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

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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 device[3].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 knowhow 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 PMsaffected 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 $m.s^{-1}$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 4^{th} 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 information[6]. 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 ($p=0.771$) differ 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 gait[7] 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 (≤1cm) 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 foundbetween 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 gaitsomewhat 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 kinematics[8]. 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.

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Table 1. Hip joint kinematic observed during the four conditions

	Uninhibited	**Force Plate**	**Footscan**	**Matscan**	***Statistical Analysis***
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, η^2=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 η^2=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 η^2=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