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Prediction of ground reaction forces for Parkinson's disease patients using a kinect-driven musculoskeletal gait analysis model

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ABSTRACT

Kinetic gait abnormalities result in reduced mobility among individuals with Parkinson's disease (PD). Currently, the assessment of gait kinetics can only be achieved using costly force plates, which makes it difficult to implement in most clinical settings. The Microsoft Kinect v2 has been shown to be a feasible clinic-based alternative to more sophisticated three-dimensional motion analysis systems in producing acceptable spatiotemporal and kinematic gait parameters. In this study, we aimed to validate a Kinect-driven musculoskeletal model using the AnyBody modeling system to predict three-dimensional ground reaction forces (GRFs) during gait in patients with PD. Nine patients with PD performed over-ground walking trials as their kinematics and ground reaction forces were measured using a Kinect v2 and force plates, respectively. Kinect v2 model-based and force-plate measured peak vertical and horizontal ground reaction forces and impulses produced during the braking and propulsive phases of the gait cycle were compared. Additionally, comparison of ensemble curves and associated 90% confidence intervals (CI90) of the three-dimensional GRFs were constructed to investigate if the Kinect sensor could provide consistent and accurate GRF predictions throughout the gait cycle. Results showed that the Kinect v2 sensor has the potential to be an effective clinical assessment tool for predicting GRFs produced during gait for patients with PD. However, the observed findings should be replicated and model reliability established prior to integration into the clinical setting.

1. Introduction

Parkinson's disease (PD) currently affects 10 million people worldwide including one million Americans, and the number of newly diagnosed cases is on the rise [1]. The particular reduction in mobility experienced by patients with PD is commonly characterized by rigidity and gait impairments [2–4], which causes significant loss of independence and increased incidences of falls. These gait impairments results from the progressive loss of dopamine producing cells in the substantia nigra compacta of the basal ganglia [5,6].

Subjective gait assessment approaches, commonly used by clinicians to examine gait patterns of individuals with PD, have been shown to be unreliable [7]. Therefore, achieving accurate gait analyses for PD patients in clinical settings require combining both subjective and objective assessments [8]. Furthermore, gait, which is a particular semiautomatic motor task, is specifically sensitive to the *on* and *off* Parkinsonian states. Thus, to precisely delineate the temporal evolution of gait-related complications, their characteristics, and their severity, more objective instrumental methods are needed. Currently, there is no marker-less and cost-effective gait analysis tool that can be used on a regular basis to assess gait patterns of patients with PD during both *on* and *off* states in clinic and home settings.

The importance of kinetics, and therefore vertical ground reaction forces (GRFv) to assessment of gait is evidenced in the literature. Morris et al. [6] indicated that analyzing changes in kinetics is necessary to provide a full understanding of the primary determinants of PD gait dysfunction. They noted that although kinematic and spatiotemporal gait parameters can be provided using visual cues, the kinetics of gait abnormalities is a necessary component in determining the reason for unexplained falls, as noted by researchers who have assessed fall probability in the elderly [9].

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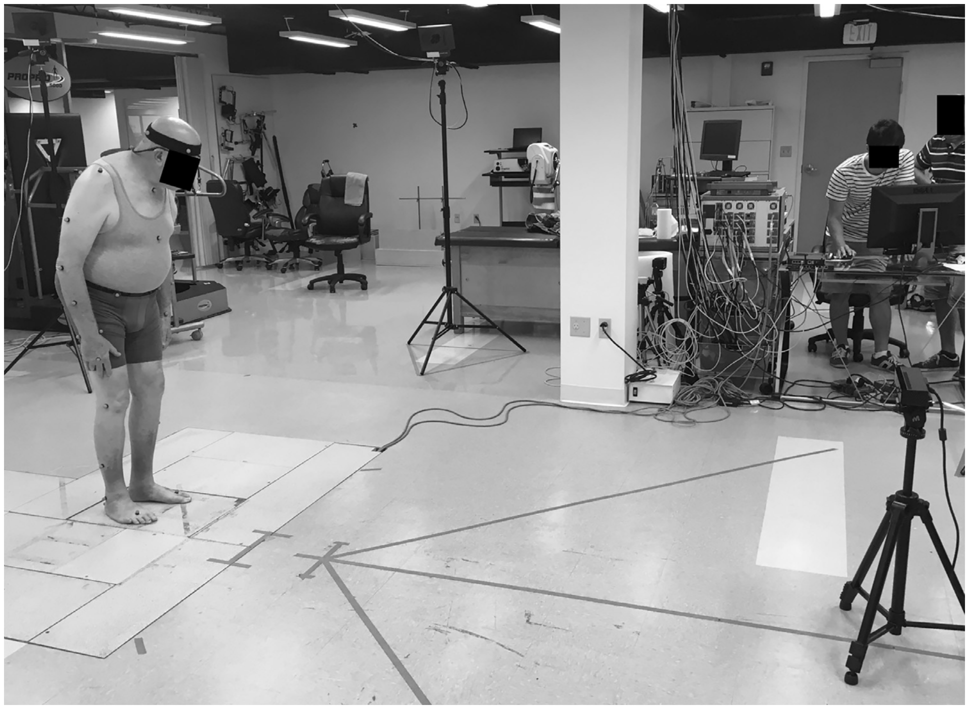

Fig. 1. The experimental setup with the two floor-impeded force plates and the Microsoft Kinect v2 sensor placed in front of the subject's direction of progression and at a height of 0.75 m from the ground.

Kinetics measures, such as the pattern of the vertical ground reaction forces (GRF_V) during gait in PD patients, can be used as an indicator of the stage the disease [10]. For instance, both GRF_V peak values are reduced in the early stages of the disease, while in more advanced stages the GRF_V pattern is characterized by only a single narrow peak [11].

Additionally, patients with PD have difficulty with both rapid force production and declination, since rapid gait termination requires concurrent increases in braking impulse and decreases in propulsion impulse. Bishop et al. [12] investigated the net braking impulse using horizontal ground reaction forces (GRF_{AP}) when braking impulse rapidly increases and propulsion impulse decreases during unplanned gait termination in patients with PD. They showed that patients with PD are less capable of generating sufficient net braking impulse in time-critical situations than age-matched healthy subjects.

Furthermore, a number of researchers used ground reaction forces to develop automatic classifiers of gait patterns in patients with PD. Manap et al. [13] used GRF_V and other kinematic parameters to classify PD gait; and in a follow-up study [14], they utilized only the GRF_V peak values during initial contact, mid-stance, and toe off to detect gait irregularities in PD patients. Additionally, Dubey et al. [15] used artificial neural networks to distinguish between normal and PD gait patterns using GRF_V; while Zhang et al. [16] developed a sparse representation method utilizing the patient's GRF_V to detect Parkinsonian gait. The main drawback of these studies, designed to analyze gait patterns and develop auto-classifiers of Parkinsonian gait using GRF, was that they required the use of floor-embedded force platforms, which makes them an impractical solution for clinical implementation.

Despite the alarming increase in the number of PD patients in the US [1]; clinicians still rely on subjective tools such as the Unified Parkinson's Disease Rating Scale [17] to determine the presence and severity of the disease, and these methods often return inconsistent diagnoses [18]. Alternatively, gait analysis using laboratory-based motion capture systems can quantitatively assess the severity and progress of the disease [19]; yet, due to the financial burden, technical challenges, lack of portability, need for relatively large space, and comprehensive setup requirements associated with its use, this approach remains difficult to adopt in clinical settings [20,21]. On the other hand, wearable sensors used to measure joints kinematics such as skin-attached optical tracking devices [22] and Inertial Measurement Units [23] can interfere with the movement performed, especially for those already suffering from gait impairment, and IMUs are known to suffer from technical issues such as interfering with surrounding magnetic fields. Also, both systems suffer from motion artifacts, where a translational displacement between bony landmark and the attached sensor is likely to occur, causing errors in estimating position during movement, which in turn leads to inaccuracies in determining joint angles. Although the IMUs measure orientation rather than position, errors related to movement can however still occur because of rotational displacement of the sensor relative to the segment [24]. Additionally, assessment of the kinetic measures produced during gait using floor-impeded force plates is affected by on the patient's foot placement over the force plate, while also the use of pressure mats limits the patient to walk within a limited width of the mat [25].

The use of the Kinect v2 in performing three-dimensional spatiotemporal and kinematics analysis was previously validated in various applications such as treadmill gait [26] and over-ground gait [27] analyses. Therefore, this paper will validate a full-body musculoskeletal model, driven by the Microsoft Kinect v2, to derive the ground reaction forces produced during over-ground gait for patients with PD. This will be achieved by comparing a number of calculated measures of the ground reaction forces to the values measured using floor-imbedded force plates. These measures will include; the peak braking and propulsive vertical and horizontal forces commonly used as automatic Parkinsonian gait classifiers [14–16], patterns of the three ground reaction forces using ensemble curves, and a single step GRF symmetry index [28] computed

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