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Reliability and minimal detectable difference in multisegment foot kinematics during shod walking and running

Clare E. Milner *, Richard A. Brindle

Department of Physical Therapy and Rehabilitation Science, Drexel University, Philadelphia, PA 19102, USA

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ABSTRACT

There has been increased interest recently in measuring kinematics within the foot during gait. While several multisegment foot models have appeared in the literature, the Oxford foot model has been used frequently for both walking and running. Several studies have reported the reliability for the Oxford foot model, but most studies to date have reported reliability for barefoot walking. The purpose of this study was to determine between-day (intra-rater) and within-session (inter-trial) reliability of the modified Oxford foot model during shod walking and running and calculate minimum detectable difference for common variables of interest. Healthy adult male runners participated. Participants ran and walked in the gait laboratory for five trials of each. Three-dimensional gait analysis was conducted and foot and ankle joint angle time series data were calculated. Participants returned for a second gait analysis at least 5 days later. Intraclass correlation coefficients and minimum detectable difference were determined for walking and for running, to indicate both within-session and between-day reliability. Overall, relative variables were more reliable than absolute variables, and within-session reliability was greater than between-day reliability. Between-day intraclass correlation coefficients were comparable to those reported previously for adults walking barefoot. It is an extension in the use of the Oxford foot model to incorporate wearing a shoe while maintaining marker placement directly on the skin for each segment. These reliability data for walking and running will aid in the determination of meaningful differences in studies which use this model during shod gait.

1. Introduction

There has been increased interest recently in measuring kinematics within the foot during gait. While several multi-segment foot models have appeared in the literature, one in particular has been used frequently for both walking and running. The two segment plus hallux Oxford foot model was originally developed for use during barefoot walking [1]. This model was subsequently modified, which improved reliability of rearfoot motion when used with children walking barefoot [2]. This model has since been used to measure multisegment foot kinematics during both walking and running. Given this model's wide adoption in the field, this study will focus on reliability and minimum detectable difference (MDD) of the modified Oxford foot model.

Reliability of a marker set is of particular concern in longitudinal studies where changes must exceed the MDD to be considered meaningful [3]. Low reliability leads to large MDDs. Several studies have reported the reliability of the Oxford foot model or modified Oxford foot model. However, MDDs have not been reported. There is a need to provide MDDs for commonly studied variables in both walking and running to aid the interpretation of longitudinal studies. In particular, studies of different foot strike patterns during running have stimulated interest in kinematics within the foot. Similarly, investigations of walking in people with osteoarthritis or other pathologies indicate a need to track walking biomechanics longitudinally.

It is considered good practice in marker-based studies for a single investigator to place markers on all participants at all visits. This reduces the between subject variability by removing the influence of inter-rater differences. In interpreting findings for between-day reliability, it is important to note that there is a minimum MDD that reflects the inherent variability of human subjects. This within-session or inter-trial reliability is a floor in terms of the smallest MDD that can be achieved. Thus, within-session MDDs are useful for interpreting the effects of different conditions within a session, such as changing velocity or stride length. They are also useful in interpreting group differences in cross-sectional studies.

* Corresponding author at: Three Parkway Building, 1601 Cherry St., MS 7-502, Philadelphia, PA 19102, USA. Tel.: +1 267 359 5550; fax: +1 267 359 5576.
E-mail address: milner@drexel.edu (C.E. Milner).

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While several studies have reported the reliability for the Oxford foot model, most have reported reliability for barefoot walking [4–7]. One study reported reliability for a multisegment foot using shoe mounted markers [8]. However, this model tracks shoe rather than foot motion and cannot provide insight into foot movement as foot and shoe likely move differently [9]. Thus, it is unknown whether similar reliability would be found for a model using skin-mounted markers during shod walking or for running. Since excursions and peak magnitudes of joint angles are larger in running than walking, MDDs should be reported separately for each. The purpose of this study was to determine between-day (intra-rater) and within-session (inter-trial) reliability of the modified Oxford foot model during shod walking and running. The focus was on variables which are commonly reported in the gait literature. In addition, MDDs were determined to aid the interpretation of the findings of gait studies.

2. Methods

2.1. Participants

Healthy male runners between 18 and 50 years of age were recruited for this study. All procedures were approved by the Institutional Review Board prior to the start of the study. All participants provided written informed consent to participate. Participants ran at least 10 miles per week and had been doing so for a year or more. Participants who answered 'yes' to any of the questions on the Physical Activity Readiness Questionnaire [10] were excluded. Those reporting a history of major lower extremity injury or surgery, or any injury in the prior 6 months were also excluded. On enrollment into the study, participants were screened for foot strike pattern during running, and only rearfoot strikers were included in this study. Strike pattern was determined using strike index [11]. Participants were recruited from the local running community via flyers, social media postings, and direct contact at running events. Eighteen men participated in this study (28 ± 7 years; 1.83 ± 0.07 m; 74.3 ± 8.0 kg; 37 ± 21 miles per week). Participants visited the laboratory on two occasions, spaced at least 5 days apart. A power analysis was conducted to estimate the minimum sample size required for a reliability study using interclass correlation coefficient [12]. A minimum sample size of 18 participants was indicated for 2 replications. This was based on an alpha level of 0.05, beta of 0.2, a minimum acceptable reliability of 0.7, and a target reliability of 0.9.

2.2. Experimental protocol

Participants wore running shorts and a close-fitting sleeveless top to expose their skin for marker attachment. Participants also wore socks and standard laboratory running shoes with cut-outs coinciding with foot marker attachment locations. Thus, all anatomical markers were placed directly on the skin. Tracking markers were placed directly on the skin for the foot and trunk segments or on marker shells which were secured to the segment via hook and loop tape to neoprene underwraps on lower limb segments [13] and via medical tape on the pelvis. Markers were placed bilaterally on both lower extremities, plus the pelvis and trunk as part of a larger study. Markers for the present study were on the right foot and shank (Fig. 1). Multisegment foot markers were placed according to the modified Oxford foot model [2]. A detailed explanation of marker placement can be found in Stebbins et al. [2]. All markers were placed by the same investigator, a biomechanist with 5 years of experience in gait analysis. Participants placed their feet in a standardized position on a template during both marker placement and collection of a standing trial [14].

Marker position data were collected using an eight camera motion capture system (Vicon T40S, Oxford, UK) sampling at 200 Hz. Ground reaction force data were collected via force platforms (AMTI, Inc., Watertown, MA) synchronized with the motion capture system and sampling at 1000 Hz. Following collection of the standing trial, anatomical markers were removed. Participants then completed five good trials each for walking and running, making contact with one of the force platforms embedded in the laboratory floor. The order of conditions was randomized. Participants ran in the laboratory at $3.70\ \text{m s}^{-1} \pm 5\%$, and walked at $1.25\ \text{m s}^{-1} \pm 5\%$ along an 18 m runway. The same data collection protocol was followed during the second visit.

2.3. Data processing

Data were processed using Visual 3D software (C-Motion, Inc., Germantown, MD) and rigid body analysis. Marker trajectories were filtered at 8 Hz using a fourth order Butterworth filter. The stance phase of each trial was determined from the onset and offset of the vertical ground reaction force with a 20 N threshold. Joint kinematics were calculated from segment coordinate axes using the joint coordinate system [15]. Segment coordinate axes were constructed from anatomical markers as described previously [2]. For each visit, variables of interest were extracted from the

Fig. 1. Marker placement on the shank, hindfoot, forefoot, and hallux segments. Both anatomical and tracking markers were present for the standing calibration trial, while only tracking markers were present during the running and walking trials. See text for details.