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A COMPARISION BETWEEN STATIC AND DYNAMIC FOOT MOBILITY MAGNITUDE MEASURES

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Traditional methods used to assess foot posture during dynamic activities rely on static measures of foot dimensions during partial weight bearing. In recent years, evidence was found which links musculoskeletal and overuse injury patterns in athletes to foot posture. To be able to accurately assess the relationship between injury patterns and foot posture, it might be necessary to study changes in the foot posture during the dynamic activities that the athlete normally undertakes. The purpose of this research is to introduce a method which can be used to measure changes in the foot posture during dynamic activities, hence providing a better prediction of the changes in the foot posture and its relationship to lower limb injuries. The results from static and dynamic Foot posture measures were compared for two subjects and the results showed significant differences.

KEY WORDS: Dynamic foot posture, Foot Mobility Magnitude, image-based measurements, Medial Longitudinal Arch

INTRODUCTION: There are a number of studies which have successfully linked foot posture classification to types of musculoskeletal overuse injuries in athletes (Korpelainen et al., 2001;Burns et al., 2005;Cain et al., 2007). The study conducted by Korpelainen et al. (2001) showed that triathletes with high Medial Longitudinal Arches (MLA) were more likely to develop multiple stress fracture injuries. Burns et al. (2005) conducted a research with similar findings when they studied 131 triathletes and found that subjects with high MLA arches were also at a higher risk of developing overuse sports injuries. Foot classification is currently determined by using a number of static foot measures and these values are used to predict the dynamic behaviour of the foot. The most common static measurement techniques include the Navicular Drop (Brody, 1982) and Navicular Drift (Menz, 1998) which measure the sagittal plane and medial-lateral changes of the Navicular Tuberosity respectively between weight bearing (WB) and non-weight bearing (NWB). However, the reliability of the Navicular Drop and Drift have been inconsistent between studies (Vinicombe et al., 2001;McPoil et al., 2008). To overcome these inconsistencies, a collective measure known as the Foot Mobility Magnitude (FMM) was developed by McPoil et al.(2009). The FMM measures the sagittal and medial-lateral changes in the foot based on the changes in the dorsum of the foot at 50% foot length (FL), as well as the change in the foot width (FW) at 50% foot length between WB and NWB. As these measurements predict the behaviour of the foot posture statically, there is limited research which aims to link static foot classification to dynamic foot posture. Hence the purpose of this study is to determine the behaviour of the foot during dynamic gait based on FMM measures and compare the results with static FMM measurements.

METHODS: Two healthy subjects volunteered to participate in the study and they both signed a participation consent form. Each participant's right foot was marked with three reflective markers placed in the following positions: 1) Dorsum at 50% foot length, 2) Medial side of foot at 50% foot length, 3) Lateral side of foot at 50% foot length. To compare the FMM during static and dynamic measurements, the study was conducted in two parts as follows:

a) Static measurements: The static measurements involved manually measuring the FL and FW using a digital caliper. Each subject's weight was determined using a digital scale and the 10% and 90% weight bearings were calculated. The participants were then asked to place their right foot on the scale and exert 10% of their weight on the scales. Two sets of measurements were then taken for two testers while the participants maintained the 10% WB position. The participants were then asked to adjust the loading until the scales showed 90% of their total weight and the two sets of manual measurements were recorded.

b) Dynamic measurements: A 3-dimensional video based system was developed for the study to allow for the changes in FL and FW to be measured during gait. Ten high definition video cameras were setup in stereo-pair configurations around a five-metre elevated platform as shown in Figure. 1 and an AMTI force plate was installed in the centre of the imaging platform. Each subject was instructed to walk across the platform at a self-selected pace while the video cameras recorded the gait sessions. At the instant the subject's heel landed on the force plate, a genlock system was activated and a flashing light was triggered to allow for all 10 cameras to be synchronised as can be shown in Figure 2. The participants repeated the gait sessions three times. Chong et al.(2009) and Mutsvangwa et al.(2011) used stereo-imaging for 3D point generation and reported measurement accuracies of less than 1 mm.

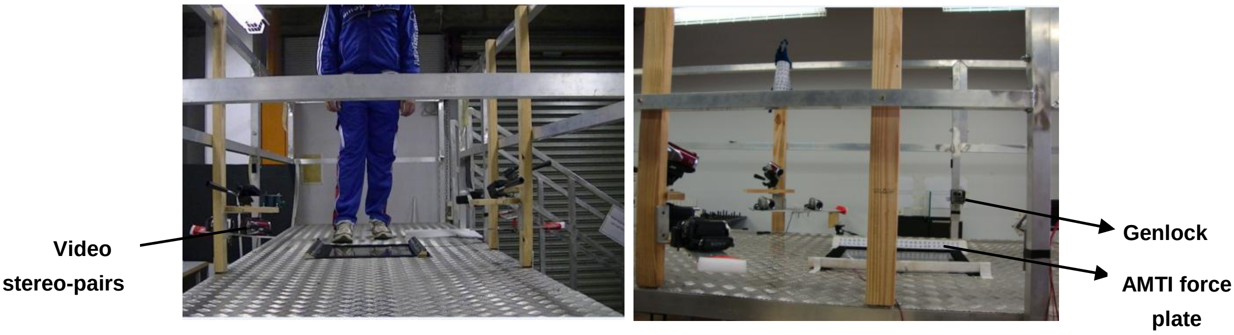

Figure 1: The imaging platform with the video camcorder setup

Figure 2: Synchronised images from different viewing cameras

To convert the video frames to images for measurements, the software VirtualDub (v 1.6.15) was used. The four positions of the contact phase of gait selected for the dynamic measurements were: 1) heel contact (A1), 2) mid-stance (A2), 3) active propulsion (A3) and 4) passive propulsion (A4). The foot positions are shown in Figure 3. The flashing light at heel-contact was used to select the same frame counts for all cameras in Virtual Dub.

Figure 3: The four positions of the contact phase of gait

To calculate the coordinates of the points of interest on the foot and consequently to be able to calculate the changes in foot width at 50% FL and the changes in dorsum height at 50% FL for each foot position, the software Australis (v 6.06) was used. Australis uses a bundle adjustment technique which can be used to calibrate the cameras to accommodate for errors in lens distortions, while also being able to determine the object-space coordinates. Literature on the algorithms used during image processing in Australis can be found in Luhmann et al.(2006).

RESULTS: To calculate the FMM, the following equation was used (McPoil et al., 2009):

$$FMM = \sqrt{(DiffAH)^2 + (DiffMFW)^2}$$

Where, DiffAH is the difference in dorsal Arch height at 50% FL between the 10% and 90% WB (for static measurements) and between A1 and the remaining foot positions (dynamic measurements).
DiffMFW is the difference in foot width at 50% FL between the 10% and 90% WB (for static measurements) and between A1 and the remaining foot positions (dynamic measurements).
Originally, McPoil et al.(2009) used the equation to calculate the FMM for static measurements between weight bearing and non-weight bearing, however in this study, the equation was adapted to determine the changes in weight bearing between 10% and 90% WB as preliminary tests showed that this provided a better estimate of foot mobility during gait. The measurements obtained are summarised in the following tables.

Table 1: Static caliper measurements at different weight bearings

	Subject 1				Subject 2			
	Tester 1		Tester 2		Tester 1		Tester 2	
	Mean (mm)	Std dev (mm)	Mean (mm)	Std dev (mm)	Mean (mm)	Std dev (mm)	Mean (mm)	Std dev (mm)
MFW at 10% WB	89.87	0.15	90.82	0.24	94.9	0.06	95.61	0.31
MFW at 90% WB	93.79	0.43	94.31	0.59	98.33	0.38	99.23	0.38
DH at 10% WB	68.59	1.81	71.15	1.11	64.34	1.14	61.97	1.12
DH at 90% WB	60.25	2.88	60.99	0.61	58.58	0.63	61.85	0.76

Table 2: Dynamic measurements at different angles of the contact phase of gait

	Subject 1				Subject 2			
	Mid-foot width		Dorsal height		Mid-foot width		Dorsal height	
	Mean (mm)	Std dev (mm)	Mean (mm)	Std dev (mm)	Mean (mm)	Std dev (mm)	Mean (mm)	Std dev (mm)
A1	88.088	1.068	69.55	0.979	93.951	1.165	65.487	1.317
A2	90.989	0.408	62.973	0.481	93.955	0.935	63.47	1.163
A3	89.199	1.523	63.503	0.597	89.918	1.952	65.11	0.582
A4	88.944	0.864	64.71	1.381	88.674	1.470	650803	1.128

Table 3: Static Foot Mobility Magnitude (FMM) measurements

	Subject 1	Subject 2
Static FMM Tester 1 (mm)	9.307	3.70
Static FMM Tester 2 (mm)	10.739	3.617

Table 4: Dynamic Foot Mobility Magnitude (FMM) measurements

	Subject 1	Subject 2
Dynamic FMM A1-A2 (mm)	7.188	4.068
Dynamic FMM A1-A3 (mm)	6.148	4.051
Dynamic FMM A1-A4 (mm)	4.928	5.286

DISCUSSION: The purpose of the current study was to compare the changes of the dorsal arch height and the changes in foot width between 10% and 90% WB using traditional static caliper measurements and dynamic measurements during gait. The results in Table 1 show mean static measurements from three sets measured with two testers. Mid-foot measurements at both 10% and 90% WB for both testers were comparable; however dorsal height measurements showed a higher measurement variation. It is predicted that the higher dorsal arch height variations are a result of the difficulty in measuring the dorsal relative to the supporting ground surface. The dynamic measurements obtained from the video-based imaging system show a slightly higher standard deviation values as shown in Table 2. This is the expected result of the slight differences in gait for each subject during three averaged gait trials. The static FMM measurements provided good agreement between the two testers as shown in Table 3. However, the static FMM values were significantly different to the dynamic measurements obtained during gait which are listed in Table 4. The dynamic FMM measurements were calculated between A1 and the remaining foot positions during the contact phase of gait. As subject 1 had a higher arch than subject 2, the changes in the dynamic FMM were larger for subject 1. As it is more difficult to predict changes in the foot posture for the subject with the more pronated foot due to very small changes in foot posture, it becomes particularly important to accurately measure the dynamic FMM measurements to gain more insight into the behaviour of the foot during dynamic activities.

CONCLUSIONS: As shown from the findings of this study, to be able to better determine the foot posture changes in athletes, it is important to be able to measure the changes in the foot posture during dynamic activities. The results of this preliminary study showed some differences between dynamic and static measurements for two subjects, particularly for the subject with the higher foot arch. In the future, the authors aim to develop this research further to include a larger sample with variations in foot arch postures for comparative purposes. The data from this research can provide better insight into the interactions of the foot with various surfaces and the effect of various exercise types on the foot arch. A similar research can also be developed for the design of athletic foot wear to meet the support needs of the individual athlete.

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