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Research report

# Compensatory postural adjustments in Parkinson's disease assessed via a virtual reality environment

Darya Yelshyna[a], Miguel F. Gago[b,c,d,*], Estela Bicho[a], Vítor Fernandes[a], Nuno F. Gago[a], Luís Costa[a], Hélder Silva[a], Maria Lurdes Rodrigues[b], Luís Rocha[a], Nuno Sousa[c,d]

[a] Algoritmi Center, Department of Industrial Electronics, School of Engineering, University of Minho, Braga, Portugal
[b] Neurology Department, Centro Hospitalar do Alto Ave, EPE, Guimarães, Portugal
[c] Life and Health Sciences Research Institute (ICVS), School of Health Sciences, University of Minho, Braga, Portugal
[d] ICVS-3Bs PT Government Associate Laboratory, Braga/Guimarães, Portugal

## HIGHLIGHTS

- Virtual reality allows the analysis of compensatory postural adjustments (CPA).
- IPD patients are highly susceptible to visually induced destabilization.
- CPA is modulated by mechanisms related to different time scales.
- Levodopa treatment increases the stabilizing effect by means of low frequencies CPA.

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## ABSTRACT

Postural control is a complex dynamic mechanism, which integrates information from visual, vestibular and somatosensory systems. Idiopathic Parkinson's disease (IPD) patients are unable to produce appropriate reflexive responses to changing environmental conditions. Still, it is controversial what is due to voluntary or involuntary postural control, even less what is the effect of levodopa. We aimed to evaluate compensatory postural adjustments (CPA), with kinematic and time-frequency analyzes, and further understand the role of dopaminergic medication on these processes. 19 healthy subjects (Controls) and 15 idiopathic Parkinson's disease (IPD) patients in the OFF and ON medication states, wearing IMUs, were submitted to a virtual reality scenario with visual downward displacements on a staircase. We also hypothesized if CPA would involve mechanisms occurring in distinct time scales. We subsequently analyzed postural adjustments on two frequency bands: low components between 0.3 and 1.5 Hz (LB), and high components between 1.5 and 3.5 Hz (HB). Vertical acceleration demonstrated a greater power for discriminating IPD patients from healthy subjects. Visual perturbation significantly increased the power of the HB in all groups, being particularly more evident in the OFF state. Levodopa significantly increased their basal power taking place on the LB. However, controls and IPD patients in the ON state revealed a similar trend of the control mechanism. Results indicate an improvement in muscular stiffness provided by levodopa. They also suggest the role of different compensatory postural adjustment patterns, with LB being related to inertial properties of the oscillating mass and HB representing reactions to the ongoing visual input-changing scenario.



## 1. Introduction

Postural control is a complex dynamic mechanism, which integrates information from visual, vestibular and somatosensory systems, with the central nervous system (brain and spinal cord) adapted to the musculoskeletal system status (muscles, bones, tendons and ligaments). Even during quiet standing, beside the mechanical antero-posterior, ankle strategy, and the medial-lateral hip strategy, the center of mass (COM) is also continuously controlled by a central nervous system (CNS) time-delayed feedback loop, in reaction to predictable and unpredictabe postural perturbations [1]. Anticipatory (APA) and compensatory postural adjustment (CPA) strategies are the two main mechanisms used

* Corresponding author at: Neurology Department, Centro Hospitalar do Alto Ave, Rua dos Cutileiros, Creixomil. 4835-044 Guimarães, Portugal.
*E-mail address:* miguelfgago@yahoo.com (M.F. Gago).

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by the CNS in order to deal with body perturbations that may either be internally generated (e.g., self-initiated movements) or externally generated (e.g., being pushed at shoulder level while walking) [2]. When postural perturbation is unpredictable, postural muscles are activated to restore stability after the moment of perturbation. These later responses (CPA) are triggered by sensory feedback signals and help in dealing with the actual effects of a perturbation [3,4]. While APA are observed only in the case of predictable perturbations, CPA are seen during both, predictable (following APA) and unpredictable perturbations. Often CPA are of larger magnitude in response to unpredictable perturbations [5].

The body schema is a perception of one's body in space and body parts associated with movement and is influenced by visuomotor processing. The temporoparietal cortex, including the posterior parietal cortex and the vestibular cortex, appears to integrate real-time signals in the visual, proprioceptive, and vestibular sensations so that the body schema can be always updated. [6]. Absence or degradation of any type of sensory input may affect balance performance. The latter is commonly observed with aging, leading to increased instability, falls and consequent injuries [7–9]. Disorders such as Idiopathic Parkinson Disease (IPD) further aggravate balance disturbances of elderly population [10,11]. Deficiency in the information processing from the temporoparietal cortex to the frontal cortex may cause errors in APA, CPA and gait difficulties, such as the "freezing of gait" [6].

Postural control is compromised in subjects with untreated IPD due to disturbed postural reflexes, poor control of voluntary movements, orthostatic hypotension and side effects of certain medications that include dyskinesia [12]. Compared to healthy elderly adults, IPD patients are unable to produce appropriate reflexive responses to changing environmental conditions. In IPD, besides motor deficits contribution, postural impairment is also associated with abnormal spatial and temporal processing of sensory information, producing incorrect signals for the preparation and execution of voluntary movement [11,13]. It has been established that APA and CPA are compromised in IPD, with patients not only having difficulty switching between postural strategies, but also being unable to appropriately scale the size of their postural responses to the size of environmental change [14–17]. Discrepancies of reports, with IPD patients presenting larger or decreased sway, are probably due to differences in voluntary and involuntary posture postural control and/or study design [18]. Moreover, effects of levodopa treatment are controversial. Some studies found a worsening of sway abnormalities in view of increased sway area and reduced mean velocity [19,20], while others report a larger and a faster sway [21,22]. Regarding CPAs, levodopa has been reported not to improve slower CPAs on IPD patients and theirs difficulty in using cognitive set to modify responses to surface perturbations [15]. In fact, levodopa therapy can compromise the immediate postural adaptation and refinement of postural strategy, changes in amplitude of vertical ground reaction forces and forces applied to support apparatus within conditions between the initial and final trials, that is present on the OFF state and on healthy subjects [23].

In the last years, the impact of visual perturbation on postural adjustments has been widely explored. Visual deprivation during quiet stance eliminates one of the inputs to the control mechanism, producing a destabilizing effect. This process results in an increasing need for postural adjustments, affecting in a larger scale elderly impaired subjects [8,24,25] Susceptibility to visual stimulation has been studied in several conditions, such as visual focus on differently distanced targets [26] or exposal to a moving surround, which in most recent researches, was implemented through an immersive virtual scene allowing for a better perception of the induced motion. This virtual reality creates an illusion that puts the subject in a different place other than where she/he physically is [27]. Besides inducing self-motion illusion, moving visual surround conflicts with perceptions from somatosensory and vestibular systems, since the body has not actually moved. As a consequence, the body generates CPA in the direction of the visual perturbation [28,29].

Balance integrity is most commonly assessed by kinetic and kinematic analyzes [30]. Estimates of center of pressure (COP) trajectory derived from force platforms have been extensively used to compute stationary sway measures, presented in time and frequency domains [7]. Recently, accelerometry emerged as an alternative technique to posturography, successfully exploiting the same measures with the advantages of lower cost, reduced size and portability. Inertial Measurement Units (IMUs), which include both accelerometers and gyroscopes, provide additional information about body tilt and orientation [31,32]. Stationary signal analysis provides insightful information regarding the postural control. However, it has long been demonstrated that this system is dynamically regulated [33]. An appropriate non-stationary technique should be employed to characterize the existing spectral variations, such as time-frequency analysis [34] . Interestingly, numerous studies have also reported that these changes occur in two distinct time scales: a fast (high frequency) open-loop control and a slower (low frequency) corrective feedback-based control [1,35].

The primary objective of this research is to evaluate visually induced CPA in a changing virtual reality scenario, in healthy subjects (controls) and IPD patients, by means of kinematic and time-frequency analyzes of IMU records. As a second objective, we aim to understand the role of dopaminergic medication on postural adjustment mechanisms.

## 2. Methodology

### 2.1. Subjects and clinical assessment

The study protocol was derived from the ICVS-3Bs and the Algoritmi Center and was approved by the hospital local ethics committee. Written informed consent was received from all participants in the study. 15 patients and 19 controls were consecutively recruited from our Movement Disorders outpatient consult, fulfilling criteria for IPD (UKPDS Brain Bank criteria). IPD patients had normal clinical postural stability measured by the retropulsion test (item 12 on MDS-UPDRS-III), had an Hoehn &Yahr of 2 (OFF state). The exclusion criteria were dementia, orthopedic, musculoskeletal, vestibular disorder, significant auditory deficit, and alcohol abuse. Patients had no somatosensory deficit, on neurological examination, nor wore glasses or contact lens to correct vision. The collected variables consisted of demographic (gender, age, and education) and biometric data reported as influencing kinetic performance, such as weight, height, body mass index. Clinical data were also collected, including years of disease duration, Movement Disorder Society-Unified Parkinson's disease rating scale III (MDS-UPDRS III) (scored as either an in the OFF or in the ON state), levodopa equivalent daily dose [36], and morning levodopa challenge dose. A brief neuropsychological examination was performed using the Portuguese version of the Montreal Cognitive Assessment test (MoCA) with scores normalized to the Portuguese population [37] no more than 1 month prior to the kinetic assessment. The levels of education were categorized by years of schooling as follows: 0 (analphabetic), 1 (1–4 years), 2 (5–9 years), 3 (10–12 years), and 4 (>12 years).