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Editor's Comment: Smartphones have become ubiquitous in modern society and can be both an incredible convenience and an irritating intrusion. In this fascinating report, Ginis and colleagues provide us a potential use for smartphone technology that may favorably impact our ability to treat patients with Parkinson's disease. They describe the feasibility and effectiveness of a smartphone application, the CuPiD system, in a controlled clinical trial comparing the use of the CuPiD system with personalized gait advice, carried out in a home environment. The results of their study are both interesting and encouraging. Further study of this unique technology is clearly indicated and will be stimulated by this important report.

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Feasibility and effects of home-based smartphone-delivered automated feedback training for gait in people with Parkinson's disease: A pilot randomized controlled trial

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ABSTRACT

Background: Inertial measurement units combined with a smartphone application (CuPiD-system) were developed to provide people with Parkinson's disease (PD) real-time feedback on gait performance. This study investigated the CuPiD-system's feasibility and effectiveness compared with conventional gait training when applied in the home environment.

Methods: Forty persons with PD undertook gait training for 30 min, three times per week for six weeks. Participants were randomly assigned to i) CuPiD, in which a smartphone application offered positive and corrective feedback on gait, or ii) an active control, in which personalized gait advice was provided. Gait, balance, endurance and quality of life were assessed before and after training and at four weeks follow-up using standardized tests.

Results: Both groups improved significantly on the primary outcomes (single and dual task gait speed) at post-test and follow-up. The CuPiD group improved significantly more on balance (MiniBESTest) at post-test (from 24.8 to 26.1, SD~5) and maintained quality of life (SF-36 physical health) at follow-up whereas the control group deteriorated (from 50.4 to 48.3, SD~16). No other statistically significant differences were found between the two groups. The CuPiD system was well-tolerated and participants found the tool user-friendly.

Conclusion: CuPiD was feasible, well-accepted and seemed to be an effective approach to promote gait training, as participants improved equally to controls. This benefit may be ascribed to the real-time

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feedback, stimulating corrective actions and promoting self-efficacy to achieve optimal performance. Further optimization of the system and adequately-powered studies are warranted to corroborate these findings and determine cost-effectiveness.

1. Introduction

In Parkinson's disease (PD), gait and balance deficits, and more specifically freezing of gait (FOG), result in reduced quality of life [1]. Exercise has been shown to improve PD motor impairments in the short term [2,3]. Also, it has been suggested that exercise effects can be enhanced by increasing subjects' cognitive engagement with practice through the provision of cueing or biofeedback in PD [4,5]. Cueing is defined as temporal or spatial stimuli, which regulate and facilitate repetitive movements by providing an explicit motor target. Several systematic reviews indicate that different cueing modalities have an immediate effect on gait and health related quality of life (HR-QoL) [6–8], and increase retention of learning in PD [9,10]. In addition, cueing reduces the severity of Freezing of Gait (FOG) [9,11,12]. Biofeedback refers to the provision of external information during or immediately after movement, which supplements sensory (proprioceptive) pathways to guide motor performance. Although augmented feedback has been shown to be effective for improving balance [13–15] and gait [16], it usually requires cumbersome laboratory setups and specialized healthcare professionals to administer. Combined with the increasing prevalence of PD and the predicted shortage of physiotherapists [17], new ways to deliver cueing and biofeedback seem therefore warranted.

Current wearable technology in PD is mainly directed towards long-term, home assessment of disease symptoms [18], rather than therapy [19]. To our knowledge, only Espay et al. investigated at-home training with wearable biofeedback technology and showed it was effective to improve gait in PD, although a control group was lacking [20]. In addition, FOG can now be detected reliably in real-time using inertial measurement units (IMUs) in a standardized setting, but home detection has not been investigated yet [21,22]. A six week training period using a FOG specific instrumented cueing method in the laboratory, found a reduction of FOG episodes but no carry-over to daily life [23]. These results highlight the challenge of designing appropriate technology, which aims to address the needs of people with PD in the home environment [19].

The current study is part of the EU-funded CuPiD-project (www.cupid-project.eu). Innovatively, and in line with recent evolutions [24,25], we designed a gait training application not only with a team of engineers and physiotherapists, but also with the active participation of persons with PD. The technology integrates 3 main functions: 1) measurement of gait in real-time; 2) auditory biofeedback (ABF) on one or more spatiotemporal gait parameters [26]; and 3) rhythmical auditory cueing to prevent or overcome FOG episodes [22]. The aims of the present study were to test the feasibility of training with the CuPiD system in the home environment, and to discover the differential effects of CuPiD training versus conventional home-based gait intervention on gait, balance and HR-QoL in PD. We hypothesized that both interventions would improve gait and balance outcomes, as participants would be stimulated to increase walking, but that the effects would be amplified in the CuPiD group because of the cognitive engagement by the wearable biofeedback.

2. Methods

2.1. Participants

Forty PD persons were recruited by telephone from databases of the Department of Rehabilitation Sciences, KU Leuven (Belgium) and the Tel Aviv Sourasky Medical Center (Israel) (Fig. 1). Participants were included if they were able to walk for 10 min continuously; had a score of 24 or higher on the Montreal Cognitive Assessment (MoCA); were in Hoehn & Yahr Stage II to III in ON-state and were on stable PD medication. People were excluded if they had severe medical conditions affecting gait other than PD, had hearing or visual problems precluding benefiting from auditory feedback and were likely to change medication regimen during the course of the study. Participants were allowed to continue with their usual care including their regular physiotherapy. After baseline screening, participants were randomly allocated to the CuPiD or control group per center by the researcher, who was not blind to group allocation. A stratified blocked randomization procedure was used (Hoehn & Yahr stage, having FOG or not). The study was approved by the local ethics committee of the University Hospitals Leuven and Tel Aviv Sourasky Medical Center. All participants gave written consent according to the declaration of Helsinki.

2.2. CuPiD system

The CuPiD system consisted of a smartphone (Galaxy S3-mini, Samsung, South Korea), a docking station and two IMUs (EXLs3, EXEL srl., Italy) with a sampling frequency of 100 Hz (Fig. 2A in Supplementary Materials). Technical features and algorithms were first validated for the detection of gait abnormalities against standard gait registration systems [26], and for FOG detection in a laboratory environment [22]. Ten people with PD (5 from each country) extensively tested the system prior to trial commencement. Battery life ensured a user-duration of up to 4 h.

Two applications were used in this study: the audio-biofeedback (ABF-gait app) and the instrumented cueing for FOG-training (FOG-cue app). Feedback and cues were provided via earphones or the smartphone's speaker. The ABF-gait app contained:

1) A large touch-screen "Start" button, establishing the connection with the IMUs (see Fig. 2A in Supplementary Materials);
2) A menu of four training targets: cadence, stride length, symmetry and gait speed;
3) A 'therapeutic window' allowing calibration of feedback according to the individual's optimal gait performance [26], and set per gait parameter as a percentage above and below the median of every 5 steps (see Fig. 2B in Supplementary Materials). Positive verbal feedback (in Dutch or Hebrew) was given when gait remained within the therapeutic window, diminishing with an exponential trend to prevent feedback overload and maximize motor learning. Corrective verbal feedback was given when gait parameters fell outside the