Gait & Posture 46 (2016) 18–25

Contents lists available at ScienceDirect

Gait & Posture

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

Three dimensional multi-segmental trunk kinematics and kinetics during gait: Test-retest reliability and minimal detectable change

Rita Fernandes [a,b,*], Paulo Armada-da-Silva [a], Annelies Pool-Goudaazward [c], Vera Moniz-Pereira [a], António P. Veloso [a]

[a] Universidade de Lisboa, Faculdade de Motricidade Humana, CIPER, LBMF, Estrada da Costa, 1499-002 Cruz Quebrada, Dafundo, Portugal
[b] Departamento de Fisioterapia, Escola Superior de Saúde, Instituto Politécnico de Setúbal, Portugal, Campus do Instituto Politécnico de Setúbal, Estefanilha, Edifício ESCE, 2914-503 Setúbal, Portugal
[c] Faculty of Human Movement Sciences, Research Institute MOVE, VU University Amsterdam, Van der Boechorststraat 9, 1081 BT Amsterdam, The Netherlands

ARTICLE INFO

Article history:
Received 9 May 2015
Received in revised form 3 February 2016
Accepted 6 February 2016

Keywords:
Three dimensional gait analysis
Multi-segmental trunk
Reliability
Measurement error

ABSTRACT

Background and Aim: Trunk kinematics and kinetics can contribute to more detailed information on gait impairment, however, data about reliability and measurement error of multi-segment trunk on three-dimensional gait analysis (3DGA) is lacking. The aim of this study is to investigate test-retest reliability and MDC of 3DGA kinematic and kinetic data in a sample of healthy individuals, using a two rigid segment model for the trunk.
Methods: A test-retest study with a median interval of 7 days and a sample of 23 healthy individuals was conducted. Anthropometric, time-distance parameters and peak values for lower limb and trunk joint angles/moments were computed. The intraclass correlation coefficient ($ICC_{3,k}$), standard error of measurement (SEM), minimal detectable change (MDC) and 95% limits of agreement (LOA) were calculated.
Results: We found acceptable test-retest reliability for most joint angles and a SEM $\leq 4^{\circ}$. The ICCs were above 0.7 for joint moments and the SEM and MDC were ≤ 0.2 Nm/kg and ≤ 0.6 Nm/kg, respectively. Bland–Altman plots with 95% LOA revealed a good agreement and time-distance parameters were all highly repeatable (majority ICCs > 0.90).
Conclusions: The results of this study suggest varied reliability indices for multi-segment trunk joint angles and moments during gait and an acceptable level of error, particularly for sagittal plane parameters. Some parameters showed wide 95% CIs for ICCs and higher SEM%. However, we believe that this study provides preliminary data regarding reliability indices for multi-segment trunk during gait, which may be valuable for clinical reasoning and decision making when dealing with movement disorders.

1. Introduction

Three-dimensional gait analysis (3DGA) is a valuable assessment method used in clinical and in research settings to support clinical functional diagnoses and decision-making. Repeated gait measurements can also be useful to evaluate the outcome of therapeutic interventions, although, the observed variability between pre- and post-intervention measurements may be due to treatment effects or measurement variation, or a combination of both [1]. Thus, knowledge about the error magnitude can minimize the risk of over-interpreting small differences as meaningful [2] and can contribute to the certainty that a measured intervention effect exceeds the measurement error. In 3DGA, there are numerous potential sources of variability affecting the error magnitude of the testing procedure, such as, instrumental errors, anatomical landmark misplacement and soft tissue artifacts (STA) [3].

Knowledge about reliability and minimal detectable change (MDC) values from healthy population is extremely important since it can help clinicians and researchers interpreting pathological

* Corresponding author at: Universidade de Lisboa, Faculdade de Motricidade Humana, CIPER, LBMF, Estrada da Costa, 1499-002 Cruz Quebrada, Dafundo, Portugal. Tel.: +351 214149100.
E-mail addresses: rita.fernandes@ess.ips.pt (R. Fernandes), parmada@fmh.ulisboa.pt (P. Armada-da-Silva), annelies.pool@gmail.com (A. Pool-Goudaazward), veramps@fmh.ulisboa.pt (V. Moniz-Pereira), apveloso@fmh.ulisboa.pt (A.P. Veloso).

http://dx.doi.org/10.1016/j.gaitpost.2016.02.007
0966-6362/

data. Several studies have investigated the reliability of 3DGA in healthy and pathological populations [1]. A systematic review, [1] examining the reliability of three-dimensional kinematic gait measurements in healthy individuals and in individuals with pathology (such as stroke or cerebral palsy), reported a variable median value of within-assessor reliability (0.54–0.96). Additionally, they revealed error values between 2° and 5°, concluding that although most errors in gait analysis are probably acceptable, they are generally not small enough to be ignored during clinical data interpretation.

Despite the importance of such information, only two studies [4,5] provided absolute measures of measurement error and MDC values for kinematic and kinetic parameters in healthy individuals. Meldrum et al. [4] reported low standard error of measurement (SEM) ($\leq$5°) for the majority of the lower limb kinematic parameters and variable intraclass correlation coefficients (ICCs) values (0.14–0.92). They also described the repeatability of key kinetic gait cycle parameters, predominantly in the sagittal plane (except for hip abductor joint moment), showing ICCs that varied from 0.51 to 0.81. Using a sample of young healthy adults, Wilken et al. [5] reported good to excellent reliability of lower limb and trunk kinematics/kinetics across a range of controlled walking velocities, as well as low MDC values (approximately of 5° for joint angles). By adding trunk data, this study made an important contribution, given the established relevance of the coordination between trunk and pelvis rotations, as well as trunk muscle activity during normal walking [6]. This coordinated pattern contributes for the maintenance of dynamic equilibrium, reduces the energy cost and helps to effectively deal with perturbations during locomotion [6]. However, in Wilken's study, the trunk was modeled as one rigid segment and kinetic transverse plane parameters were lacking, which excludes valuable information for clinical reasoning and decision making when dealing with movement disorders. Thus, the aim of this study is to investigate test-retest reliability and MDC of 3DGA kinematic and kinetic data in a sample of healthy individuals, using a two rigid segment model for the trunk.

2. Materials and methods

2.1. Study design

A prospective within assessor test-retest study was conducted.

2.2. Sample size calculation

The sample size calculation for a pre-defined 5% level of significance with 80% power was performed using the formula of Kraemer and Thiemann [7]. The desired reliability co-efficient was set at 0.90 with a minimum reliability of 0.70. This resulted in a sample size requirement of 17, however, to allow for non-attenders and increased precision, 23 subjects were recruited.

2.3. Participants

A convenience sample of 23 volunteers (12 females and 11 males; age 35 ± 7.3 years, height 1.70 ± 0.07 m, mass 66.39 ± 9.2 kg and body mass index 23.01 ± 2.3 kg/m^2) was recruited from university staff and their associates to participate in a 12-week prospective study, according to a standardized recruitment protocol. Firstly, physiotherapists from the research team carried out individuals' recruitment based on predefined inclusion/exclusion criteria. Healthy individuals were considered eligible if they were aged between 18 and 65 years old and were excluded if they had any clinical condition (musculoskeletal, neurological, cardiac or pulmonary) or symptom that could affect gait. Pregnant women were also excluded. After this screening, from the 35 participants recruited, one was excluded because of depression diagnosis and 11 were not available to perform two consecutive assessments with a mean interval of 7 days due to the lack of time.

The local Ethics Committee approved the study. All the participants were informed of the procedures and risks of the study and signed an informed consent.

2.4. Procedures

Gait analysis was performed twice with an interval of 7–11 days (median of 7). This time interval was considered long enough to avoid assessor memory bias and short enough to avoid a change in individuals' gait pattern [8]. On the first visit to the laboratory, participants' history was reviewed. This was complemented with the measurement of body mass and height. Body segments' length was obtained using the respective proximal and distal anatomical landmarks collected during the static trial described below. For pelvis, anterior and posterior superior iliac spine (ASIS and PSIS) markers were used.

Finally, gait data was collected using a 13-camera optoelectronic system (Oqus 300, Qualisys AB, Gothenburg, Sweden) synchronized in time and space with two Kistler (Kistler Group, Winterthur, Switzerland) and one AMTI (Advanced Mechanical Technology, Inc Watertown, USA) force platforms at 200 Hz. The marker set used was based on previous reports [9,10] (see Supplementary material). After a static trial, participants were instructed to walk barefoot at their preferred walking speed, continuously and during short periods of time (1–2 min) to avoid fatigue. A familiarization trial was performed before data collection. Each participant was assessed at the same time of the day to minimize the effects of diurnal variations in joint mechanics. All the procedures were carried out by the same assessor.

2.5. Data processing

Considering the natural variability in kinematic and kinetic gait parameters, 10 cycles were selected [11]. Cycles were extracted using Qualysis Track Manager (v2.8 build 1554, Qualisys AB, Gothenburg, Sweden) and exported to be processed under Visual 3D software (v5.01.10, C-Motion Inc., Rockville, USA).

A 9-segment model (feet, shanks, thighs, pelvis, lumbar and thoracic spine) was built for each participant [9,10]. All the local coordinate systems (LCS) were defined in accordance with Robertson et al. [12] and their origin was the joint center. The ankle and knee joint centers were defined as the midpoint of the tibia malleoli and as the midpoint of the femur epicondyles, respectively [12]. The hip joint centers were computed using the pelvis markers, according to published regression equations [13]. The lumbar joint center was defined through a virtual marker created along the distance connecting the L5–S1 marker and the midpoint between the two ASIS markers [9], projected from the thoracic joint center. The thoracic joint center was defined using a virtual marker projected from the mid-point of the markers placed bilaterally on the ribcage at the T12–L1 joint space level onto the thorax longitudinal axis. The proximal end of this axis was defined as the mid-point between the suprasternal notch and the second thoracic vertebra, while the distal end was defined as the mid-point between the xiphoid process and the inferior angles of most caudal points of the two scapulae. For the pelvis, a second LCS was created based on the CODA pelvis Model [12] in order to achieve a more clinically recognisable pelvic tilt (sagittal plane). Each segment was considered to be independent and to have 6 degrees of freedom (segment optimization (SO) method) [14]. Lower limb segment masses were determined according to