Gait & Posture 64 (2018) 75–83

Contents lists available at ScienceDirect

Gait & Posture

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

Full length article

Modified conventional gait model versus cluster tracking: Test-retest reliability, agreement and impact of inverse kinematics with joint constraints on kinematic and kinetic data

Benjamin F. Mentiplay[a,*], Ross A. Clark[b]

[a] La Trobe Sport and Exercise Medicine Research Centre, La Trobe University, Bundoora, VIC, 3086, Australia
[b] Faculty of Health, Science, Education and Engineering, University of the Sunshine Coast, Sippy Downs, QLD 4556, Australia

ARTICLE INFO

Keywords:
Walking
Inverse kinematics
Plug-in gait
Gait analysis
Vicon clinical manager
Six degrees-of-freedom

ABSTRACT

Background: Three-dimensional gait analysis is often used to assess kinematics and kinetics to discriminate gait patterns and examine change over time. Test-retest reliability is therefore imperative; however, many variations of gait models currently exist.

Research question: This study examined the test-retest reliability of, and agreement between, two commonly used methods of gait modelling, a modified Conventional Gait Model and cluster-based model, using both six degrees-of-freedom or inverse kinematics computational methods in Visual3D.

Methods: Thirty healthy participants attended two identical sessions. The data for both models were collected concurrently and analysed in Visual3D using either six degrees-of-freedom or inverse kinematics computational methods. Outcomes were taken as the peak measurements for kinematics (joint angles and angular velocity) and kinetics (joint moments and power) for the hip, knee and ankle. Intraclass correlation coefficients were used to examine reliability, with the standard error of measurement and minimal detectable change also calculated. Agreement between models was examined with Pearson correlations and intraclass correlation coefficients.

Results: Test-retest reliability was good to excellent for all models for lower limb kinematics and kinetics. The inverse kinematic models had slightly lower reliability across outcomes compared to the six degrees-of-freedom models. Agreement between the Conventional Gait Model and cluster model was mostly good to excellent. Comparison of the two modified CGMs (with six degrees-of-freedom and inverse kinematics) showed much higher agreement against the comparison of the two cluster-based models (with six degrees-of-freedom and inverse kinematics).

Significance: This study provides a comprehensive assessment of the test-retest reliability and agreement between two gait models with various computational methods. Future research may use these results to guide their decision making for the gait model and outcomes of interest to be used.

1. Introduction

The most common three-dimensional gait analysis model implemented is the Conventional Gait Model (CGM) [1–4]. The CGM refers to a group of similar models with different names (e.g. Plug-in Gait, Vicon Clinical Manager, Newington, Helen Hayes). The CGM has a minimal marker set, which allows for relatively quick preparation, is less computationally intensive as there are fewer markers to track, and can potentially result in less marker drop out and switching. Despite being widely used, the CGM has known limitations that potentially affect the quality of the gait data [2]. An example of one of the limitations is that CGMs often only allow three degrees-of-freedom (3DoF) that are constrained about an assessor-defined joint centre, with previous work showing that even slight variations in marker placement will have large impacts on the kinematic results [5,6].

Other models implement additional markers to potentially overcome this limitation, such as cluster-based marker sets [7,8]. Cluster-based models are less dependent on precise placement of the markers as they use marker clusters to track the segments and joint centres, as well as often allowing six degrees-of-freedom (6DoF) that treat body segments independent of each other [8]. Cluster models are thought theoretically to provide improvements in accuracy [8,9]; however, they are less practical compared to the CGM due to the extra markers, which increases the time required during participant preparation and data

* Corresponding author.
E-mail address: b.mentiplay@latrobe.edu.au (B.F. Mentiplay).

https://doi.org/10.1016/j.gaitpost.2018.05.033
Received 26 October 2017; Received in revised form 18 May 2018; Accepted 30 May 2018
0966-6362/

analysis.

Previous research has shown similarities between the CGM and cluster-based models for kinematics and kinetics [8–12]. Stronger agreement between models has been shown for the sagittal plane compared to coronal or transverse planes [8–12]. Other research has also examined the test-retest (or inter-session) reliability of various models, with higher reliability shown in the sagittal plane compared to the other planes [1]. Previous work has examined differences in test-retest reliability between the CGM and cluster models [8,13], with high reliability between sessions found for both the CGM and cluster-based models. Some slight differences were found between models, although overall neither model showed stronger reliability [8,13].

The CGM commonly uses direct kinematic (DK) computation methods, which assumes the markers are rigidly attached to the segments and allows for only 3DoF [14]. However, two other computational methods are available including segment optimisation, that assumes a rigid segment, treats each segment individually and often allows for 6DoF (e.g. cluster models), and global optimisation, also known as inverse kinematics (IK) [14–16]. IK computes a 'best match' between the actual markers and the model determined markers [14,15], which therefore allows for errors in the actual marker locations. IK may provide improved accuracy as it has the potential to minimise errors such as soft tissue artefact [17]. One previous study by Mantovani and Lamontagne [15] examined the impact of IK on three various marker sets and found high agreement between the models for kinematic outcomes in the sagittal plane, but not in the coronal and transverse planes. Another study by Kainz et al. [14] found large differences between models with different reference frames and joint constraints, although the difference solely caused by the computational method (DK versus IK) was very small. Other studies have examined the reliability of various models with DK, 6DoF and IK during walking [13,18]. One recent study in children showed similar reliability between various models using DK, 6DoF and IK [13], while another study on one participant showed the CGM with IK to provide improved repeatability compared to the CGM with DK [18].

As there currently exists a plethora of gait models with varied anatomical definitions, joint constraints and computational methods, the aim of the current study was to examine the test-retest reliability of, and agreement between, kinematics and kinetics from two specific custom lower limb gait models created in Visual3D, a modified CGM with 6DoF and a cluster-based model with 6DoF, as well as using IK computational methods for both models. This comparison of models with 6DoF and IK may provide information on where the better placement of markers is for tracking when using these computational methods. Based on similar previous research, it was hypothesised that all models would have strong agreement and similar test-retest reliability for both kinematics and kinetics, with higher agreement and reliability shown for the sagittal plane.

2. Methods

2.1. Participants

A convenience sample of healthy participants were recruited who were ≥ 18 years, had no recent lower limb injury (e.g. hamstring strain) or medical comorbidity (e.g. arthritis) that would affect their gait pattern. Procedures were approved by the university ethics committee and participants provided written informed consent.

Portney and Watkins [19] suggest that intraclass correlation coefficient (ICC) values ≥ 0.75 should be interpreted as indicating good reliability. To ensure our values exceeded 0.75, this study was powered to detect an ICC of 0.85 with a confidence interval of ± 0.1. Consequently, based on a power calculation [20], 30 participants were required.

2.2. Gait models

Varied implementations of the lower limb CGM include differences in the pelvis model (three or four markers), the definition of the hip joint centre (e.g. Bell and Brand [21,22], Davis [3]), the use of a knee alignment device [23], the use of wand markers, or the use of medial knee and ankle markers. We chose methods that were simple to implement for participant preparation and processing, which may differ from other implementations of the CGM. The hip joint centre was defined using the Davis regression equations [3]. No knee alignment device was used, the lateral thigh and shank markers were placed directly on the skin rather than wands [24], and medial markers on the epicondyles and malleoli were used to define the knee and ankle joint centres [25]. The cluster-based lower limb gait model was similar to previous models [8], with markers placed directly on the skin and not on rigid plates. The cluster model used the Bell and Brand regression equations for the hip joint centre definition [21,22], which was different from our modified CGM. Further details of the implementation of each model is provided in Supplementary material 1.

2.3. Computational methods

All models were calculated in Visual3D version 5.01.6 (C-motion, Inc., Germantown MD, USA). Visual3D has two distinct computational methods for computing the position and orientation of a segment, segment optimisation (6DoF) or global optimisation (IK). Whilst the CGM commonly uses DK, the methods used in Visual3D for the CGM were chosen to best replicate DK methods even though segment optimisation was used. It is acknowledged that, as Visual3D does not allow for DK methods, the modified CGM used in this study would differ from the standard implementations of the CGM using Vicon or other processing software. For the purposes of this study, both the modified CGM and cluster model used 6DoF and IK. For the joint constraints, both the CGM and the cluster model allowed 6DoF. The IK models did not allow any translations between segments, with the rotation between segments restricted for knee varus-valgus and knee rotation. As such both IK models had 3DoF at the hip and ankle, with only 1DoF at the knee joint as per previous models [13]. All tracking markers had the same weighting. Further information for the methods used in Visual3D can be found in Supplementary material 1.

2.4. Procedure

Participants attended two identical testing sessions separated by seven days. The laboratory contained a 9-camera Vicon system sampling at 100 Hz (Vicon, Oxford, UK) with a single embedded AMTI OR6-Series force plate sampling at 1000 Hz (AMTI, Watertown MA, USA), with data recorded using Vicon Nexus software (version 1.8.5). Forty-two reflective markers were placed on the lower body so that both gait models could be analysed concurrently (Supplementary material 1), with all marker placements performed by the same assessor (author BFM). The assessor has a PhD in Exercise Science and has been trained in three-dimensional gait analysis with three years of research and hospital experience prior to this study. Participants had a static trial recorded where they stood in the middle of the laboratory in an anatomical position, with instructions to stand in a comfortable position with feet shoulder width apart and palms facing forward. Participants then completed a series of walking trials at a habitual pace, with instructions to 'walk at a comfortable pace'. Trials were only recorded when the participant walked in the same direction across the laboratory, and were deemed successful when a clear foot placement on the force plate was visually observed and confirmed by replaying the trial. Five successful trials were recorded for each session and only the right limb was assessed.