The Foot 29 (2016) 29–35

Contents lists available at ScienceDirect

The Foot

journal homepage: www.elsevier.com/locate/foot

Reliability and minimal detectable change in foot pressure measurements in typically developing children

Timothy Niiler*, Chris Church, Nancy Lennon, John Henley, Ameeka George, Daveda Taylor, Angelica Montes, Freeman Miller

Gait Laboratory, Nemours/Alfred I. duPont Hospital for Children, P.O. Box 269, Wilmington, DE 19899, United States

HIGHLIGHTS

- Variability in foot pressures is broken down by age group and source.
- The data were collected from a larger age range than is currently in the literature.
- We present a framework for detection of measurable changes in foot pressures.

ARTICLE INFO

Article history:
Received 12 February 2015
Received in revised form 15 April 2016
Accepted 19 October 2016

Keywords:
Pedobarography
Foot pressure
Uncertainty
Minimal detectable change

ABSTRACT

Background: In pedobarography, clinically meaningful comparison of measurements within or between subjects is limited by data variability and measurement error. This study aims to determine the components of the minimal detectable change (MDC) in impulse across all foot regions and the reliability of these measures.

Methods: A convenience sample of foot pressures from 108 visits by normal, healthy subjects aged 2–17 years was studied. Each subject had three pedobarograph measurements taken per foot, with six subjects returning for a second visit for assessment of day-to-day variability. Using a five-region mask, segmental impulses were determined, and from these we obtained the coronal plane pressure index (CPPI). Inter-rater, intra-rater, and day-to-day data were analyzed using intraclass correlation coefficients (ICC) to quantify reliability. Variability of the data was analyzed to quantify the MDC.

Results: Inter- and intra-rater reliability was high for all measurements while variability was low, indicating small direct measurement error. Generally, the largest contributing factor to the MDC was day-to-day variability. Step-to-step variability was more dependent on foot segment than age although minor age-related changes were noted. Finally, the high relative variability in the CPPI and the medial mid foot impulse resulted in very high MDCs for these measures.

1. Introduction

Pedobarography is commonly used to assess foot deformities [1–6], but for it to be truly useful clinically, one must better understand its limitations and reproducibility. To this end, there have been a number of studies that have sought to measure pedobarographic reliability [1–3].

Cousins *et al.* [1] looked at the reliability of pedobarographic measurements in 47 typically developing (TD) children across the span of one week to assess within and between session reliability and group variability. A similar study done by Riad *et al.* [2] also included a comparison between a small number of TD children and children with cerebral palsy (CP). Additionally, Riad *et al.* characterized how an increased number of foot pressures contributed towards the reliability of data from children with CP. Finally, Riad *et*

Abbreviations: MDC, minimal detectable change; ICC, intraclass correlation coefficient; CPPI, coronal plane pressure index; LFF, lateral forefoot impulse; MFF, medial forefoot impulse; LMF, lateral midfoot impulse; MMF, medial midfoot impulse; TD, typically developing; CP, cerebral palsy; se, standard error; δ, uncertainty in estimate of an average percentage impulse over a region of the foot; $\delta_{session}$, uncertainty due to step-to-step combined with intra-rater variability; $\delta_{step2step}$, uncertainty due to step-to-step variability; δ_{intra}, uncertainty due to intra-rater variability; δ_{inter}, uncertainty due to inter-rater (technician) variability; $\delta_{day2day}$, uncertainty due to day-to-day variability; Δ, difference between estimated mean values of an average percentage impulse for a given foot region from one visit to the next; $\bar{x}_{age}$, estimated mean value of a percentage impulse for a given foot region at the specified age.

* Corresponding author. Fax: +1 302 651 5144.
E-mail addresses: tim.niiler@gmail.com, tim@niiler.com (T. Niiler), chris.church@nemours.org (C. Church), nancy.lennon@nemours.org (N. Lennon), john.henley@nemours.org (J. Henley), ameeka.george@gmail.com (A. George), daveda.taylor@nemours.org (D. Taylor), amontes@udel.edu (A. Montes), freeman.miller@nemours.org (F. Miller).

http://dx.doi.org/10.1016/j.foot.2016.10.001
0958-2592/

al. examined the inter-rater and intra-rater reliability of foot pressure data from a single subject. Gurney *et al.* [3] investigated the reproducibility of foot pressure measures for nine subjects over five days. All these studies concluded that foot pressure data was generally reliable except in the segments where the lowest foot pressures occurred.

Despite this earlier work, little is known about the relative magnitudes of the different sources of variability for TD children. Nor is much known about the minimal detectable change (MDC) needed to be able to distinguish one foot pressure pattern from another in TD individuals. The MDC is the smallest difference between estimates of a variable beyond which a change in that variable may be detected above the error of measurement. Understanding this information is essential if we are to effectively evaluate if observed differences in foot pressures originated from treatment, a subject's typical random variation, or data processing.

Rather than using the entire foot-pressure pattern, it is common in gait laboratories to use masks which sum the impulse values within different regions of the foot [1–3,5,6,8,9]. This technique allows clinicians to easily assess foot pressure profiles using a standard frame of reference. Both intra-rater and inter-rater variability are introduced in the masking process because manual intervention is required to align the data with regional masks. Additional variability is present in the act of walking itself. In TD subjects, range of motion is variable because of the many accessible degrees of freedom [7]. This, in turn, leads to a large variability in pedobarographic data between steps, as well as a potentially large variability from day-to-day.

These variabilities imply that estimates of the mean impulses, $\bar{x}$, for a region within a given data collection session will then have a step-to-step uncertainty, $\delta_{step2step}$, along with a processing related uncertainty, δ_{intra}. In practice, it is not necessary to independently determine the step-to-step uncertainty and the intra-rater uncertainty for a session since the final estimate of the mean impulse of interest and its respective uncertainty, $\delta_{session}$, depends on both the variability of the stepping and the consistency of the technician. It also includes instrumental uncertainty.

Differences of mean impulse estimate between sessions $\Delta = \bar{x}_2 - \bar{x}_1$ are only meaningful if they exceed the sum of the uncertainties inherent in the measurements. In the event that sessions occurred on different days and different technicians processed the data, then one must account for the day-to-day uncertainty, $\delta_{day2day}$, as well as the inter-rater uncertainty, δ_{inter}. Quantitatively, the MDC is given by the sum of the session uncertainties as well as the day-to-day and inter-rater uncertainties, if applicable.

$$MDC = \delta_{session1} + \delta_{session2} + \delta_{inter} + \delta_{day2day} \quad (1)$$

Because session and inter-rater uncertainties are dependent on the quality of the masking process, it is also important to estimate the reliability of raters. If intra-rater and inter-rater variability is low while the reliability is high, then the measurement process itself is relatively effective and the majority of the variability in the data comes from the subject.

The purpose of this study was to quantify variability and reliability of segmented pedobarograph data and thereby provide a framework for the estimation of the MDC and its component uncertainties for individual subjects as a function of age. Additionally, we provide estimates of average session uncertainties by age, inter-rater uncertainties, and day-to-day uncertainties which establish a rough baseline for interpretation of foot pressure data that uses a similar masking system.

2. Materials and methods

2.1. Subjects

In this IRB-approved study, we analyzed data from a convenience sample of 46 males and 62 females aged 2–17 years (mean = 10.6 ± 5.1 years) with no identified history of abnormalities in gait, of foot deformities, or of pain.

2.2. Data collection

At each visit, three pedobarograph measurements were taken per subject, per foot using a mid-gait protocol. Subjects walked at a self-selected pace along a walkway with an embedded TekScan resistive foot pressure mat (Boston, MA) with dimensions of 48.8 cm × 44.7 cm and 8448 sensing elements. Data collection was conducted at 60 Hz. Due to the size of the mat and need for unmodified gait, multiple trials were collected until three full foot prints per side were obtained. The pressure plate was camouflaged as part of our "yellow brick road" walkway so that targeting of the plate

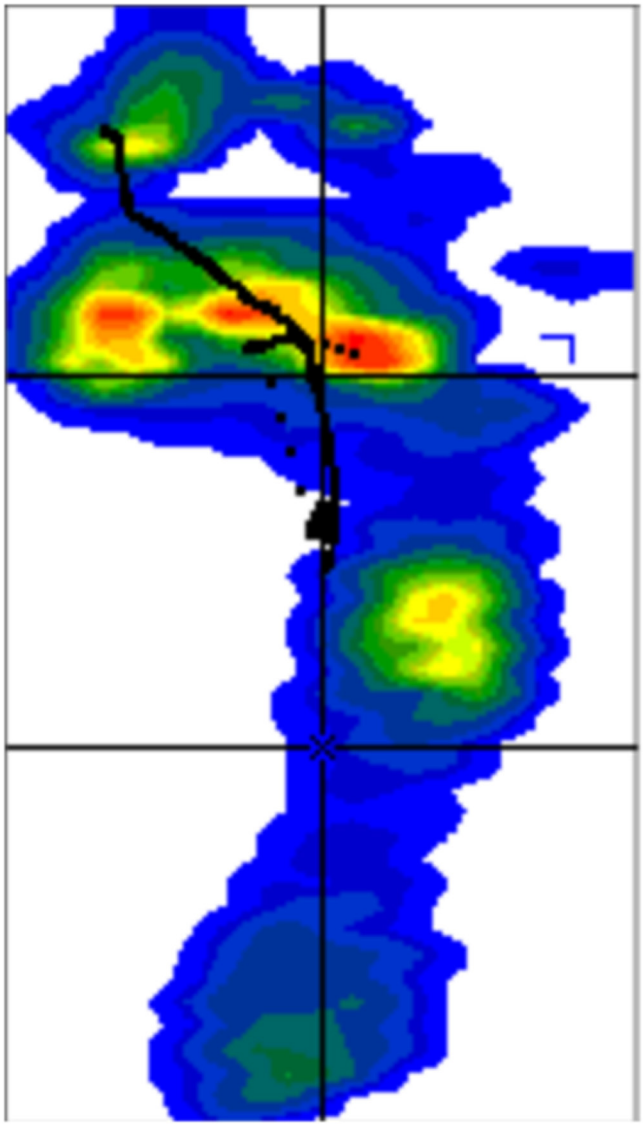

Fig. 1. Typical foot pressure data divided into segments as per our masking: medial forefoot (MFF), lateral forefoot (LFF), medial midfoot (MMF), lateral midfoot (LMF), and heel (bottom two segments).