Parkinsonism and Related Disorders 22 (2016) 28–34

Contents lists available at ScienceDirect

Parkinsonism and Related Disorders

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

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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ARTICLE INFO

Article history:
Received 11 July 2015
Received in revised form
22 October 2015
Accepted 1 November 2015

Keywords:
Parkinson's disease
Physical therapy
Gait training
Auditory feedback
Wearable sensor
Smartphone

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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http://dx.doi.org/10.1016/j.parkreldis.2015.11.004

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

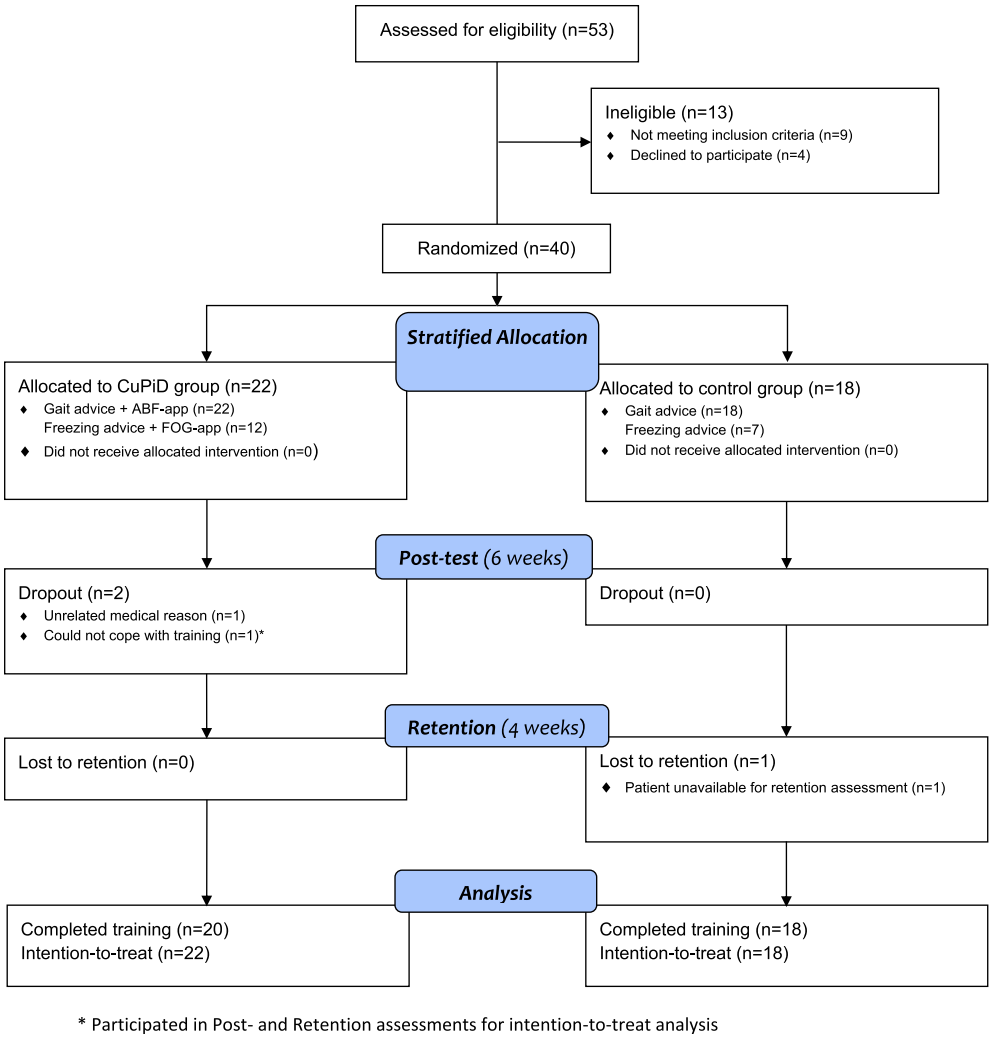

Fig. 1. Study flowchart.

therapeutic window. Fig. 3 shows training examples of 2 PD persons (see supplementary materials).

The FOG-cue app contained:

1) A FOG detection sensitivity option, adjusted by the physiotherapist to low or high to accommodate excessive false positive or false negative detections.
2) An exercise menu, including walking in a figure of 8, maneuvering through cluttered spaces and making turns with and without responding to a visual GO–NO–GO signal provided by the smartphone.
3) Intelligent cueing options, providing continuous cueing during walking which faded when FOG occurred or was initiated when FOG was detected (based on the participant's preference).

2.3. Intervention

2.3.1. CuPiD training

CuPiD group participants received weekly home visits from the researcher during the six week of intervention. Participants were instructed to walk at least 3 times per week for 30 min, according to ACSM's exercise guidelines for health benefits [27]. They were instructed to use the ABF-gait app, which provided feedback on selected gait parameters during their walks. Participants with FOG received instruction on how to avoid FOG and practiced for an additional 30 min three times a week using the FOG-cue app, similar to previous work [23].

The smartphone was carried in a pocket of the participant's clothing, except for during FOG-training when the phone was handheld (to see the visual signals). Participants were taught how to apply the IMUs to their shoes (when using the ABF-gait app) and above their ankles when using the FOG-cue app. A booklet with pictures and personalized instructions was left in the home and consultation by telephone was offered in case of difficulties using the system. An optimal performance walk was performed during the initial visit and repeated twice over the 6-week study period to calibrate the ABF-gait app. Spatiotemporal parameters and FOG-cue settings were on average 4 times adjusted by the researcher during weekly visits.

Participants were asked to record the frequency and duration of their training sessions in a diary. The CuPiD system also recorded the duration of walks with the system. Training data were provided in summary statistics, consisting of simple displays of positive and corrective feedback received and number of steps performed.

2.3.2. Control training

The control group also received weekly visits by the same researcher for six weeks and was provided with the same practice

schedule, personalized approach and recommendations for training, except for the CuPiD system. Control participants also recorded the frequency and duration of their training sessions in a diary. People allocated to this group were informed about the documented effectiveness of the intervention.

2.4. Assessment procedure and outcomes

During the first session (pre-test), in- and exclusion criteria were checked and baseline values of the primary and secondary outcomes collected. The same outcomes were assessed after the 6 weeks intervention (post-test) and after a 4 week (follow-up) period by the same assessor at each clinical center. Testers were not blinded to group allocation. Measurements' order was standardized within the test procedure and conducted when participants were optimally medicated, about 1 h after PD medication intake.

Primary outcomes were gait speed under usual and dual task (DT) conditions. We were particularly interested in detecting changes in DT gait speed, as it may better represent improved gait automaticity than single task outcomes. Participants were asked to walk for one minute over an instrumented walkway (PKMAS, Protokinetics, USA): (1) at comfortable speed and (2) while reciting as many words as possible starting with a pre-specified letter. Secondary gait, balance and HR-QoL outcomes included the 2 Minute Walk Test (2MWT) [28], the mini-Balance Evaluation Systems Test (MiniBESTest) [29], the Four Square Step Test (FSST) [30], the Falls Efficacy Scale-International (FES-I) [31] and the Physical Activity Scale for the Elderly (PASE) [32]. FOG severity was determined by the New-FOG questionnaire (NFOG-Q) [33] and the Ziegler protocol [34]. Disease severity was quantified using the Movement Disorders Unified Parkinson's Disease Rating Scale – motor examination (UPDRS III) [35]. Cognitive assessments included Color Trail Test (CTT) A and B [36] and verbal fluency (VF) scores in sitting and walking. Quality of life was determined by the Short Form 36 Health Survey (SF-36) [37]. At post-test, a 5-item Likert scale investigated whether participants found the CuPiD system user-friendly or not (1 = no agreement and 5 = total agreement).

2.5. Statistical analysis

Kolmogorov–Smirnov analysis and Levene's test evaluated the data distribution. In case of abnormal distributions, non-parametric analyses were performed. As this did not lead to different results, only parametric test results are reported.

To compare baseline characteristics and adherence outcomes between both groups, an independent samples T-test was used for continuous and a chi-square for categorical variables. A 2 (group) by

Table 1
Outcomes of PD persons who completed the training period.

Variables	CuPiD (n = 20)			Control (n = 18)			Effects		
	Pretest	Posttest	Follow-up	Pretest	Posttest	Follow-up	Time	Group	Time × group
Comfortable gait									
Gait speed [m/s]	1.11 (0.23)	1.21 (0.24)[b]	1.22 (0.23)[b]	1.16 (0.14)	1.22 (0.14)[b]	1.24 (0.17)[b]	P < 0.001	P = 0.70	P = 0.34
Stride length [m]	1.18 (0.22)	1.26 (0.21)[b]	1.26 (0.21)[b]	1.26 (0.16)	1.32 (0.14)[b]	1.31 (0.17)[b]	P < 0.001	P = 0.31	P = 0.31
DS time [% GCT]	32.42 (4.62)	30.71 (3.99)[b]	30.59 (4.28)[b]	29.51 (3.12)	28.79 (3.26)[b]	28.88 (3.59)[b]	P < 0.01	P = 0.07	P = 0.17
Dual task gait									
Gait speed [m/s]	0.96 (0.24)	1.09 (0.28)[b]	1.07 (0.27)[b]	1.03 (0.12)	1.09 (0.11)[b]	1.09 (0.17)[b]	P < 0.001	P = 0.66	P = 0.33
Stride length [m]	1.07 (0.22)	1.16 (0.26)[b]	1.14 (0.24)[b]	1.15 (0.14)	1.21 (0.11)[b]	1.19 (0.18)[b]	P < 0.001	P = 0.35	P = 0.51
DS time [% GCT]	34.70 (4.81)	32.64 (4.60)[b]	32.94 (4.75)	31.78 (3.26)	31.02 (3.58)[b]	31.51 (4.05)	P < 0.01	P = 0.12	P = 0.22
Balance									
MiniBESTest [0–32]	24.75 (5.61)	26.10 (4.64)[b]	24.95 (4.78)	25.33 (4.04)	24.44 (4.96)	25.00 (4.89)	P = 0.79	P = 0.82	P = 0.04
FSST [s]	11.02 (3.57)	9.70 (2.28)	9.86 (3.34)[b]	10.26 (2.21)	10.51 (3.53)	10.12 (2.59)[b]	P < 0.05	P = 0.92	P = 0.09
FES-I [16–64]	26.90 (7.21)	27.35 (9.45)	26.74 (9.57)	27.28 (10.02)	27.82 (12.07)	28.00 (9.93)	P = 0.91	P = 0.84	P = 0.89
Endurance and physical capacity									
2 MWT [m]	145.56 (38.17)	157.54 (39.23)[b]	152.47 (43.38)	150.09 (25.89)	153.89 (25.20)[b]	154.97 (24.18)	P < 0.005	P = 0.95	P = 0.15
PASE [0–400]	125.86 (85.56)	115.31 (73.77)	102.30 (68.55)	103.30 (60.37)	102.66 (50.00)	99.92 (48.19)	P = 0.18	P = 0.52	P = 0.56
Disease severity									
UPDRS III [0–132]	28.35 (14.77)	28.15 (15.57)	30.85 (14.26)	33.77 (14.36)	31.00 (14.62)	34.65 (15.21)	P = 0.09	P = 0.44	P = 0.64
Freezing of gait[a]									
NFOG-Q [0–28]	14.43 (7.84)	12.93 (7.65)	13.93 (8.27)	13.70 (7.82)	15.10 (6.57)	15.70 (7.30)	P = 0.49	P = 0.73	P = 0.19
Ziegler [0–36]	5.50 (8.25)	5.07 (6.97)	5.00 (6.67)	4.40 (4.12)	4.00 (6.91)	4.30 (4.27)	P = 0.79	P = 0.69	P = 0.93
Cognition									
CTT-A [s]	73.65 (34.67)	58.70 (26.27)	64.30 (29.87)	59.78 (19.16)	69.94 (47.08)	64.77 (26.59)	P = 0.08	P = 0.67	P = 0.08
CTT-B [s]	136.32 (59.42)	142.95 (67.38)	126.00 (60.25)	122.33 (66.07)	119.78 (56.24)	120.65 (58.93)	P = 0.23	P = 0.36	P = 0.25
VF Sit [#]	30.05 (12.19)	29.50 (14.89)	27.75 (14.43)	31.78 (16.95)	31.22 (17.84)	32.88 (22.02)	P = 0.86	P = 0.58	P = 0.46
VF Walk [#]	11.00 (5.06)	10.20 (4.56)	10.35 (5.58)	10.28 (6.32)	10.33 (6.82)	11.18 (7.49)	P = 0.59	P = 0.99	P = 0.47
Quality of life									
SF-36 [0–100]	58.59 (18.60)	59.76 (17.95)	59.46 (17.13)	53.24 (16.55)	59.28 (18.73)	53.81 (20.42)	P = 0.23	P = 0.51	P = 0.65
SF-36 Phys. health [0–100]	53.79 (18.50)	53.28 (18.45)	54.80 (16.48)	50.41 (15.60)	56.67 (17.32)	48.29 (15.54)[c]	P = 0.21	P = 0.71	P < 0.05
SF-36 Ment. health [0–100]	59.76 (18.01)	63.56 (18.41)	60.60 (18.05)	55.00 (18.69)	58.13 (20.04)	56.59 (24.21)	P = 0.38	P = 0.44	P = 0.75
CuPiD System usability [1–5]									
I can turn on the smartphone easily			4.5 (0.9)						
I can turn on the CuPiD applications easily			4.6 (0.7)						
I think CuPiD is simple to use			4.3 (0.8)						
I can attach/remove the sensors easily			4.0 (1.3)						
I think I can use the system independently			4.0 (1.2)						

m: meters; s: seconds; DS: Double Support; GCT: gait cycle time; Phys: Physical; Ment: Mental.
Values are presented as mean (±standard deviation).
[a] Analysis performed only on PD persons reporting freezing of gait;
[b] Significantly different from pretest;
[c] Significantly different from posttest.

3 (time: pre-test/post-test/follow-up) repeated measures ANOVA evaluated differences for the dependent variables on the primary and secondary outcomes, being the independent variables. Because of the exploratory nature of this trial, Fisher's LSD post-hoc analyses were applied. Effect sizes expressed as partial eta squared (η^2) are reported for the most important findings. The level of statistical significance was set at $\alpha = 0.05$.

We report the data from all participants who completed the 6 weeks of training (per protocol analysis) and also conducted an intention-to-treat analysis with a last observation carried forward method to impute missing values. Statistical analysis was performed using SPSS version 22 (IBM, USA).

3. Results

Twenty-two participants were allocated to CuPiD, of which 20 completed training. Eighteen participants were allocated to the control arm, all of whom completed training (Fig. 1). Reasons for dropout (N = 2) were unrelated to CuPiD in one person. However, the second person was unable to cope with the CuPiD system without supervision at home. Both training groups were similar at baseline (see supplementary materials: Table S1). Fourteen CuPiD participants and 10 control participants experienced FOG. Only 11 participants (29%) had used a smartphone before entering the study.

3.1. Gait

There were no interaction effects for the primary outcomes (Table 1), gait speed under single tasking ($F_{(2,108)} = 1.11$, $p = 0.34$, $\eta^2 = 0.03$) and gait speed under dual tasking ($F_{(2,108)} = 1.14$, $p = 0.33$, $\eta^2 = 0.03$). Also the group differences for the primary outcomes, were not significantly different (Single tasking: $F_{(1,108)} = 0.15$, $p = 0.70$, $\eta^2 = 0.01$; Dual tasking: $F_{(1,108)} = 0.19$, $p = 0.66$, $\eta^2 = 0.01$). However, there was a main effect of time (Single tasking: $F_{(2,108)} = 14.31$, $p < 0.001$, $\eta^2 = 0.29$; Dual tasking: $F_{(2,108)} = 9.57$, $p < 0.001$, $\eta^2 = 0.23$). These results indicate that both groups improved gait speed during single and dual tasking from pre-test to post-test, whereby the CuPiD group improved their gait speed with 9.0% and 13.5% and the control group with 5.2% and 5.8% for single and dual tasking, respectively. Other gait outcomes showed a similar pattern of results and most gait benefits were maintained at follow-up in both groups.

3.2. Balance

A significant time by group interaction was found for the miniBESTest ($F_{(2,108)} = 3.73$, $p = 0.04$, $\eta^2 = 0.11$), indicating that the improvement in balance for the CuPiD group was significantly greater than the control group at post-test (Table 1). However, this effect was not maintained at follow-up. This result was also reflected with a trend towards a significant interaction effect of time by group for the FSST ($F_{(2,108)} = 3.38$, $p = 0.09$, $\eta^2 = 0.10$).

3.3. Endurance

The aforementioned gait improvements were also reflected in the 2MWT which showed a significant main effect of time ($F_{(2,108)} = 4.32$, $p < 0.005$, $\eta^2 = 0.11$) as shown in Table 1.

3.4. Health related quality of life

A significant time by group interaction was found for the physical health score of the SF-36 ($F_{(2,108)} = 1.85$, $p < 0.05$, $\eta^2 = 0.06$), indicating that the control group experienced a decrease in self-reported physical health at follow-up, while the CuPiD group did not.

There were no significant between-group or within-group differences for FOG outcomes and cognitive measures. Intention-to-treat analysis yielded similar results with the exception that the time by group interactions for the MiniBESTest and SF-36 (physical health) were no longer significant (both $p = 0.07$).

3.5. Feasibility

Adherence data (Table 2) showed that the CuPiD group spent less time training compared to the control group, while the number of training sessions was identical (CuPiD: 28 ± 9 sessions; control: 28 ± 10 sessions; $p = 0.91$). Training duration was based on the CuPiD system logs for the CuPiD group, and diary data for the control group. When checking for differences between diaries and CuPiD logs in 13 CuPiD participants, diary notations (701 ± 304 min) were not significantly different from CuPiD logs (646 ± 254 min; $p = 0.25$). Participants with incomplete diary data, were excluded from this analysis.

In general, participants were very positive about the CuPiD system, as scores on user-friendliness were on average above 4 on a 5-point scale. However, attaching and removing the IMUs and using the CuPiD system without technical support resulted in more variable answers (Table 1). It was observed that participants with previous smartphone experience had the least problems using the CuPiD system. Some participants were so enthusiastic about the system that they expressed disappointment after its withdrawal.

Table 2
Adherence data.

	CuPiD[a]	Control[b]	*p*-value
Overall			
PD persons [#]	20	18	
Total duration [minutes]	649.5 (234.7)	923.8 (342.6)	<0.01
Sessions [#]	28.3 (8.7)	27.9 (10.3)	0.91
ABF-app/Gait advice			
PD persons [#]	20	18	
Total duration [minutes]	494.7 (274.5)	742.7 (286.7)	0.01
Sessions [#]	20.7 (6.5)	20.7 (6.1)	0.99
FOG-cue/FOG advice			
PD persons [#]	10	7	
Total duration [minutes]	309.6 (141.5)	465.6 (179.1)	0.06
Sessions [#]	16.3 (4.5)	18.6 (1.5)	0.17

Values are presented as mean (±standard deviation).
[a] Based on CuPiD-system adherence data.
[b] Based on diary adherence data.

4. Discussion

This phase II RCT investigated the feasibility of the CuPiD system and its effectiveness on gait and balance, compared to conventional gait training in people with PD. The system was well-accepted and showed to be useful for providing minimally supervised at-home gait training. Both study arms improved on the primary outcomes of gait speed under comfortable and DT conditions at post-test and at follow-up. The CuPiD approach demonstrated to be better at improving balance than conventional gait training in people with PD.

Despite the non-superior findings of the CuPiD system for gait, the results revealed a larger improvement in gait speed during both comfortable (9.0%) and DT conditions (13.5%), whereas controls improved gait speed by only 5.2% and 5.8%. According to the recommendations by Hass et al., the control group's effect sizes can be interpreted as small [38], whereas those of the CuPiD group can be considered as clinically moderate and as comparable to other

cueing and treadmill studies [9,16,39]. These results are the more notable, considering that total training time was lower in the CuPiD group, suggesting that the CuPiD system may have improved training efficiency.

In contrast to gait, we found an interaction effect for the Mini-BESTest balance outcome favoring the CuPiD group. However, it should be noted that the between-group mean difference for the MiniBESTest of 1.7 points is below the smallest real difference of 3.4 points [40]. CuPiD participants also tended to improve more than controls on the FSST, another test of dynamic stability, requiring fast steps in different directions over a small obstacle. Together, these findings suggest that CuPiD induced benefits of dynamic stability, which may be ascribed to the fact that CuPiD targeted larger step sizes and greater gait stability.

There were no between- or within-group effects on FOG, although pre-to post-test differences of 1.5 points in NFOG-Q scores were found in favor of the CuPiD group. Since both groups devoted less time to training FOG, it is possible that the dose was insufficient to be effective. In addition, FOG training was only undertaken by 17 participants. Therefore, the study was not powered to detect significant differences.

This study showed that the CuPiD group trained as much as the control group in terms of training sessions, but had a lower training duration. Possible explanations could be related to the self-reporting of adherence, overestimating actual compliance for reasons of social desirability. However, when training diaries and CuPiD logs were compared, no significant differences were detected, albeit in participants with complete diaries only. The fact that CuPiD participants were aware that their training was logged, may also have contributed to this finding. The number of training sessions was similar in both groups, indicating that the intention to train was equal in both groups. Also, the reported training duration is in line with earlier reported adherence of approximately 80% in home-based PD interventions [41,42]. The CuPiD system was used with minimal supervision, while most participants were unfamiliar with a smartphone. Except for difficulties with the correct placement of the IMUs and the touchscreen the system was very well-tolerated as indicated by the positive scores on the user-friendliness scale.

Lack of statistical confirmation of the CuPiD system's benefits may indicate that it does not offer an added clinical value. Alternatively, the study may have been underpowered to show a surplus effect. Post-hoc power calculations based on the DT gait speed results showed that 164 (82 per group) persons would be required to achieve the desired power of 0.80 assuming effect sizes of 13.5% for the CuPiD group and 5.8% for controls. However, when compared against a passive control group, a total of 54 (27 per group) participants would suffice. Other limitations which may have influenced the trial outcomes, were the lack of assessor blinding for group allocation and uncorrected post-hoc analyses for multiple comparisons. Also, the placebo effect resulting from increased attention during therapy was not controlled for and we did not take usual care characteristics into consideration. Despite these drawbacks, we conclude that the CuPiD system was feasible for unsupervised home-use and was an effective approach for gait and balance training in PD. Given the shorter training duration with the CuPiD systems, these benefits may possibly be associated with the online biofeedback model, enhancing training efficiency. Large scale clinical trials to investigate its long-term use and cost-effectiveness are indicated before future implementation can be considered.

Conflict of interest

AF and LC have a significant financial interest in mHealth Technologies, a company that may have a commercial interest in the results of this research and technology. All other authors declare no competing interests.

Funding sources

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement No. 288516 (CuPiD project).

Authors' contribution

All authors contributed to the research design. PG, MD and EG were responsible for recruitment, home-based training and assessments. PG was principally responsible for data-analysis and drafting of the manuscript. AF was responsible for implementing necessary adjustments to the CuPiD system. All authors critically reviewed the manuscript and approved the submitted version.

Acknowledgments

The authors would like to thank all volunteers who were willing to participate in this study.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.parkreldis.2015.11.004.

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