Annals of Physical and Rehabilitation Medicine 61 (2018) 380–385

Available online at ScienceDirect www.sciencedirect.com

Elsevier Masson France EM|consulte www.em-consulte.com

Original article

Home-based training of rhythmic skills with a serious game in Parkinson's disease: Usability and acceptability

Celia Dauvergne [a,b,1], Valentin Bégel [a,c,1], Christian Gény [a,d], Frédéric Puyjarinet [a], Isabelle Laffont [a,e], Simone Dalla Bella [a,f,g,h,i,*]

[a] Euromov, Montpellier University, Montpellier, 34090 France
[b] Medicine and Rehabilitation, Nîmes University Hospital, 30029 Nîmes, France
[c] NaturalPad, SAS, Montpellier, 34090 France
[d] Neurology, Parkinson Expert Center, Montpellier University Hospital, 34090 Montpellier, France
[e] Physical Medicine and Rehabilitation, Montpellier University Hospital, 34090 Montpellier, France
[f] International Laboratory for Brain, Music, and Sound Research (BRAMS), H3C 3J7 Montreal, Canada
[g] Department of Psychology, University of Montreal, H3C 3J7 Montreal, Canada
[h] Centre for Research on Brain, Language and Music (CRBLM), H3C 3J7 Montreal, Canada
[i] Department of Cognitive Psychology, WSFiZ in Warsaw, 01-030 Warsaw, Poland

ARTICLE INFO

Article history:
Received 30 March 2018
Accepted 11 August 2018

Keywords:
Serious games
Training
Rehabilitation
Parkinson disease
Beat perception
Synchronization
Rhythmic skills

ABSTRACT

Objectives: To evaluate the adherence, usability and acceptance of a rehabilitation protocol with a music-based serious game (SG) and its effect on rhythmic skills in Parkinson disease (PD).
Methods: Sixteen PD patients with mild cognitive and motor impairments were included (mean [SD] age 65 [7.28] years and Hoehn & Yahr score 2–3). Rehabilitation consisted of a 6-week at-home training program targeting rhythmic skills with a dedicated SG, *Rhythm Workers*, implemented on a tablet device. Patients were asked to play the game at least 30 min, 3 times a week. Two half-day evaluations were conducted before and after rehabilitation. Time played and average game scores were recorded. Suitability was evaluated by a questionnaire inspired by the Suitability Evaluation Questionnaire (SEQ) and rhythmic skills by the Beat Alignment Test from the Battery for the Assessment of Auditory Sensorimotor and Timing Abilities (BAASTA).
Results: Patients played a mean (SD) of 313 (243) min, namely 57.9% of the expected time; the mean game score was 48.8/100 (19.5). The mean SEQ score for 12 patients was 29.2/45 (8.2); suitability was good to excellent for 10 patients. Beat perception reflecting rhythmic skills improved significantly in all but 5 patients.
Conclusion: This study showed good to excellent suitability of an SG used on a tablet interface for rhythmic training in PD and the feasibility of this type of training in this population.

1. Introduction

1.1. Serious games with neurological patients

"Serious games" (SGs) are video games combining serious intentions, such as educational, professional or medical purposes, with pleasant and recreational aspects [1]. When used for rehabilitation, SGs are supposed to strengthen patients' adherence to the program by increasing their motivation and engagement. SGs are known to augment the dose of rehabilitation by increasing the intensity and repetition of exercises because of their motivational properties and to enrich the panel of rehabilitation contents [2]. Notably, there is some evidence of the specific effect of video games on learning and possibly neuroplasticity, even if this is still debated [3]. From a practical point of view, because video games are currently developed on a large number of supports such as smartphones, tablets, computers and consoles and with a broad number of interfaces (e.g., handheld devices, gloves, sensor-less motion-capture systems) [4], they are universally available and potentially usable for several medical applications.

There is growing interest in using SGs in a number of rehabilitation programs for neurological diseases: Parkinson disease (PD) [5], stroke [2], traumatic brain injury [6], spinal cord injury [7], dementia [8], multiple sclerosis [9], and cerebral palsy [10]. Despite an increasing number of studies assessing the effects

* Corresponding author. Department of psychology, University of Montreal, 90, avenue Vincent d'Indy, QC H2V 2S9 Montreal, Canada.
E-mail address: simone.dalla.bella@umontreal.ca (S. Dalla Bella).
[1] Shared first authorship.

https://doi.org/10.1016/j.rehab.2018.08.002
1877-0657/

of SGs, to date the literature is inconclusive and provides contradictory findings about the efficacy of game-based rehabilitation programs in neurological conditions, especially stroke [2] and PD [5]. The variability of the study designs, diversity of the devices, and poor methodology including lack of randomized controlled trials limit the generalization of conclusions. Unfortunately, commercial off-the-shelf games are not designed for use with clinical populations, are often too quick and difficult, and typically include too many distractors; therefore, they are generally considered inadequate for rehabilitation of neurological patients. In contrast, video games devised for rehabilitation and tailored to a patient population, despite their potential for providing promising rehabilitation strategies, have received less attention in the medical literature [2,5].

In PD, most studies tested commercial games [11–13] with variable results for disabilities and function. Hassad et al. [14] described the methodology for building playable games tailored to PD patients that were based on a participatory design approach including therapists and patients. A positive motivational effect of these games was reported but no functional benefits. To our knowledge, no other tailored video game system for PD rehabilitation has proven efficiency in the medical literature.

1.2. Rhythm impairment and rhythmic training in PD

Movement disorders, characteristic of PD (tremor, bradykinesia, and rigidity), are usually associated with timing and rhythm deficits [15–17]. There is evidence that patients with PD benefit from rhythmic training, as a way to improve their gait performance. Rhythmic Auditory Stimulation (RAS), consisting of using external rhythmic stimuli (e.g., a metronome or music) during walking, benefited gait rehabilitation in PD in several clinical studies [18]. An immediate positive effect of RAS on gait is visible in terms of increased speed, stride length, and improved symmetry and stability [19]. Benefits are visible in non-cued gait after an extensive training period with RAS [20] and generalize to other rhythmic tasks not involving walking (finger tapping and beat perception) [17]. These findings suggest that the effects of RAS might be mediated by mechanisms responsible for rhythm processing, which may be supported by the residual activity of the basal-ganglia-thalamo-circuitry, typically malfunctioning in PD, or by a cerebello-thalamo-cortical compensatory circuitry [21,22]. This hypothesis leads to major therapeutic and rehabilitation perspectives. RAS and motor synchronization to the beat of music such as in paced finger-tapping tasks can be used to improve global rhythmic skills, with therefore beneficial effects on gait.

Usually, rhythmic rehabilitation in PD is performed by auditory cueing protocols demanding patients to walk with RAS. A considerable number of studies evaluated the use of rhythmic external auditory cueing [23]. A shortcoming of these methods is that the protocols are typically demanding and tiring for PD patients and have associated risks (e.g., falling). They can be performed at home, for example, by using a portable device [24,25], as in the RESCUE trial [25], in which patients walked at home with use of a mobile rhythmic stimulator. However, these methods are limited by the usability and adherence to the device. Their long-term use and effects have not been examined. Thus, SGs present a true alternative for efficient, safe, and motivating rhythmic training in a home environment.

1.3. "Rhythm Workers" and aim of the study

On the basis of previous evidence showing the positive effects of rhythmic training via RAS on gait and timing in PD [17], here we examined the possibility of delivering a similar training exploiting finger tapping in a dedicated SG [26]. We tested an SG named *Rhythm Workers* implemented on a tablet device [27] in a 6-week at-home rehabilitation program for PD patients, as a complementary rehabilitation tool to standard programs in PD. We hypothesized that training with *Rhythm Workers* would be associated with high motivation and adherence to the rhythmic rehabilitation program, thereby leading to improved rhythmic skills. In this pilot study, we aimed to evaluate the usability, adherence and acceptance of a music-based SG rehabilitation protocol for training rhythmic skills in a small sample of PD patients.

2. Methods

2.1. Patients

Patients were recruited in the Physical Medicine and Rehabilitation Department and the Neurology Department of Montpellier University Hospital. The inclusion criteria were 1) PD with gait impairment (i.e., with at least one of these symptoms: reduced stride length, freezing of gait, akinesia), 2) Modified Hoehn & Yahr scale in "ON" state ≤ 3 [28], 3) no medication change for 1 month, 4) walking without crutches or orthosis, 5) absence of falls during the last 3 months, and 6) no severe dyskinesia. The exclusion criteria were 1) rejecting the therapy, 2) inability to operate a tablet device, 3) having deep brain stimulation, 4) presence of cognitive disorders (Mini-Mental State Examination score < 24), and 5) severe visual or hearing impairment.

All patients gave their written consent before taking part in the study. This study is a part of a prospective randomized study evaluating the impact of rhythmic rehabilitation with an SG on a tablet device on gait parameters in PD. It was approved by the CPP Sud Méditerranée III (no. 2015-A01090-49). ClinicalTrials.gov registration NCT02855710.

2.2. Intervention: training of rhythmic skills via finger tapping, with the Rhythm Workers game

Rhythm Workers is a new SG designed for training perceptual and sensorimotor rhythmic skills [27] that results from a collaboration between the Euromov laboratory (Montpellier University) and the NaturalPad® Company. The main goal of the game is to construct buildings whose aesthetic quality depends on the player's rhythmic performance in a finger-tapping task (Fig. 1). The patients are asked to tap their finger on the screen as accurately as possible to the beat of a variety of rhythmic auditory stimuli, such as metronomes, rhythmic sequences, and music. The quality of the tapping performance (i.e., its accuracy and variability in synchronizing to the beat) determines the performance in the game. High accuracy and low variability lead to obtaining more points in the game and constructing buildings that are more aesthetically appealing. The game involves different levels of difficulty, associated with a different rhythmic sequence. In total, 99 levels are divided into 9 "worlds" (from 0 to 8). At the end of each level, a score between 5 and 100 points is calculated, which leads to unblocking or not the next level, and is converted into a number of stars: from 1 star corresponding to a score < 70 to 5 stars for a score > 95. The stars appear on the screen accompanied by a motivating message: "Try again" for 1 star, "It's ok" for 2 stars, "Good" for 3 stars, "Very good" for 4 stars, and "Champion" for 5 stars. After 5 trials at the same level, the next level is automatically unblocked.

Rehabilitation with *Rhythm Workers* was performed at home for 6 weeks. Participants were asked to play 30 min each day, 3 times a week, for a total of 18 sessions and 540 min. The tablet device recorded the performance of the patient at each level and the time played.

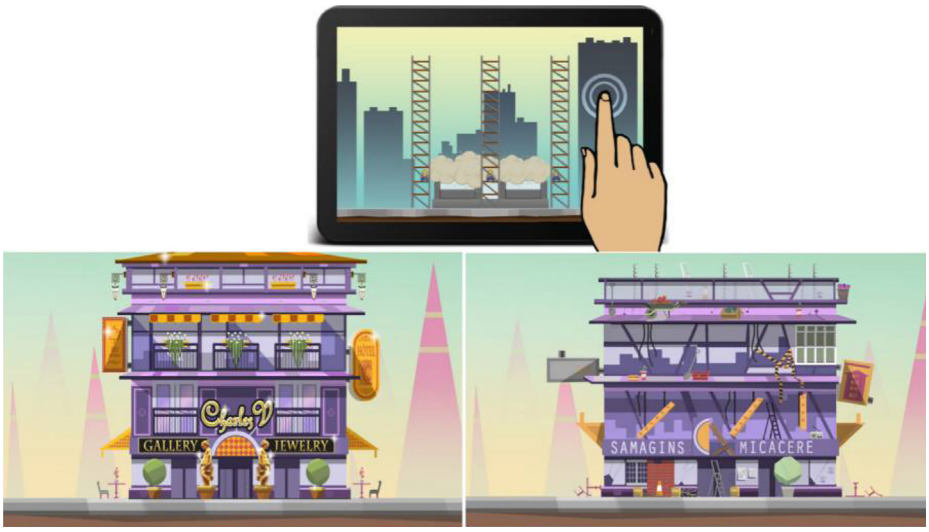

Fig. 1. Two examples of buildings generated by one patient, corresponding to a good performance (left building) and a bad performance (right building).

2.3. Experimental design

After inclusion in the study (V1), patients underwent a 6-week period of home-rehabilitation with the SG. Patients were phone-called regularly during the home-rehabilitation period, corresponding to the V1–V2 interval, to ensure that they could use the game and the device. A half-day complete evaluation was conducted at each visit.

3. Assessments

At V1 and V2, the clinical status of the patients was tested with the Movement Disorder Society-Unified Parkinson's Disease Rating Scale (MDS-UPDRS [29]). Cognitive impairment was assessed by the Montreal Cognitive Assessment (MoCA [30]) scale at V1 only. Patients' medication status was verified. Patients completed the Parkinson Disease Quality Questionnaire (PDQ-39 [31]) to assess quality of life in areas specific to PD.

Suitability of the game and satisfaction were evaluated by the French adaptation of the Suitability Evaluation Questionnaire (SEQ [32]) at the second visit (V2). This scale was the only one found in the literature to afford a global evaluation of an SG. It is based on the Short Feedback Questionnaire elaborated by Kizony [33], itself based on the Singer's Presence Questionnaire [34], which is more oriented to virtual environment assessment. The SEQ consists of 14 questions evaluating the device, the feeling of the user while using the device, and the game itself. In our study, we translated and adapted this questionnaire by using 9 questions, rated on a scale from 1 to 5, with a total score from 9 (poor suitability) to 45 (excellent suitability).

Rhythmic skills were assessed at each visit by a beat perception task, the Beat Alignment Test (BAT) [35] taken from the Battery for the Assessment of Auditory Sensorimotor and Timing Abilities (BAASTA) [36]. The BAT was chosen among the possible rhythmic tasks because it is a reliable index of participants' general rhythmic skills and highly correlated with synchronization capacities [37]. In the BAT, participants are asked to detect whether the tones of a metronome superimposed on a short musical excerpt are aligned or not to the beat of music. The sensitivity index (d') was calculated as an unbiased measure of detection performance, based on the number of Hits (when unaligned tones are correctly detected) and False alarms (when lack of alignment is incorrectly reported). d' is the difference between the z-transform of Hits rate and False Alarm rate.

4. Results

4.1. Clinical and neurological evaluation

We included 16 right-handed participants (12 men), aged 50 to 77 years old. Patients' demographic and clinical characteristics at baseline are in Table 1. Four patients did not complete the SEQ. Therefore, SEQ data are available for only 12 participants.

4.2. Usability and compliance

4.2.1. Time played

The mean time played over the 6 weeks of the rehabilitation protocol, number of sessions, and time per session are in Table 2, as are individual results. The mean total time played corresponded to 57.9% of the maximum expected playing time, and the mean time per session (16 min) to 53.3% of the expected session duration. Moreover, the mean number of sessions performed (20.56) was 114.2% of the maximum number of sessions. Of note, 6 patients played more than the 18 requested sessions, and 4 played less than 10.

4.2.2. Mean score in Rhythm Workers and game achievement

The mean scores obtained in the game across the different levels of difficulty and the game achievement (world/level) are in Table 3 and the mean scores in the 9 worlds are in Fig. 2. We found important differences among the patients. Five patients were able to finish the game, and 5 could not end the first world (with 1 to 9 levels achieved). The mean score did not differ during the progression of the game (across the worlds).

4.2.3. Results of SEQ

The mean and individual results for the SEQ test are in Table 4. Ten of 12 patients reported good to excellent suitability of the game (SEQ score > 23). The positive points associated with *Rhythm Workers* were the design and fun in playing the game and the user-friendly instructions. Nevertheless, some patients noted technical difficulties with the sound level, the levels of difficulty, and the use of the tablet device. Two patients were disturbed by increased tremor during finger tapping.

Table 1
Demographic and clinical characteristics of patients with Parkinson disease (PD) at baseline.

Patient number	Age, years	Sex	PD evolution (years)	Dopa dosage (mg/d)	Freezing	MoCA	PDQ-39	MDS-UPDRS
1	68	M	20	862.5	Yes	25	74	19
2	51	F	4	1040	No	22	59	24
3	68	F	17	500	No	24	48	17
4	68	M	6	450	No	28	42	57
5	56	M	5	625	Yes	26	63	20
6	68	F	12	200	No	24	56	56
7	61	M	6	250	No	26	57	49
8	67	M	3	625	Yes	27	38	25
9	68	M	16	1000	Yes	26	48	27
10	77	M	10	350	Yes	27	22	35
11	72	M	23	425	Yes	22	72	51
12	68	M	9	35	No	27	NA	38
13	70	M	10	1300	No	26	16	42
14	64	M	10	NA	No	30	40	24
15	50	F	10	1400	No	27	78	4
16	64	M	2	360	No	30	16	15
Mean (SD)	65.00 (7.28)		10.19 (6.13)	628 (407)		26.06 (2.32)	48.60 (19.93)	31.44 (15.92)

NA: not available; MoCA: Montreal Cognitive Assessment; PDQ-39: Parkinson Disease Questionnaire; MDS-UPDRS: Movement Disorder Society-Unified Parkinson's Disease Rating Scale

Table 2
Individual and mean results for time played, number of sessions, and mean time per session.

Patient number	Time played (min)	Number of sessions	Mean time per session (min)
1	63	4	15
2	121	5	20
3	300	21	14
4	407	22	19
5	223	10	22
6	577	52	11
7	198	13	15
8	236	20	12
9	181	13	14
10	265	19	14
11	367	55	7
12	441	15	29
13	27	3	9
14	247	21	12
15	290	20	14
16	1060	36	29
Mean (SD)	312.69 (243.45)	20.56 (15.27)	16 (6.35)

Table 3
Individual results and mean game score attained during the rehabilitation program.

Patient number	World attained (World:Level)	Mean score attained
1	00:05	30
2	07:03	76.93
3	07:10	49.64
4	08:10	44.88
5	08:10	72.61
6	04:00	32.59
7	07:06	78.94
8	01:09	50.42
9	00:08	60.07
10	00:09	21.49
11	00:07	24.45
12	05:02	53.80
13	00:01	29.94
14	08:10	63.81
15	08:10	27.32
16	08:10	64.61
Mean (SD)		48.84 (19.4)

4.2.4. Rhythmic skills evaluation: BAT

The results obtained with the BAT before and after the training program are in Table 5. Higher d' values indicate better beat perception. Patients' detection of misaligned beats improved after the training program, as shown by an increase in the discrimination index ($t(14) = 2.06$, $P < 0.05$). Five patients had lower scores at the end of the training period. However, note that most of the patients who did not show an increase in performance after the training performed very well before the training (patients 7, 15 and 16), which left little room for improvement.

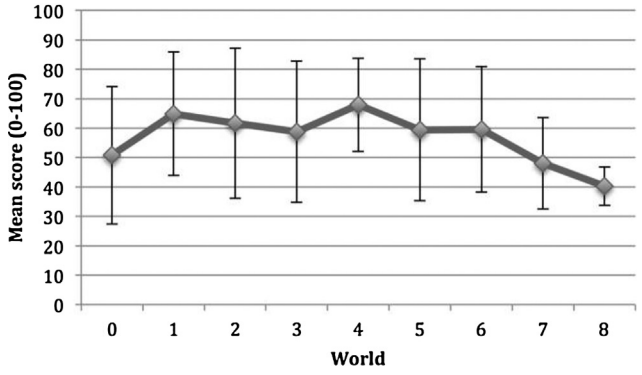

Fig. 2. Patients' mean scores obtained with *Rhythm Workers* for each of the 9 worlds. Data are mean (SD).

Table 4
Individual and mean scores on the Suitability Evaluation Questionnaire (SEQ)[a].

Patients	SEQ score
1	39
2	30
3	37
4	34
5	38
6	28
7	33
8	10
9	21
10	25
11	28
12	27
Mean (SD)	29.17 (8.2)

[a] Total score ranging from 9 to 45.

5. Discussion

The aim of this pilot study was to test the suitability, use and adherence to a music-based training of rhythmic skills in PD with a dedicated SG on a tablet device. We showed that a 6-week period

Table 5
Patients' performance on the Beat Alignment Test before and after the training with the serious game.

Patient number	Before training (d')	After training (d')
1	1.44	1.25
2	2.42	3.27
3	0.23	1.76
4	0.69	1.33
5	2.78	2.92
6	1.50	0.76
7	3.92	3.69
8	2.20	2.42
9	2.38	3.17
10	0.97	2.15
11	0.68	2.15
12	NA	NA
13	1.43	1.94
14	3.08	3.27
15	3.93	3.43
16	3.69	3.43
Mean (SD)	2.09 (1.22)	2.46 (0.93)

NA: not available.

of self-rehabilitation at home with the game is feasible. Most of our patients (83%) reported good or excellent suitability of the SG. Nevertheless, adherence to the SG treatment was low considering our expectations: the mean total duration was 58% of the maximum expected playing time, and the mean time per session, 53% of the expected session duration. Notably, however, the patients played the game slightly more often than instructed: 14% played more sessions than expected.

The results point to a significant improvement in rhythmic skills after a training period with a dedicated SG, as shown by increased performance in a rhythm perception test. However, this finding, although promising, must be treated with caution, because of the lack of a control condition, the small sample size and the included patients being at an early stage of the disease. Hence, our results cannot be generalized to the PD population as a whole. Regardless, from our results, patients at an early stage of PD might be ideal targets for this kind of intervention and future rhythm-based self-rehabilitation programs.

More than half of the patients respected the instructions to play 18 sessions over 6 weeks. Yet, there were individual differences that are worth considering. Nine patients played more than the 18 requested sessions, and 4 played less than 10 sessions. This protocol involving 3×30 min of rehabilitation per week corresponds to the usual recommended time in rehabilitation programs [25] and also to the usual physiotherapy sessions prescribed in clinical practice in PD. For example, in a review of exergaming in PD [5], most of the protocols involved 30- to 60-min sessions during 4 to 8 weeks. Regarding the duration of the rehabilitation program, patients were expected to play overall 540 min divided into eighteen 30-min sessions spread over 6 weeks. In the tested sample, only 2 patients (patients 6 and 16) reached this goal, and 6 patients played more than half of the required duration. In contrast, the other half played less than half of the expected time. Unfortunately, we cannot compare this result with those from previous studies because to our knowledge, no study has investigated playing an SG on a tablet device in PD.

We chose 30-min sessions to increase adherence and avoid fatigability in PD patients. However, the difficulty of the game as well as its repetitiveness may explain why some patients did not play the instructed time in a session. A strategy to improve adherence to time instructions might be to provide a visual feedback of the playtime as proposed in other studies [38]. This information, not presented in the current version of our game, could be added in a future version. Another possibility is to limit the instructed playtime to 15 min, which, as we could observe, was sufficient to improve rhythmic skills. Another point, which deserves particular attention, concerns the individual differences among patients. Given that the efficacy of RAS is linked to patients' rhythmic skills [39], future research could pinpoint factors that foster a positive response to rhythmic training with an SG. This identification will allow for individualizing the treatment to patient characteristics, thus maximizing its effectiveness, as recently proposed in gait training with RAS [40].

Patients' performance in the game resulted in scores across levels of difficulty, which may seem quite low (between 40 and 60/100). However, because of the construction of the game, this finding must be treated with caution. These scores cannot be used as an indicator of patient performance as in other studies [11,12]. Indeed, to unblock a level and to move to the next one, patients needed to exceed a 70-point score or perform 5 trials at the same level. This explains why 2 patients finished the game despite low scores, whereas other patients, although they obtained good scores, did not move to the next level.

To evaluate the suitability and the satisfaction with the game and the tablet device, the patients were administered a French adaptation of the SEQ [32] immediately after the rehabilitation program. Global satisfaction with *Rhythm Workers* was high, with 10 of 12 patients reporting good to excellent suitability (SEQ score > 23). Unfortunately, evaluating the suitability of an SG is not trivial, because there is no standard questionnaire. There is a paucity of studies on game suitability in PD [5]. In some studies, the performance during gaming was recorded without considering the learning effect [11,12], inferring that increasing performance reflects game suitability, which is highly debatable. Other authors created their own suitability questionnaires [14] based on Likert scales. Moreover, none of the previous studies evaluated the suitability of a tablet-based intervention. Note that scores were used in the game mainly to increase patients' motivation by providing positive reinforcement. The impact of such positive feedback has been widely explored in the literature [41,42].

Six weeks of game-based rhythmic self-rehabilitation with the SG were sufficient to improve patients' rhythmic skills as assessed by the BAT. This is a very promising result, suggesting that *Rhythm Workers* may provide a good and cost-effective solution for rhythmic training via tapping in PD. In recent studies, our research team showed that patients who positively responded to auditory cueing had better scores on the BAT [19,40]. Therefore, improving perceptual rhythmic skills is critical to pave the way for rhythmic-based gait re-education. Nevertheless, these results are still preliminary and await confirmation with other measures of rhythmic abilities and including a larger sample of patients and a control group. Note that because the BAT is a perceptual task, the improvement in rhythmic skills cannot be ascribed merely to motor practice throughout the program.

The small sample size and lack of a control group or control condition are the main limitations of this pilot study. Moreover, we did not assess patients' involvement in using the game at home, which would have provided further information about usability. A randomized clinical trial including a control group performing a non-rhythmic task is currently under way and will provide significant information about the specificity of the training with *Rhythm Workers* for rhythmic skills.

6. Conclusion

We lack studies examining self-rehabilitation of rhythmic skills using a SG on a tablet device in PD. This pilot study shows good to excellent suitability of an SG — *Rhythm Workers* — for this purpose and the feasibility of an at-home rehabilitation program using the game in PD. Adherence and real use of the SG should be improved

in future versions of the application. This first evidence of a positive effect of *Rhythm Workers* on rhythm perception suggests that SGs may be a promising avenue for successful rehabilitation of rhythmic abilities in patients with PD.

Financial support

This study was supported by a CIFRE grant to VB, in collaboration with the company NaturalPad, a Junior Grant from the Institut Universitaire de France to SDB, and a SOFMER (French Society of Physical Medicine and Rehabilitation) grant to CD.

Disclosure of interest

The authors declare that they have no competing interest.

References

[1] Annetta LA. The "I's" have it: a framework for serious educational game design. Rev Gen Psychol 2010;14:105–12. http://dx.doi.org/10.1037/a0018985.
[2] Laver KE, Lange B, George S, Deutsch JE, Saposnik G, Crotty M. Virtual reality for stroke rehabilitation. Cochrane Database Syst Rev 2011;9:160–1. http://dx.doi.org/10.1002/14651858.CD008349.pub2.
[3] Morin-Moncet O, Therrien-Blanchet J-M, Ferland MC, Théoret H, West GL. Action video game playing is reflected in enhanced visuomotor performance and increased corticospinal excitability. PLOS One 2016;11:e0169013. http://dx.doi.org/10.1371/journal.pone.0169013.
[4] Bégel V, Di Loreto I, Seilles A, Dalla Bella S. Music Games: potential application and considerations for rhythmic training. Front Hum Neurosci 2017;11:273. http://dx.doi.org/10.3389/fnhum.2017.00273.
[5] Barry G, Galna B, Rochester L. The role of exergaming in Parkinson's disease rehabilitation: a systematic review of the evidence. J Neuroeng Rehabil 2014;11:33. http://dx.doi.org/10.1186/1743-0003-11-33.
[6] Martínez-Pernía D, Núñez-Huasaf J, Del Blanco A, Ruiz-Tagle A, Velásquez J, Gomez M, et al. Using game authoring platforms to develop screen-based simulated functional assessments in persons with executive dysfunction following traumatic brain injury. J Biomed Inform 2017;74:71–84. http://dx.doi.org/10.1016/j.jbi.2017.08.012.
[7] Burns P, Kressler J, Nash MS. Physiological responses to exergaming after spinal cord injury. Top Spinal Cord Inj Rehabil 2012;18:331–9. http://dx.doi.org/10.1310/sci1804-331.
[8] McCallum S, Boletsis C. Dementia Games: a literature review of dementia-related serious games. In: Ma M, Oliveira MF, Petersen S, Hauge JB, editors. Serious Games Development and Applications. Springer, Berlin, Heidelberg; 2013. p. 15–27.
[9] Lozano-Quilis J-A, Gil-Gómez H, Gil-Gómez J-A, Albiol-Pérez S, Palacios-Navarro G, Fardoun HM, et al. Virtual rehabilitation for multiple sclerosis using a kinect-based system: randomized controlled trial. JMIR Serious Games 2014;2:e12. http://dx.doi.org/10.2196/games.2933.
[10] Kassee C, Hunt C, Holmes MWR, Lloyd M. Home-based Nintendo Wii training to improve upper-limb function in children ages 7 to 12 with spastic hemiplegic cerebral palsy. J Pediatr Rehabil Med 2017;10:145–54. http://dx.doi.org/10.3233/PRM-170439.
[11] dos Santos Mendes FA, Pompeu JE, Modenesi Lobo A, Guedes da Silva K, Oliveira TDP, Peterson Zomignani A, et al. Motor learning, retention and transfer after virtual-reality-based training in Parkinson's disease–effect of motor and cognitive demands of games: a longitudinal, controlled clinical study. Physiotherapy 2012;98:217–23. http://dx.doi.org/10.1016/j.physio.2012.06.001.
[12] Pompeu JE, Arduini LA, Botelho AR, Fonseca MBF, Pompeu SMAA, Torriani-Pasin C, et al. Feasibility, safety and outcomes of playing Kinect Adventures!™ for people with Parkinson's disease: a pilot study. Physiotherapy 2014;100:162–8. http://dx.doi.org/10.1016/j.physio.2013.10.003.
[13] Pompeu JE, dos Santos Mendes FA, da Silva KG, Lobo AM, de Paula Oliveira T, Zomignani AP, et al. Effect of Nintendo Wii™-based motor and cognitive training on activities of daily living in patients with Parkinson's disease: a randomised clinical trial. Physiotherapy 2012;98:196–204. http://dx.doi.org/10.1016/j.physio.2012.06.004.
[14] Assad O, Hermann R, Lilla D, Mellies B, Meyer R, Shevach L, et al. Motion-based games for Parkinson's disease patients. In: Anacleto JC, Fels S, Graham N, Kapralos B, El-Nasr MS, Stanley K, editors. Entertainment Computing – ICEC 2011. Springer, Berlin, Heidelberg; 2011. p. 47–58.
[15] Jones CRG, Jahanshahi M. Motor and perceptual timing in Parkinson's disease. Adv Exp Med Biol 2014;829:265–90. http://dx.doi.org/10.1007/978-1-4939-1782-2_14.
[16] Grahn JA, Brett M. Impairment of beat-based rhythm discrimination in Parkinson's disease. Cortex 2009;45:54–61. http://dx.doi.org/10.1016/j.cortex.2008.01.005.
[17] Benoit C-E, Dalla Bella S, Farrugia N, Obrig H, Mainka S, Kotz SA. Musically cued gait-training improves both perceptual and motor timing in Parkinson's disease. Front Hum Neurosci 2014;8:494. http://dx.doi.org/10.3389/fnhum.2014.00494.
[18] Lim I, van Wegen E, de Goede C, Deutekom M, Nieuwboer A, Willems A, et al. Effects of external rhythmical cueing on gait in patients with Parkinson's disease: a systematic review. Clin Rehabil 2005;19:695–713. http://dx.doi.org/10.1191/0269215505cr906oa.
[19] Cochen De Cock V, Dotov DG, Ihalainen P, Bégel V, Galtier F, Lebrun C, et al. Rhythmic abilities and musical training in Parkinson's disease: do they help? Npj Park Dis 2018;4:8. http://dx.doi.org/10.1038/s41531-018-0043-7.
[20] Ford MP, Malone LA, Nyikos I, Yelisetty R, Bickel CS. Gait training with progressive external auditory cueing in persons with Parkinson's disease. Arch Phys Med Rehabil 2010;91:1255–61. http://dx.doi.org/10.1016/j.apmr.2010.04.012.
[21] Dalla Bella S, Benoit C-E, Farrugia N, Schwartze M, Kotz SA. Effects of musically cued gait training in Parkinson's disease: beyond a motor benefit. Ann N Y Acad Sci 2015;1337:77–85. http://dx.doi.org/10.1111/nyas.12651.
[22] Nombela C, Hughes LE, Owen AM, Grahn JA. Into the groove: can rhythm influence Parkinson's disease? Neurosci Biobehav Rev 2013;37:2564–70. http://dx.doi.org/10.1016/j.neubiorev.2013.08.003.
[23] Ghai S, Ghai I, Schmitz G, Effenberg AO. Effect of rhythmic auditory cueing on parkinsonian gait: a systematic review and meta-analysis. Sci Rep 2018;8:1–19. http://dx.doi.org/10.1038/s41598-017-16232-5.
[24] Nieuwboer A. Cueing for freezing of gait in patients with Parkinson's disease: a rehabilitation perspective. Mov Disord 2008;23:475–81. http://dx.doi.org/10.1002/mds.21978.
[25] Nieuwboer A, Kwakkel G, Rochester L, Jones D, van Wegen E, Willems AM, et al. Cueing training in the home improves gait-related mobility in Parkinson's disease: the RESCUE trial. J Neurol Neurosurg Psychiatry 2007;78:134–40. http://dx.doi.org/10.1136/jnnp.200X.097923.
[26] Harris DM, Rantalainen T, Muthalib M, Johnson L, Teo W-P. Exergaming as a viable therapeutic tool to improve static and dynamic balance among older adults and people with idiopathic Parkinson's disease: a systematic review and meta-analysis. Front Aging Neurosci 2015;7:167. http://dx.doi.org/10.3389/fnagi.2015.00167.
[27] Bégel V, Seilles A, Dalla Bella S. Rhythm Workers: a music-based serious game for training rhythm skills. Music Sci 2018 [In Press].
[28] Hoehn MM, Yahr MD. Parkinsonism: onset, progression and mortality. Neurology 1967;17:427–42.
[29] Goetz CG. Movement Disorder Society-Unified Parkinson's Disease Rating Scale (MDS-UPDRS): a new scale for the evaluation of Parkinson's disease. Rev Neurol (Paris) 2010;166:1–4. http://dx.doi.org/10.1016/j.neurol.2009.09.001.
[30] Nasreddine ZS, Phillips NA, Bédirian V, Charbonneau S, Whitehead V, Collin I, et al. The Montreal Cognitive Assessment MoCA: a brief screening tool for mild cognitive impairment. J Am Geriatr Soc 2005;53:695–9. http://dx.doi.org/10.1111/j.1532-5415.2005.53221.x.
[31] Auquier P, Sapin C, Ziegler M, Tison F, Destée A, Dubois B, et al. Validation of the French language version of the Parkinson's Disease Questionnaire - PDQ-39. Rev Neurol (Paris) 2002;158:41–50.
[32] Gil-Gómez J-A, Gil-Gómez H, Lozano-Quilis J-A, Manzano-Hernández P, Albiol-Pérez S, Aula-Valero C. SEQ: Suitability Evaluation Questionnaire for virtual rehabilitation systems. Application in a virtual rehabilitation system for balance rehabilitation. Proc. 7th Int. Conf. Pervasive Comput. Technol. Healthc., ICST. Brussels, Belgium: ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering); 2013. p. 335–8. http://dx.doi.org/10.4108/icst.pervasivehealth.2013.252216.
[33] Kizony R, Katz N, (Tamar) Weiss PL. Adapting an immersive virtual reality system for rehabilitation. J Vis Comput Animat 2003;14:261–8. http://dx.doi.org/10.1002/vis.323.
[34] Witmer BG, Singer MJ. Measuring presence in virtual environments: a presence questionnaire. Presence Teleoperators Virtual Environ 1998;7:225–40. http://dx.doi.org/10.1162/105474698565686.
[35] Iversen JR, Patel AD. The Beat Alignment Test (BAT): surveying beat processing abilities in the general population. In: Miyazaki K, Hiraga Y, Adachi M, Nakajima Y, Tsuzaki M, editors. Proc. 10th Int. Conf. Music Percept. Cogn. Adelaide: Causal Productions; 2008. p. 465–8.
[36] Dalla Bella S, Farrugia N, Benoit C-E, Begel V, Verga L, Harding E, et al. BAASTA: Battery for the Assessment of Auditory Sensorimotor and Timing Abilities. Behav Res Methods 2017;49:1128–45. http://dx.doi.org/10.3758/s13428-016-0773-6.
[37] Puyjarinet F, Bégel V, Lopez R, Dellacherie D, Dalla Bella S. Children and adults with Attention-Deficit/Hyperactivity Disorder cannot move to the beat. Sci Rep 2017;7:11550. http://dx.doi.org/10.1038/s41598-017-11295-w.
[38] van den Heuvel MRC, Kwakkel G, Beek PJ, Berendse HW, Daffertshofer A, van Wegen EEH. Effects of augmented visual feedback during balance training in Parkinson's disease: a pilot randomized clinical trial. Parkinsonism Relat Disord 2014;20:1352–8. http://dx.doi.org/10.1016/j.parkreldis.2014.09.022.
[39] Dalla Bella S, Benoit C-E, Farrugia N, Keller PE, Obrig H, Mainka S, et al. Gait improvement via rhythmic stimulation in Parkinson's disease is linked to rhythmic skills. Sci Rep 2017;7:42005. http://dx.doi.org/10.1038/srep42005.
[40] Dalla Bella S, Dotov DG, Bardy BG, Cochen De Cock V. Individualization of music-based rhythmic auditory cueing in Parkinson's disease. Ann N Y Acad Sci 2018. http://dx.doi.org/10.1111/nyas.13859 [In Press].
[41] Petersen K, Van Wouwe N, Stark A, Lin Y-C, Kang H, Trujillo-Diaz P, et al. Ventral striatal network connectivity reflects reward learning and behavior in patients with Parkinson's disease. Hum Brain Mapp 2018;39:509–21. http://dx.doi.org/10.1002/hbm.23860.
[42] Sihvonen AJ, Särkämö T, Leo V, Tervaniemi M, Altenmüller E, Soinila S. Music-based interventions in neurological rehabilitation. Lancet Neurol 2017;16:648–60. http://dx.doi.org/10.1016/S1474-4422(17)30168-0.