Gait & Posture 46 (2016) 1–4

Contents lists available at ScienceDirect

Gait & Posture

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

Short communication

Analytical evaluation of the effects of inconsistent anthropometric measurements on joint kinematics in motion capturing

Dominik Krumm [a,*], John Cockcroft [b], Falk Zaumseil [c], Stephan Odenwald [a], Thomas L. Milani [c], Quinette Louw [b]

[a] Sports Equipment and Technology, Technische Universität Chemnitz, Germany
[b] Division of Physiotherapy, Stellenbosch University, South Africa
[c] Human Locomotion, Technische Universität Chemnitz, Germany

ARTICLE INFO

Article history:
Received 6 October 2015
Received in revised form 23 December 2015
Accepted 25 January 2016

Keywords:
Gait analysis
Sensitivity
Joint kinematics

ABSTRACT

Clinical decisions based on gait data obtained by optoelectronic motion capturing require profound knowledge about the repeatability of the used measurement systems and methods. The purpose of this study was to evaluate the effects of inconsistent anthropometric measurements on joint kinematics calculated with the Plug-in Gait model. Therefore, a sensitivity study was conducted to ascertain how joint kinematics output is affected to different anthropometric data input. One previously examined gait session of a healthy male subject and his anthropometric data that were assessed by two experienced examiners served as a basis for this analytical evaluation. This sensitivity study yielded a maximum difference in joint kinematics by the two sets of anthropometrics of up to 1.2°. In conclusion, this study has shown that the reliability of subjects' anthropometrics assessed by experienced examiners has no considerable effects on joint kinematics.

1. Introduction

Optoelectronic motion capturing is widely used in clinical gait analysis services [1]. Using gait data to make clinical decisions about therapeutic interventions, however, requires profound knowledge about the validity and repeatability of the used measurement systems and methods [2–4].

In three dimensional gait analysis that uses computer models to derive joint kinematics and kinetics from surface markers, the reliability is mainly influenced by intrinsic and extrinsic factors [2]. Intrinsic factors are related to the individuals' variability. These variations arise naturally, reflect the inherent variation of individuals and cannot be reduced [2]. Extrinsic factors arise from experimental errors [5] and can be reduced through quality improvements. Exact values for the reliability caused by intrinsic and extrinsic variations associated with gait analysis were presented by Schwartz et al. [5]. Their intrinsic variation at a self-selected speed was up to 3.5° for knee flexion, whereas, the extrinsic variation was approximately 5° for the same joint and up to approximately 7.5° for hip rotation [5].

Although there are several causes of experimental errors, such as speed [1,6], precision of models [3,5], data processing [6], measurement equipment errors [4], or inconsistent marker placement [1,6], this paper will focus on anthropometric measurements (an extrinsic factor). Anthropometric measurements are used in several models, e.g. Plug-in Gait model (PiG), to estimate joint centres and thenceforth joint kinematics. Hence, the purpose of this paper was to ascertain the effects of different anthropometric datasets obtained from two experienced examiners on joint kinematics calculated with PiG by means of a sensitivity study.

2. Methods

2.1. Data acquisition

One gait session of a healthy male participant previously measured at the clinical human motion laboratory of Stellenbosch University was randomly chosen for implementation in the sensitivity study. The acquisition of gait kinematics during that session was conducted using an 8-camera VICON optoelectronic

* Corresponding author at: Sports Equipment and Technology, Reichenhainer Str. 70, D-09126 Chemnitz, Germany. Tel.: +49 3 71/5 31-3 85 28; fax: +49 3 71/5 31 2 31 49.
E-mail addresses: dominik.krumm@mb.tu-chemnitz.de (D. Krumm), johnc@sun.ac.za (J. Cockcroft), falk.zaumseil@hsw.tu-chemnitz.de (F. Zaumseil), stephan.odenwald@mb.tu-chemnitz.de (S. Odenwald), thomas.milani@hsw.tu-chemnitz.de (T.L. Milani), qalouw@sun.ac.za (Q. Louw).

http://dx.doi.org/10.1016/j.gaitpost.2016.01.024
0966-6362/

tracking system (MX T-series, Oxford Metrics, Oxford, UK) with a frequency of 200 Hz. Post processing was used to evaluate kinematic variations by recalculating joint kinematics with revised anthropometric data input. Revised anthropometric data was determined as being a combination of the median ($\tilde{x}$), the maximum and/or the minimum of the subject's original anthropometric data (Table 1) that was previously obtained by two experienced examiners [7]. In total, 15 different combinations were implemented. The first combination, using median values for left leg length (LLL), right leg length (RLL), left knee width (LKW), right knee width (RKW), left ankle width (LAW) and right ankle width (RAW) to recalculate joint kinematics of the randomly chosen gait session, was used as a reference (REF). The next two combinations used either only maximum (MAX) or minimum (MIN) values for all revised anthropometric data. For the other 12 combinations, only one parameter was either set to maximum (+) or to minimum (−), while the remaining five parameters were left at median values. Subsequently, revised anthropometric data will be presented as the abbreviation of the changed anthropometric parameter plus/minus an absolute measure that identifies how many millimetres the value changed from the median value.

2.2. Post processing

One gait session comprised five gait trials. Gait events were manually detected for each trial. A random stride was taken from each trial and normalized to 101 points using Matlab (R2013b, MathWorks, Natick, MA, US). Joint kinematics were calculated using PiG together with the approach introduced by Baker et al. [8].

2.3. Statistical analysis

Joint kinematics were presented as median of five normalized gait cycles individually for the left and the right side. The gait cycle was defined as the overall movement pattern between two successive foot contacts of the same side. The effects of inconsistent anthropometric measurements on joint kinematics were evaluated by comparison of the normalized gait cycle of REF kinematics with the recalculated kinematics. In detail, the following parameters were estimated:

- Median ($REF_{\tilde{x}}$) and standard deviation (REF_{SD}) of joint angles of the reference measurements.
- Median absolute deviation of joint angles using median anthropometric values (MAD_{REF}).
- Difference between $REF_{\tilde{x}}$ and median joint angles from revised anthropometric data (DIFF).

A median absolute deviation of joint angles up to two degrees will be regarded as an acceptable level of reliability for making clinical decisions [2].

3. Results

The smallest median absolute deviation of the reference measurement (MAD_{REF}) was 0.1° and occurred for hip rotation (Table 2). The highest MAD_{REF} was 1.6° and occurred for knee flexion. The absolute difference of joint kinematics (DIFF) was greater for joints in the coronal and transverse plane compared to the sagittal plane by a factor of four (Fig. 1). Joint kinematics in the coronal and transverse plane had a notably higher variability compared to joint kinematics in the sagittal plane. The greatest absolute difference was 1.2° and was obtained in the transverse plane for hip rotation while all anthropometrics were set to minimum (MIN). The maximum absolute difference in the sagittal plane was 0.3° and was obtained for ankle dorsiflexion while all anthropometrics were set to MIN. However, the maximum absolute difference in the coronal plane was 1.1° and was obtained for hip adduction while anthropometrics were set to RLL-15 or LKW+8.

4. Discussion

The reliability of clinical gait analysis services is influenced by non-modifiable intrinsic and potentially modifiable extrinsic factors. This research analysed the effects of anthropometric measurements on motion analysis. By adjusting subject anthropometrics, a linear scaling of the model relative to skin markers was performed which perturbed joint centre locations and subsequently joint kinematics. For instance, if the left knee width is measured low (cf. LKW-5), then the left knee joint centre will be closer to the lateral knee marker and this will induce an increased adduction/varus of the left knee angle (median increases 0.7°, cf. Appendix 1). However, knee and ankle width had no effects on the transverse plane kinematics, since the applied approach to determine hip rotation [8] does not use joint

Table 1
Median ($\tilde{x}$), minimum (min) and maximum (max) anthropometric data of the subject's original anthropometric data assessed by two experienced examiners within a total of $n = 14$ anthropometric measurement sessions.

	$\tilde{x}$ (mm)	Max (mm) Min (mm)	Deviation (mm)
LLL	960.0	970.0 950.0	+10.0 −10.0
RLL	955.0	965.0 940.0	+10.0 −15.0
LKW	103.0	111.0 98.0	+8.0 −5.0
RKW	103.0	110.0 99.0	+7.0 −4.0
LAW	78.0	80.0 75.0	+2.0 −3.0
RAW	77.0	79.5 73.0	+2.5 −4.0

Table 2
Mean ($\tilde{x}$), minimum (min) and maximum (max) of median absolute deviation of the reference measurement (MAD_{REF}).

	$\tilde{x}$ (mm)	Max (mm) Min (mm)
Hip flexion	0.6	0.9 0.2
Hip adduction	0.5	1.0 0.3
Hip rotation	0.7	1.4 0.1
Knee flexion	0.7	1.6 0.2
Knee adduction	0.4	1.3 0.1
Knee rotation	0.9	1.3 0.3
Ankle dorsiflexion	0.6	1.0 0.3
Foot progression	1.0	1.5 0.4