Journal of the Neurological Sciences 368 (2016) 337–342

Contents lists available at ScienceDirect

Journal of the Neurological Sciences

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

Characterization of multi-joint upper limb movements in a single task to assess bradykinesia

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ARTICLE INFO

Article history:
Received 28 March 2016
Received in revised form 7 July 2016
Accepted 25 July 2016
Available online 26 July 2016

Keywords:
Parkinson's disease
Bradykinesia
Rapid alternating movements
Kinematics

ABSTRACT

Bradykinesia is a disabling symptom of Parkinson's disease (PD) which presents with slowness of movement. Visual assessment using clinical rating scales is currently the gold standard to assess bradykinesia. Such assessments require multiple separate movements, are subjective, and rely on the ability of the rater to determine frequency and amplitude features of excursion of multiple joints simultaneously.

The current study introduces the use of wearable inertial measurement units (IMUs) to characterize full-arm repetitive movements and provide a new index score for bradykinesia severity (BKI) in the upper limbs. The BKI provides an approach to measuring bradykinesia reliably and objectively. Importantly, this index is needed to demonstrate separability between healthy individuals and PD participants, and also between bradykinetic and non-bradykinetic PD participants.

Thirteen PD participants and ten age-matched healthy control participants were studied. Using a single upper limb task that activated multiple joints and recordings from angular displacements from all joints, features relevant to demonstrating bradykinesia were extracted and systematically combined to create the total BKI. A strong correlation coefficient was obtained comparing BKI to upper limb UPDRS bradykinesia scores ($r_s = -0.626$, $p = 0.001$). The BKI successfully identified differences between control and PD participants ($p = 0.018$). The BKI was also sensitive enough to identify differences within the PD population, separating PD participants with and without bradykinesia ($p < 0.001$).

This study demonstrates the feasibility of using IMU-based motion capture systems and employing the new BKI for quantitative assessment of bradykinesia. This approach when generalized to lower extremity and truncal movements would be able to provide an objective and reproducible whole body bradykinesia index.

1. Introduction

Bradykinesia is recognized as the most reliable diagnostic clinical sign of Parkinson's disease (PD), traditionally interpreted as the slowness of voluntary movements with progressive reduction in speed and amplitude of repetitive and sequential actions [1,2,3]. Bradykinesia is commonly assessed using clinical scales such as the Unified Parkinson Disease Rating Scale – Part III (UPDRS-III) [4] by the visual examination of three repetitive motor tasks, including pronation and supination of forearm, opening and closing of fist, finger tapping in the upper limb and foot tapping in the lower extremity [5]. These tasks are appropriate since they are rarely affected by dyskinetic movements.

These tasks are evaluated based on the slowness and hesitation (speed) of the performance of the motor task, as well as decline in the smoothness and amplitude of the movement [4,5]. The performance of the patient is then rated on a scale ranging from zero (normal) to four (very severe). The scores rely on the observer and the skill of the observer's evaluation of a frequency and amplitude decrement, at multiple joints, simultaneously leading to a high degree of subjectivity in the assessment results [4,6]. Therefore such clinical scales are affected by inter- and intra-raters variability and may not detect subtle treatment-related changes over-time [7].

The three different tasks are performed largely for assessing different joints individually. Although in the pronation-supination task the wrist, elbow, and the shoulder joints' movements occur together, it is visually impossible to assess the amplitude and frequency simultaneously. Thus, although upper limb bradykinesia could be assessed with only one maneuver, several actions that assess different joints have to be

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http://dx.doi.org/10.1016/j.jns.2016.07.056
0022-510X/

Table 1
Participants' demographics.

	Participant groups		
	Control ($n = 10$)	PD ($n = 13$)	p value
Age (yrs), mean (SD)	64.90 (3.91)	63.69 (5.65)	0.944
Females, n (%)	6 (60%)	5 (38%)	0.302
PD Duration (yrs), mean (SD)	–	10.31 (3.83)	–
*LED (mg/day), mean (SD)	–	1374.13 (477.34)	–
UPDRS ON score, mean (SD)	–	22.10 (14.08)	–

* Levodopa equivalency dosage; calculation for LED was based on a standardized formula from literature by Tomlinson et al. [21].

used clinically, further adding to the potential for error in measurements and reproducibility.

The subjectivity of measurement of bradykinesia by movement disorder experts and especially non-experts can have direct impact on the quality of the assessment, diagnosis, follow-up evaluation and hence treatment of PD patients. Similarly, important assessment endpoints in clinical trials can be impacted by these variabilities. The use of technology-based tools has become increasingly popular for making such assessments objective [4,8,9]. A limited number of commercial movement analysis systems are available for remote-monitoring of PD patients, including: Opal wearable sensors [10,11], Kinesia system [12,13], and the Motus Movement Monitor [10,14]. Optical 3D motion trackers are also available in lab environments [15]. However, these systems are relatively stationary and need to be used in a lab environment or are able to only assess single joints or limbs, although some are expandable [16]. Developing an accurate, portable, and easy-to-use tool using novel wearable technology which is paired with intelligent software still remains an unmet need. Such development would enable health professionals to consistently and reliably monitor bradykinesia in clinic as well as remotely.

Furthermore, the outputs of measurement systems need to be clinically relevant and easily interpretable for the clinicians to make therapeutic decisions. Such technology can immediately be used for monitoring patients' progress and track motor changes after treatment, enabling individualized therapy and improving patient quality of life.

Inertial measurement units (IMUs) which employ Attitude and Heading Reference Systems (AHRS) are emerging technologies, proposed as an alternative to optical motion capture systems [16]. Such technologies have recently been evaluated and used for applications such as tele-rehabilitation [16–18]. Previous studies have used single IMUs, mostly on the participants' hand, to assess bradykinesia [4]. IMUs have the added benefit of assessing bradykinesia on a continuous scale rather than an ordinal scale to capture small changes through the use of bradykinesia relevant features, such as root-mean-square (RMS) of angular velocity [8], hand activity [19], and modified mean range [20]. However, no global index for bradykinesia that includes multiple upper limb joints has to date been developed. Due to this, full limb bradykinesia has not been examined and characterized in the literature.

This paper outlines four main research results: [1] evaluation of a single movement (henceforth deemed the pronation-supination task) of the upper limb motion to assess multi-joint upper limb bradykinesia in PD; [2] use of wearable IMUs to record this motion and reliably generate a bilateral whole upper limb bradykinesia index (BKI); [3] show correlation of the BKI to the standard UPDRS measure; [4] demonstrate the ability of the BKI to clearly separate bradykinetic PD participants from controls and non-bradykinetic PD participants.

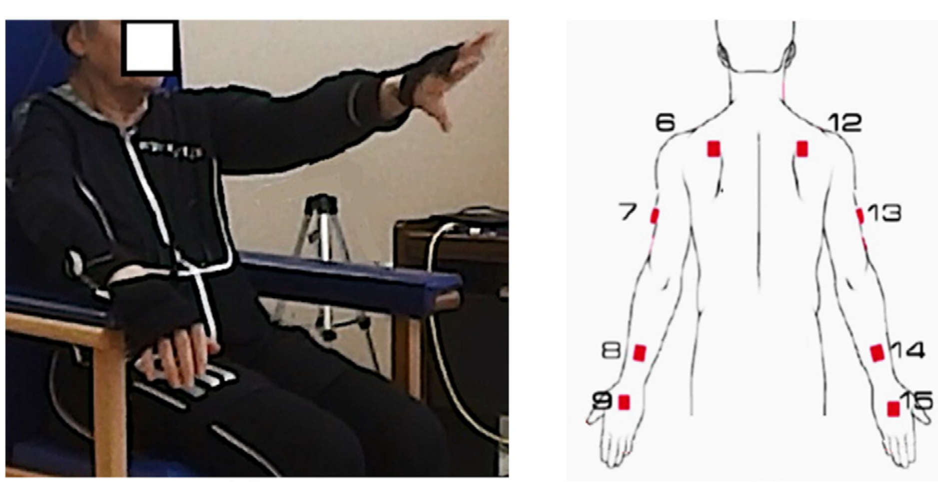
2. Methods

2.1. Participants

Thirteen PD participants and ten healthy controls participated in the study (Table 1). All PD participants were assessed in their best-on state. The inclusion criteria for the PD participants were: [1] idiopathic Parkinson's disease, [2] Hoehn-Yahr stage II–III, [3] no dementia or psychiatric abnormalities, [4] able to give informed consent, and [5] able to visit the clinic for assessment. Control participants were healthy and age-matched with no dementia or psychiatric abnormalities. The study was approved by the Research Ethics Board (REB #103928) at Western University and all participants provided their written informed consent prior to participation.

2.2. Assessment and study timeline

To quantify and evaluate bradykinesia, a wearable motion capture system (Synertial IGS-180, UK – Fig. 1). The system integrates 3D



(a) (b)

Fig. 1. (a) Assessment of repetitive rotation task in Synertial motion capture suit, (b) position of the IMU sensors on the upper limbs.