in future research.

Conflict of interest: There were no known conflicts of interest amongst any authors of this paper.

References

- [1] Nester CJ, Van der Linden ML, Bowker P. Effect of foot orthoses on the kinematics and kinetics of normal walking gait. *Gait Posture* 2003;17:180–187.
- [2] Willems T, Witvrouw E, Delbaere K, De Cock A, De Clercq D. Relationship between gait biomechanics and inversion sprains: a prospective study of risk factors. *Gait Posture* 2005;21:379–387.
- [3] Challis JH. The Variability in Running Gait Caused By Force Plate Targeting. *J Appl Biomech* 2001;17:77–83.
- [4] Sinclair J, Richards J, Taylor PJ, Edmundson C, Brooks D, Hobbs SJ. Three-dimensional kinematic comparison of treadmill and overground running. *Sports Biomech* 2013;1–11.
- [5] Sinclair J, Greenhalgh A, Brooks D, Edmundson C, Hobbs SJ. The influence of barefoot and barefoot-inspired footwear on the kinetics and kinematics of running in comparison to conventional running shoes. *Footwear Sci* 2013;5:45–53.
- [6] Zeni Jr. JA, Richards JG, Higginson JS. Two simple methods for determining gait events during treadmill and overground walking using kinematic data. *Gait Posture* 2008;27:710–714.
- [7] Van der Linden MH, Hendricks HT, Bloem BR, Duysens J. Hitting a support surface at unexpected height during walking induces loading transients. *Gait Posture* 2009;29:255–260.
- [8] Bus SA. Ground reaction forces and kinematics in distance running in older-aged men. *Med Sci Sport Exer*, 2003; 35: 1167-1175.

Table 1. Hip joint kinematic observed during the four conditions

	Uninhibited	Force Plate	Footscan	Matscan	<i>Statistical Analysis</i>
Hip					
X (+ = flexion/ - = extension)					
Angle at Footstrike (°)	20.47 ± 11.21	20.13 ± 11.16	20.51 ± 12.94	19.10 ± 12.18	
Angle at Toe-off (°)	-7.46 ± 13.26	-7.25 ± 12.64	-8.77 ± 12.97	-9.76 ± 13.79	
Range of Motion (°)	27.93 ± 8.07	27.38 ± 5.74	29.28 ± 7.17	28.87 ± 5.28	
Peak Extension (°)	-17.37 ± 11.10	-16.18 ± 11.11	-17.97 ± 11.31	-17.99 ± 11.54	
Y (+ =adduction/-=abduction)					
Angle at Footstrike (°)	-3.78 ± 5.49	-6.10 ± 3.78 A	-4.12 ± 5.99	-3.88 ± 5.68	P=0.001, η²=0.42
Angle at Toe-off (°)	-6.08 ± 4.78	-7.19 ± 4.52	-6.91 ± 4.42	-6.33 ± 5.11	
Range of Motion (°)	2.75 ± 0.90	2.57 ± 1.37	3.19 ± 1.89	2.82 ± 1.44	
Peak Adduction (°)	1.73 ± 5.05	0.11 ± 4.44	0.72 ± 4.91	1.37 ± 5.22	
Z (+ =internal/ - =external)					
Angle at Footstrike (°)	-9.98 ± 7.46	-6.51 ± 7.39	-9.97 ± 8.71	-10.12 ± 8.32	
Angle at Toe-off (°)	-8.97 ± 6.55	-6.15 ± 5.47	-9.55 ± 7.23	-9.12 ± 7.27	
Range of Motion (°)	6.95 ± 5.06	7.54 ± 4.86	7.17 ± 5.91	6.93 ± 4.34	
Peak rotation (°)	-3.10 ± 5.87	-1.14 ± 4.55	-3.87 ± 7.09	-4.22 ± 6.99	

Bold text = Significant main effect.

A = Significantly different from Uninhibited

B = Significantly different from Force Plate

C = Significantly different from Footscan

D = Significantly different from Matscan

Table 2. Knee joint kinematic observed during the four conditions

	Uninhibited	Force Plate	Footscan	Matscan	
Knee					
X (+ = flexion/ - = extension)					
Angle at Footstrike (°)	-0.58 ± 5.89	0.39 ± 4.52	2.02 ± 6.70	1.40 ± 6.35	
Angle at Toe-off (°)	43.32 ± 9.83	42.21 ± 7.72	42.60 ± 9.22	40.46 ± 10.19	
Range of Motion (°)	43.90 ± 5.86	41.83 ± 5.34	40.58 ± 6.29	39.07 ± 5.51 AB	P<0.001 η²=0.47
Peak Flexion (°)	43.32 ± 9.83	42.21 ± 7.72	42.60 ± 9.22	40.46 ± 10.19	
Y (+ =adduction/-=abduction)					
Angle at Footstrike (°)	1.83 ± 3.54	2.45 ± 3.21	1.80 ± 2.72	1.43 ± 3.31	
Angle at Toe-off (°)	-1.91 ± 7.41	-0.38 ± 5.87	-2.79 ± 6.90	-2.50 ± 6.99	
Range of Motion (°)					
Peak Abduction (°)	3.52 ± 4.35	3.87 ± 3.80	3.11 ± 3.93	2.64 ± 4.25 AB	P=0.001 η²=0.40
Z (+ =internal /- =external)					
Angle at Footstrike (°)	-3.57 ± 8.11	-5.92 ± 4.09	-2.12 ± 8.72	-2.02 ± 8.55	
Angle at Toe-off (°)	-0.91 ± 6.24	-0.34 ± 4.57	1.51 ± 7.37	1.31 ± 6.97	
Range of Motion (°)	2.53 ± 3.11	5.21 ± 2.61	3.11 ± 1.69	3.09 ± 1.79	
Peak Internal rotation (°)	5.59 ± 6.65	4.12 ± 3.57	6.73 ± 6.77	6.67 ± 6.95	

Bold text = Significant main effect.

A = Significantly different from Uninhibited

B = Significantly different from Force Plate

C = Significantly different from Footscan

D = Significantly different from Matscan

Table 3. Ankle joint kinematic observed during the four conditions

	Uninhibited	Force Plate	Footscan	Matscan	
Ankle					
X (- = plantar/ + = dorsi)					
Angle at Footstrike (°)	-0.77 ± 7.46	-0.67 ± 7.41	-1.03 ± 6.99	-0.17 ± 7.11	
Angle at Toe-off (°)	-17.36 ± 6.16	-16.97 ± 6.22	-15.87 ± 6.26	-15.29 ± 6.29	
Range of Motion (°)	16.59 ± 9.36	16.30 ± 9.16	14.84 ± 8.68	15.12 ± 8.83	
Peak Dorsiflexion (°)	4.86 ± 4.84	5.76 ± 4.93	6.05 ± 4.17	5.90 ± 4.65	
Y (+ =inversion/-=eversion)					
Angle at Footstrike (°)	-0.24 ± 3.60	0.54 ± 2.77	-0.33 ± 3.08	-0.82 ± 3.04	
Angle at Toe-off (°)	-1.51 ± 2.43	-0.53 ± 2.23	-0.69 ± 2.29	-0.97 ± 2.71	
Range of Motion (°)	3.59 ± 0.95	2.84 ± 1.38	2.70 ± 1.42	2.60 ± 1.86	
Peak Eversion (°)	-7.56 ± 2.14	-8.33 ± 1.61	-9.02 ± 2.10	-9.10 ± 2.46	
Z (+ =external/- =internal)					
Angle at Footstrike (°)	-6.39 ± 4.96	-6.30 ± 5.05	-6.51 ± 3.93	-6.70 ± 4.75	
Angle at Toe-off (°)	-4.25 ± 5.89	-5.46 ± 5.90	-5.06 ± 4.89	-5.86 ± 5.93	
Range of Motion (°)	1.87 ± 3.99	1.12 ± 2.82	1.60 ± 2.72	1.08 ± 2.83	
Peak rotation (°)	-3.32 ± 3.08	-4.55 ± 3.72	-4.23 ± 2.99	-3.84 ± 3.61	

Bold text = Significant main effect.

A = Significantly different from Uninhibited

B = Significantly different from Force Plate

C = Significantly different from Footscan

D = Significantly different from Matscan