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Agreement of spatio-temporal gait parameters between a vertical ground reaction force decomposition algorithm and a motion capture system

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ABSTRACT

Introduction: A ground reaction force decomposition algorithm based on large force platform measurements has recently been developed to analyze ground reaction forces under each foot during the double support phase of gait. However, its accuracy for the measurement of the spatiotemporal gait parameters remains to be established.
Objective: The aim of the present study was to establish the agreement between the spatiotemporal gait parameters obtained using (1) a walkway (composed of six large force platforms) and the newly developed algorithm, and (2) an optoelectronic motion capture system.
Methods: Twenty healthy children and adolescents (age range: 6–17 years) and 19 healthy adults (age range: 19–51 years) participated in this study. They were asked to walk at their preferred speed and at a speed that was faster than the preferred one. Each participant performed three blocks of three trials in each of the two walking speed conditions.
Results: The spatiotemporal gait parameters measured with the algorithm did not differ by more than 2.5% from those obtained with the motion capture system. The limits of agreement represented between 3% and 8% of the average spatiotemporal gait parameters. Repeatability of the algorithm was slightly higher than that of the motion capture system as the coefficient of variations ranged from 2.5% to 6%, and from 1.5% to 3.5% for the algorithm and the motion capture system, respectively.
Conclusion: The proposed algorithm provides valid and repeatable spatiotemporal gait parameter measurements and offers a promising tool for clinical gait analysis. Further studies are warranted to test the algorithm in people with impaired gait.

1. Introduction

Gait analysis, including kinematic and kinetic aspects of gait, is used to recommend therapeutic interventions [1] or to monitor the effect of an intervention on gait [2]. However, full gait analysis is time consuming and requires expensive devices as well as well-trained technicians [3]. The clinical need for simpler over-ground gait analysis instruments has driven the development of new tools, such as pressure sensor mats [4] or accelerometer-based devices [5]. Most of these systems measure spatiotemporal gait parameters (e.g., step length and time), which provide easy to collect and useful gait information, because spatiotemporal gait parameters are related to functional conditions such as risk and fear of falling [6], risk of cognitive decline and dementia [7] and early risks of mortality [8]. Spatiotemporal gait parameters are also useful to

Abbreviations: COP, center of pressure; CI, confidence interval; CV, coefficient of variation; GRF, ground reaction force; ICC, intra-class correlation coefficient; LoA, limit of agreement; SD, standard deviation; vGRF, vertical ground reaction force.

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monitor disease progression or in assessing the efficiency of a surgical or physical intervention [9]. However, most of these methods provide little or no information on the kinetic aspects of gait even though ground reaction forces (GRFs) are of major importance to characterize gait [10]. During the stance phase of a healthy walking cycle, vertical ground reaction forces present a characteristic sinusoidal curve with a typical 'double bump' [10]. Vertical ground reaction forces (vGRF) are also characterized by low intra-participant variability and high inter-limb symmetry [11]. In rehabilitation, the amount of weight bearing during walking is crucial after many orthopedic interventions on the lower extremities, as non weight bearing or excessive weight bearing can both lead to complications [12]. For this reason and given the consistent characteristics of vGRF mentioned above, this parameter is often used to assess gait asymmetry and joint loads in pathological populations such as cerebral palsy [13] or stroke [14].

Traditionally, to measure GRFs during walking the participant must place two consecutive steps on individual force platforms with no foot contact outside the surface of the platform. A large number of trials can be necessary before achieving valid measurements because it is key that participants do not voluntarily 'target' the force plate by adapting their step length [15]. Such targeting has been cited as a major limitation of gait studies [16] because it can modify both the vertical and horizontal component of GRFs [17–19]. Targeting also alters spatiotemporal parameters of the targeted steps as well as several steps preceding and following the target area [20].

An option to overcome the targeting problem is the use of large force plates, which offer many advantages over smaller ones. For instance, large force plates are easier to hit while walking, which reduces the time needed to gather the required valid trials. They are also more versatile as they can be used for large human movements such as manual materials handling [21] or for fast human movement such as running and jumping [22]. However, one important limitation of large force plates is their incapacity in dissociating the forces generated by both feet individually when they hit the platform simultaneously. To overcome this limitation Davis and Cavanagh [23] developed a method that uses force data measured with a single large force plate to decompose the left and right GRF profiles during the double support phase of walking and to determine the spatiotemporal gait parameters from the global values of the GRF. Nevertheless, the robustness of the method has not been extensively tested, and the variation in intra-subject gait pattern has not been taken into account in the method validation process.

Providing a valid algorithm that could decompose GRFs measured by large force plates would allow minimizing the number of walking trials which is critical in many clinical settings as fatigue may affect results [24]. It would be innovative to have a device not limited to the measurement of the vertical GRF under each foot but that can also estimate spatiotemporal gait parameters, without any additional equipment on the subject and with a minimum time requirement. Recently, Ballaz et al. [25] developed an algorithm (referred to as the 'force decomposition algorithm' throughout the remaining of the manuscript) which uses single large force platform measurements to estimate spatiotemporal gait parameters as well as the left and right vertical ground reaction forces. The original description of the method validated the decomposition of vertical force into left and right GRFs [25], but the validity of this method to determine the spatiotemporal gait parameters remained to be tested. Consequently, the primary aim of the present study was to assess the agreement between the spatiotemporal gait parameters obtained with the approach developed by Ballaz et al. [25] and those measured with optoelectronic (3D) motion capture system, viewed as a 'gold standard' method [4,26,27]. The secondary aim was to determine the intra-session repeatability of both methods.

2. Method

Twenty healthy children and adolescents (age range: 6–17 years; mean age [standard deviation; SD]: 10 [3] years; mean height [SD]: 1.46 [0.17] m; mean body mass: 40 [14] kg; 14 males) and nineteen healthy adults (age range: 19–51 years; mean age [SD]: 26 [8] years; mean height [SD]: 1.59 [0.09] m; mean body mass: 67 [12] kg; 8 males) participated in this study. Participants were recruited from hospital and research staff and students. This study was approved by the ethics committee of the Sainte-Justine University Hospital Research Center. Informed consent was provided by participants or for minors by their parents. Assent was provided by participants aged 7–17 years.

2.1. Measurement equipment

2.1.1. Force measuring walkway

Vertical GRFs were recorded using the Leonardo Mechanograph® Gangway system (Novotec Medical GmbH, Pforzheim, Germany) sampled at 800 Hz, as described in detail elsewhere [28,29]. Six force plate modules (dimensions of each module:150 cm long × 78 cm wide × 7 cm high) were placed on the floor to form a 9 m long walkway on which ground reaction forces were measured. A 2 m long custom-build wooden platform was added at the end of the walkway in order to obtain at least a 10 m long walkway, the length classically used in clinical gait analysis [3]. The first two meters of the walkway allowed participants to accelerate and reach steady state walking velocity whereas the last two meters of the walkway were used to decelerate. This allowed us to assess gait during steady state walking [4].

2.1.2. Optoelectronic motion capture system

Displacement of the lower legs and the feet in space and time were measured using an 8-camera motion capture system sampled at 60 Hz (Vicon®, 512, Oxford Metrics, Oxford, United Kingdom). Six reflective markers were placed by the same experienced examiner on the lower limbs at the following anatomic landmarks: lateral malleoli, heels and second metatarsals, as usually done to assess spatiotemporal gait parameters with an optoelectronic motion capture system [30]. To ensure that gait cycles measured by the motion capture system corresponded to that of the force measuring gangway system, 2 reflective markers were placed on each corner of the third walkway platform. This served as a spatial landmark which was used to detect the first step that was concurrently measured by the motion capture and walkway system. Using this approach, spatiotemporal parameters were calculated on the same steps with each of the two methods.

2.2. Test procedure

For each participant, the experimenter provided a description of the procedure and a task demonstration. The force measuring platform was zeroed before a participant stepped onto it. Participants performed the walking trials in two different conditions: at a normal/preferred speed ('Preferred' condition) and at a speed that was faster than your preferred speed ('Faster' condition). Different walking speeds were tested because walking speed is known to influence GRFs [31]. Prior to the beginning of testing, the participant received one of the two following instructions depending on the testing condition: "Start walking at your preferred speed or a speed comfortable for you. The test