The Potential of Visual Cues to Overcome Freezing of Gait in Parkinson's Disease*

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***Abstract*— Freezing of Gait (FOG) is arguably the most disabling motor dysfunction in Parkinson's Disease (PD), being pharmacological an unfeasible approach in the long-run, which justifies the emergence of non-pharmacological solutions. In fact, patients easily overcome FOG when it is provided a rhythmical temporal information (external cues), favoring a goal-directed gait (biofeedback systems). In this paper, it was intended to assess the tolerability and acceptability of a healthy group towards an augmented reality interface which aims to apply visual cues in temporal synchrony with heel-strike event by an augmented reality glasses. It is intended to be later assessed, the visual cues ability to facilitate motor activity in PD patients. The experimental setup comprised a group of 15 healthy subjects, being those instructed to perform a 30 m straight-walking along an unobstructed walkway, both in the presence of external cues and without any feedback applied. Questionnaires proven visual feedback to be perceived by the users with ease. Users reported interest and curiosity towards the system and proved to be keen to integrate the system into their daily life if they would ever face this disease.**

I. Introduction

Parkinson's Disease (PD) is a neurodegenerative disorder of the Central Nervous System that greatly impairs motor and non-motor functions, compromising gait activity and resulting in a substantial diminished degree of autonomy and independence in daily life activities [1]. Freezing Of Gait (FOG) is arguably the motor impairment with the most startling aftereffects, corresponding to an episodic, sudden, transient, unpredictable absence or marked reduction of forward progression despite the intention to keep moving [2].

FOG can be targeted via either a pharmacological or non-pharmacological approach. Currently, a levodopa-based medication is always adopted. Nevertheless, this approach is not feasible in the long-run to improve PD patients' quality of life, as a result of the decreasingly efficacy of the medication over the years and the lack of further scientific advances. Consequently, it does not alter the course of PD symptoms, and consequently, cannot prevent FOG [2], [3], [4], [5]. Following this line of thought, an increasingly attention has been given to non-pharmacological approaches, argued as a non-invasive and efficient method for helping PD patients improving motor symptoms and alleviating FOG episodes [5], [6]. General training exercises, physiotherapy, treadmill, robotic gait training, mechanical assistive devices, and systems based in biofeedback including virtual reality/augmented reality can be pointed out [5], [7]. Undoubtedly all these non-pharmacological approaches mentioned have proven to result in positive outcomes as far as improving gait impairments are related. Nonetheless, neither one of these approaches aside from biofeedback systems are capable of being integrated in the patients' daily life, as these techniques rely on a control environment and the involvement of specialized technicians. On the other hand, wearable biofeedback systems reached fever pitch these days due to its capability of ambulatory monitoring PD patients' gait and predicting/detecting FOG events, and consequently act upon those events to alleviate the burden.

In fact, patients present less difficulties in overcoming FOG when using external sensory cues through biofeedback systems. External cues stimulate the motor cortex to make up for the hypoactive/impaired basal ganglia-supplementary motor brain area, leading to a goal-oriented type of motor control, potentially overcoming FOG and facilitating motor activity in general [5].

The hypothesis underlying the use of external sensory cues via biofeedback systems lies on the evidence that PD is marked by severe deficits in temporal processing [8]. Two modes of timing, which are associated with distinct underlying neural networks can be pointed out: implicit and explicit timings [9]. On one hand, implicit timing takes advantage of external cues and relies on automatic timing systems, therefore characterized by a less self-aware character and less dependent of conscious time-based judgments. In this mode of timing, the subject depends on a regularly timed stimulus to make temporal predictions regarding future stimuli. Paradoxically, explicit timing is imperative for deliberate estimates of duration, being characterized by a more self-aware character. Studies shown that PD mostly impairs functions dependent on explicit timing. Nonetheless, patients still can perform temporal predictions based on implicit time. This way, sensory external cues can be provided to instruct the patients regarding a certain decision based on time, e.g. when the next step should occur, being possible to bypass the mostly impaired explicit timing through motor-sensory systems interaction [9], [10], [11]. Activating the neural network area responsible for implicit timing can favor the alleviating of FOG episodes' duration and severity. To activate such neural network area, the following biofeedback modalities

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can be implemented: visual feedback, acoustic feedback or vibrotactile feedback. Acoustic feedback implementation can be compromised in the presence of noisy environments, whereas the effect of vibrotactile feedback is strongly dependent on the specific characteristics of the vibratory stimulus (frequency and amplitude), being the users' sensitivity to the perceived frequency range variable [12]. Moreover, its perception strongly relies on the used outfit by the user. Based on these evidences, the choice lied on the appliance of visual feedback to achieve the desired purpose.

For this purpose, it is mandatory to develop an algorithm capable of identifying the gait cycle to apply the stimuli in temporal synchrony. In the scope of this study, an algorithm able of discriminating the heel-strike (HS) event was developed. Patients reported that during FOG they feel like their feet are glued to the ground, so it seems ideal to provide the stimulus exactly prior to the foot-flat, acting as pre-emptive approach.

Given this, in this paper, prior to evaluating the potential of visual cues provided by a wearable biofeedback system (augmented reality glasses – ORA2) to overcome FOG episodes, by exploiting the neural network underlying implicit timing, it is addressed the acceptability and tolerability of a healthy group towards the developed augmented reality interface and the augmented reality glasses themselves.

The outline of this system focused on mitigating the limitations present in the current biofeedback systems, never deviating our attention from the user-centered principle. The use of an augmented reality glasses ensures the fulfillment of crucial requirements: free hands concept, enable-multitasking, discrete/ergonomics, comfort. Additionally, the augmented reality interface was developed, considering a low cognitive effort by the user, which will be addressed in the next section.

II. Proposed Augmented Reality Interface

The augmented reality environment/interface to be presented to the patients by the ORA-2 should comply with some requirements to favor tolerability and acceptability by the end-users. Several systems exploiting virtual reality and augmented reality technologies fall short in result of the implementation of highly complex environments. Not only complex environments deviate the users' attention from the real-word, jeopardizing their safety, but also increases the cognitive demand. It is known that the stress induced by cognitive-demanding interfaces results in the inability to overcome FOG and even exacerbates these episodes [13].

Thus, ORA-2 accesses in real-time to the camera and projects the background (real world) onto the lens. Additionally, merely a green footprint is displayed superimposed on the background. This straightforward and non-obtrusive interface imposes no threat to the patients, allowing them to see real world with ease and, simultaneously, demanding a low cognitive effort by the user. Furthermore, a head movements compensation algorithm was embedded into the algorithm, in order to solely apply the visual cue when the user is facing the head towards the ground, favoring an even more user-friendly interface.

It is worthy of mention that a footprint was elected as the visual cue to be displayed, once it must have relevance to the action in cause (gait). Cues with relevance to the action in cause increase the chance of success, favoring a goal-directed gait. The reasons sustaining the choice of the green color are that the eye is most sensitive to a yellowish-green color under normal lighting conditions [14] and, green is commonly associated with a general perception of "go", as is the case of traffic lights.

Upon left HS occurrence, the system projects a right footprint to serve as a temporal and spatial guideline, indicating when to initiate the following step and where to place the foot. Once the right HS occurs, the left footprint is displayed and so on. External cues are applied in temporal synchrony with the HS event, inducing into the patients' physiological system a rhythmic temporal information capable of bypassing the impaired brain area. Discrete event-driven cues decrease the chance of the habituation phenomena [15]. For this purpose, it was developed a finite state machine-based algorithm capable of discriminating the gait events relying on a set of decision rules applied over accelerometer, gyroscope and magnetometer data.

Fig. 1b) presents the interface developed, aiming to provide visual stimuli accordingly to HS detections.

III. Validation

A. Subjects/Participants

The assessment of tolerability and acceptability towards the proposed interface comprised a group of 15 healthy subjects, being in Table I presented the morphological

a) b)

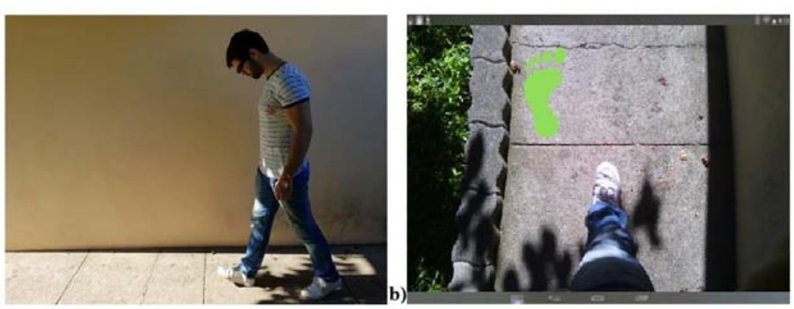

Figure 1. a) Photography displaying the HS event b) detection of the right heel-strike by ORA-2, and consequently display of the left footprint.

characteristics of the healthy group.

TABLE I. MORPHOLOGICAL CHARACTERISTICS (NUMBER, GENDER, MEAN AGE (± SD), MEAN WEIGHT (± SD) AND MEAN HEIGHT (± SD) OF THE INVOLVED HEALTHY SUBJECTS

Subjects	**Gender**		**Age**	**Weight**	**Height**
	Female	***Male***	**(years)**	**(Kg)**	**(m)**
Healthy	7	8	41.83±0.48	68.83±10.91	1.71±8.51

B. Experimental Setup

Subjects involved in the validation of the proposed system were invited to perform the following experiment-block:

- 30 m straight-walking along an unobstructed walkway, without any feedback applied;
- 30 m straight-walking along an unobstructed walkway, including feedback.

Each experiment was performed under three different conditions: walking slowly, comfortable walking speed and walking as fast as they safely could without running. Subjects undergone three trials to ensure data consistency and reliability. Prior to each trial, the system was removed from the patient and repositioned to assess test-retest repeatability.

Furthermore, subjects were asked to fill up a questionnaire inquiring about the system level of ergonomics, comfort, usability and feedback stimulus perception, in order to assess its potential for future integration in the patients' daily life.

These questionnaires allowed for a subjective analysis of the participants concerning the interface developed and whether the participants perceived correctly and effectively the feedback provided, being crucial to understand the users' feedback in order to make the necessary adjustments to meet the users' requirements and achieve an augmented reality interface that favours acceptance.

IV. QUESTIONNAIRES

Table II depicts the results obtained regarding the questionnaires carried out at the end of each experiment. It is inferred that the visual feedback stimulus presents, globally, a high perception by the users (4.33±0.58). Furthermore, the users presented a high degree of acceptability and tolerability towards the augmented reality glasses and its interface, as far as comfort and weight is concerned (4.33±0.58 and 4.33±0.58 respectively). Users reported the simplicity of the interface to be an interesting feature, as it increases the comfort conferred on users, by demanding a lower cognitive effort and, simultaneously, enabling the users to see the real-world obstacles with ease. Given this, users reported to be keen to integrate this system into their daily life tasks if they would ever face this disease (3.67±1.15).

TABLE II. SCORES OF THE SELF-ASSESSMENT QUESTIONNAIRES FOR THE ORA-2 (MEAN ± SD), BEING 1-NOTHING, 2-MEDIOCRE, 3-MODERATE, 4-HIGH, 5-VERY HIGH

Questions	**Scores**
Visual feedback perception	4.33±0.58
Comfort	4.33±0.58
Light	4.33±0.58
Usability/possible integration of the ORA-2 with visual feedback into their daily life tasks	3.67±1.15

V. CONCLUSION & FUTURE PERSPECTIVES

It is argued that activating the neural network area responsible for implicit timing can favor the alleviating of FOG episodes' duration and severity and favor a more self-sufficient motor activity.

Experimental tests were carried out in order to assess to what extend can an augmented reality interface capable of applying external cues be easily accepted by users.

In fact, users have shown interest in the system, raising pertinent questions and evidenced a high degree of acceptability and tolerability towards the implemented interface.

For future work, it is imperative to perform experimental tests with PD patients, and particularly freezers. For this purpose, in future experimental tests, it will be mandatory to include protocols with FOG-provoking tasks and a redefinition of the inclusion criteria must be done. The developed system will be evaluated in a multitasking context, considering its potential to trigger FOG. To demonstrate that activating the neural network responsible for implicit timing-based decisions by applying visual cues can in fact favor gait improvements, it will be necessary to address gait parameters computation.

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