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# BETWEEN CENTRE RELIABILITY OF WALKING AND RUNNING THREE-DIMENSIONAL GAIT KINEMATICS

[1,4]Cristina Porto Alves Alcantara, [2]Reginaldo K Fukuchi, [3]Marcos Duarte, [2]Reed Ferber
[1]Physical Education and Sport School, University of Sao Paulo, Brazil
[2]Running Injury Clinic, Faculty of Kinesiology, University of Calgary, Canada
[3]Biomedical Engineering Program, Federal University of ABC, Brazil
[4]Corresponding author: cristina.alcantara@usp.br

## INTRODUCTION

Three-dimensional movement (3D) gait analysis is widely used in both clinical and research areas [1]. Biomechanical studies usually involve a limited sample size due to the challenge in obtaining homogenous samples of individuals in a single site [2]. Hence, multicentre studies are an alternative to increase the sample size. However, the measurement error and variability may increase when the data are collected in different centres, particularly when there is lack of standardization in the data collection procedures. Usually gait kinematic reliability is greater in the sagittal plane compared to the frontal and transverse planes [1] and within-tester reliability is greater than between-tester reliability [2]. Within-subject intrinsic variability across data collection days must also be considered and thus controlled [3].

The main sources of measurement errors are skin movement artifact [4], calibration error, different gait speeds and marker placement error [1]. The last factor, marker placement error, can be considered the main factor since the other sources usually have the same magnitude either between days or across centers. Therefore, a model consisting of technical markers only would likely minimize the marker placement errors compared to a model consisting of both technical and anatomical markers. On the other hand, if the marker protocol (technical and anatomical) present similar reliability for gait kinematic variables, it may be assumed that marker placement was reliable between sessions.

Therefore, the aim of this study was to evaluate the reliability between two motion analysis laboratories in measuring joint kinematics in both walking and running conditions. In addition, we tested the reliability of different marker sets (technical and anatomical) for the variables of interest. We hypothesized that due to the standardization method, and the experience of the examiners, we would have reliable data between centers. We also hypothesized that the reliability between centres would be lower as compared with within-center reliability. Finally, we hypothesized that the technical marker set would be more reliable than the combined anatomical and technical marker set.

## METHODS

One single female subject (29 yrs; 154 cm; 52 kg) free of any musculoskeletal, cardiovascular, sensory or motor disorders was assessed in both a Canadian and a Brazilian Gait Analysis Laboratory. The subject was familiar with treadmill walking and running and the data collection procedures involved. The subject walked at 5 km/h and ran at 9 km/h for 30 seconds after a 3 minute accommodation period. The examiners were different but they were trained in the same Laboratory (Brazil) and followed the same data collection procedures for placement of the anatomical markers. In addition, both examiners were experienced physiotherapists with approximately 5 and 8 years of experience, respectively, in gait analysis and clinical practice. To account for within-subject variability, the data collection procedures were performed across four consecutive days in both sites, first in Canada and then in Brazil starting two days later.

Two different conventions were adopted to determine the segment coordinate systems for the pelvis and the lower extremity segments during an anatomical standing calibration trial. First, anatomical markers were used to determine the position and orientation of the foot, shank, and thigh segments [5]. Second, a separate procedure was performed where the relative global position of the segments were determined using only the technical markers. A calibration board was used to ensure that the subject's feet had the same alignment, relative to the Laboratory reference frame, for all data collections during the standing calibration trial. This procedure also allowed the calculation of the joint angles using only technical markers, by assuming the segment reference frames had the same orientation as the laboratory reference frame at both sites. Thus, the joint angles were obtained using these different approaches for further comparison. The subject performed the dynamic trials (walking and running) on an instrumented treadmill (Bertec Inc.) in both sites.

Kinematic data were collected at 200 Hz using an 8-camera motion capture system (Vicon MX cameras in Canada and Raptor-4 Cortex Motion Analysis in Brazil) and the marker trajectories were filtered with a low-pass Butterworth filter with 6 Hz. The strides were determined by the vertical ground reaction force (heel strike and toe off), which was sampled at 1000Hz.

The variables selected for further analyses were the hip, knee and ankle peak joint angles in the frontal, sagittal and transverse planes, and they were calculated using Visual 3D (C-motion Inc.) software. The statistical analyses were performed using a custom code written in Matlab according to Schwartz et al. [6]. The within-day and between-centre errors were determined using standard error of the mean (SEM) values from the time-series joint angles curves for each of the 101 discrete points in the curve. The mean values across the 101 points were obtained to represent the error in each kinematic variable of interest.

## RESULTS AND DISCUSSION

The mean values for SEM for each variable, between-days and between-centres, during walking and running are showed in Table 1 and Table 2.

**Table 1:** Mean values of SEM (degrees) using anatomical markers, during walking (5km/h) and running (9km/h) for each variable analyzed across days and between Canada (CA) and Brazil (BR) laboratories.

| | Inter Day | | | | Inter Centre | |
|---|---|---|---|---|---|---|
| | Walking | | Running | | Walking | Running |
| | CA | BR | CA | BR | CA / BR | CA / BR |
| Ankle Dorsi/Plantar | 0.71 | 1.21 | 0.70 | 0.61 | 1.64 | 2.43 |
| Ankle Ab/Adduction | 0.30 | 1.12 | 0.38 | 0.78 | 1.23 | 2.67 |
| Ankle Inv/Eversion | 1.03 | 1.15 | 0.56 | 0.40 | 1.17 | 1.82 |
| Knee Flex/Extention | 1.30 | 1.07 | 1.04 | 0.60 | 3.18 | 2.48 |
| Knee Ab/Adduction | 0.41 | 0.49 | 0.17 | 0.39 | 0.99 | 1.52 |
| Knee Rotation | 1.37 | 0.58 | 1.13 | 0.74 | 2.26 | 1.84 |
| Hip Flex/Extention | 0.49 | 1.63 | 0.87 | 0.91 | 1.39 | 3.29 |
| Hip Ab/Adduction | 0.32 | 0.59 | 0.64 | 0.25 | 2.01 | 3.45 |
| Hip Rotation | 1.13 | 0.79 | 0.82 | 0.93 | 4.37 | 3.46 |

**Table 2:** Mean values of SEM (degrees) using technical markers, during walking (5km/h) and running (9km/h) for each variable analyzed across days and between Canada (CA) and Brazil (BR) laboratories.

| | Inter Day | | | | Inter Centre | |
|---|---|---|---|---|---|---|
| | Walking | | Running | | Walking | Running |
| | CA | BR | CA | BR | CA / BR | CA / BR |
| Ankle Dorsi/Plantar | 0.92 | 1.38 | 2.08 | 0.64 | 1.59 | 2.22 |
| Ankle Ab/Adduction | 0.47 | 0.82 | 1.52 | 0.50 | 1.43 | 2.53 |
| Ankle Inv/Eversion | 0.57 | 0.80 | 0.72 | 0.44 | 1.00 | 1.58 |
| Knee Flex/Extention | 1.59 | 2.01 | 1.83 | 0.50 | 2.96 | 2.76 |
| Knee Ab/Adduction | 0.37 | 0.45 | 0.58 | 0.32 | 0.87 | 1.65 |
| Knee Rotation | 1.65 | 0.67 | 0.89 | 0.88 | 2.27 | 1.85 |
| Hip Flex/Extention | 0.77 | 1.57 | 0.86 | 0.91 | 1.44 | 3.29 |
| Hip Ab/Adduction | 0.38 | 0.62 | 0.67 | 0.39 | 1.67 | 3.20 |
| Hip Rotation | 1.14 | 1.08 | 0.73 | 0.75 | 4.21 | 3.18 |

This study presented the within- and between-center reliability of the lower extremity joint angles during walking and running. The aim of this preliminary investigation was to determine the reliability of these measurements for potential multi-centre collaborative research. Kinematic variability was examined across days, marker set types and centres.

We measured the joint angles using only technical markers and anatomical markers in an attempt to remove the influence of the examiner placing markers on specific anatomical landmark. The preliminary results indicated that using anatomical and technical markers was reliable (Table 1: SEM range 0.99-4.37$^{o}$ walking; 1.52-3.46$^{o}$ running) and that there were no remarkable differences in the reliability between these marker sets. This result may be partly explained by the experience of the examiners and by the successful standardization of the data collection procedures. Moreover, the results highlight that a technical marker set may be a reasonable alternative for future multicentre studies since it is easier to standardize for data collection procedures and demonstrates similar SEM error (Table 2: SEM range 0.87-4.21$^{o}$ walking; 1.58-3.29$^{o}$ running. Future research on this topic is warranted to answer this question.

The SEM between centers showed similar values compared to previous studies [1,2,4,6]. In fact, McGinley et al. [3] reported that greater values are usually found in the transverse plane of the knee and hip, similarly to the current study. Therefore, standardized data collection procedures are important to minimize potential sources of errors that affect gait kinematic reliability, particularly in the secondary planes of motion.

## CONCLUSIONS

The results of the present study indicate that a multicenter study can be conducted between these two centres with reasonable reliability of gait kinematic variables. Despite the preliminary nature of this investigation, this is the first study to assess the reliability of running gait kinematics across centres removing the effect of inter-subject reliability. The marker set model apparently did not influence the results, indicating that either set of markers may be adopted when conducting multicenter studies. Future studies are required to determine if the magnitude of the errors within and between centres can be minimized.


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