Exergaming-Based Dexterity Training in Persons With Parkinson Disease: A Pilot Feasibility Study

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Background and Purpose: Many individuals with Parkinson disease (PD) suffer from impaired dexterity, which impacts activities of daily living and quality of life. Exergaming, video game-based training with augmented virtual reality, may have value for improving function. The aim of the present pilot study was to comprehensively evaluate the feasibility of a dexterity training program using exergaming, in individuals with PD.

Methods: Ten participants with PD (aged between 55 and 75 years, Hoehn and Yahr stages II-IV) trained over a period of 4 weeks, twice a week for 30 minutes. Baseline (T0) and postintervention (T1) assessments were done. Primary outcomes with respect to feasibility were the adherence rate, open-end questions, the level of participation (Pittsburgh Rehabilitation Participation Scale), and the usability (System Usability Scale). Dexterous function was measured with the Nine-Hole Peg Test and the Dexterity Questionnaire-24. Upper limb motor impairment was assessed by a modified version of the Movement Disorders Society Unified Parkinson's Disease Rating Scale III. Finally, quality of life was assessed by the 39-item Parkinson's Disease Questionnaire (PDQ-39).

Results: Adherence rate was 99%, motivation increased significantly from 3.9 to 4.8 (Pittsburgh Rehabilitation Participation Scale, $P = 0.03$), and system usability of the exergaming system was acceptable to very good. Regarding potential efficacy, participants with impaired dexterity at T0 significantly improved in the Nine-Hole Peg Test and the PDQ-39.

Discussions and Conclusions: The outcomes of this pilot study suggest that exergaming is feasible and has potential to improve dexterity in individuals with PD. Its efficacy should be investigated in a properly powered randomized controlled trial.

Video Abstract available for more insights from the authors (see Supplemental Digital Content 1, available at: http://links.lww.com/JNPT/A270).

Key words: *dexterity, exergaming, feasibility, Parkinson disease, rehabilitation, virtual reality*

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INTRODUCTION

Impaired dexterity is a common problem faced by many individuals with Parkinson disease (PD).[1-5] Even in early stages of PD, individuals often experience difficulty performing manual activities of daily living (ADL), such as handling mobile phones, fastening buttons, or tying shoe laces.[2] Subsequently, many individuals perceive fine motor skills as very problematic.[6] Impaired dexterity contributes to reduced quality of life (QoL),[4] adding to the burden of the disease.[2]

To date, evidence is scarce with respect to specific dexterity interventions for individuals with PD.[5] Just recently, it has been shown, in a first large randomized controlled trial (RCT), that home-based dexterity training significantly improved dexterity in individuals with PD.[5] A relatively new, but rapidly growing aspect of training in neurorehabilitation is exergaming.[7,8] Exergaming combines video game-based training with augmented virtual reality (VR),[8] and is intended to be engaging and challenging, therefore stimulating motivation and increasing exercise adherence.[7] Further advantages of exergaming are the possibilities to adapt the level of exercise difficulty, and to provide online visual and/or verbal feedback during the exercise.[7] All these aspects are important to optimize motor learning in individuals with PD.[9] Two recent pilot RCTs using exergaming based on commercially available systems (Microsoft Kinect[10] and Nintendo Wii-Fit[11]) demonstrated improved standing balance and reduced fatigue in participants with PD. However, these devices are not capable of detecting and monitoring fine, coordinated dexterous movements. Exergaming systems consisting of an optoelectronic device that track the motion of both hands as well as fingers within a VR environment may be of value as an adjunct to training for improved dexterity.[12,13] In participants with stroke, good feasibility of this exergaming system to train dexterity has been shown.[14] Butt and colleagues[15] also demonstrated the

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potential use of this approach to evaluate motor performance in participants with PD.

To our knowledge, no studies have comprehensively addressed the feasibility, usability, and potential efficacy of exergaming dexterity training in participants with PD. Exergaming-based dexterity training might be an attractive way to improve dexterity within a VR environment in individuals with PD, as it offers extrinsic feedback and the possibility to modulate task difficulty. Therefore, the aim of the present study was to evaluate the feasibility and usability of a 4-week video Exergaming-based dexterity training program with augmented VR in participants with PD. We hypothesized that 4 weeks of exergaming would be feasible and usable, and would show potential to improve dexterity and QoL in participants with PD. The current study will be used to inform the planning of a larger study.

METHODS

Participants

A convenience sample of 10 participants with PD, defined by the UK Parkinson's Disease Society Brain Bank Criteria,[16] with Hoehn and Yahr stages II to IV, 55 years and older or 75 years or younger, was recruited from the Neurocenter, Luzerner Kantonsspital, Switzerland. Participants were included when they reported subjective dexterous difficulties during clinic visits. Exclusion criteria were severe medical conditions, including psychiatric disease, impaired cognitive functioning as defined by a Montreal Cognitive Assessments (MoCA) score of less than 21,[17] excessive or uncontrollable tremors of the upper extremities, or presence of any neurological disorder other than PD. Prior to study participation, written informed consent was obtained from all participants according to the latest Declaration of Helsinki.[18] Ethical approval was given by the ethics committee of the State of Lucerne, Switzerland. The study conformed to the recommendations for reporting the results of pilot feasibility studies,[19] which are adopted from the CONSORT Statement.

Procedure

The intervention took place at an outpatient Parkinson center, Luzerner Kantonsspital, and all participants were instructed and supervised by an expert clinician (J.v.B.). The training program consisted of 30 minutes' sessions performed twice a week for 4 weeks, so in total 8 training sessions. Upon consent, baseline (hereafter called T0) outcome assessments were done, which were repeated after completion of the training program (T1). At T1 participants completed further feasibility and usability measures. We aimed to test the participants in their best dopaminergic "On" state (approximately 1-1.5 hours after medication intake).

Exergaming Dexterity Intervention

We used a commercially available exergaming system (Leap Motion Controller, see also: https://www.leapmotion.com/) that comprises an inexpensive, markerless motion sensing system that tracks the motion of both forearms, wrists, and hands with an accuracy of less than 0.2 mm.[12,13] Illustrated in Figure 1, the exergaming system used in this study consists of 3 infrared light emitters (triangles) and 2 charge-coupled device cameras (hexagons) placed inside a small casing.[12] The light of the infrared emitters reflects back from the surfaces of the hands.[12] Consequently, no markers are needed, which makes the exergaming system easy to use. Furthermore, it is small (80 mm × 30 mm × 11.25 mm),[12] portable, and can easily be connected to a computer or laptop. Moreover, the exergaming system is user friendly since no physical contact is needed to interact with the computer or laptop.

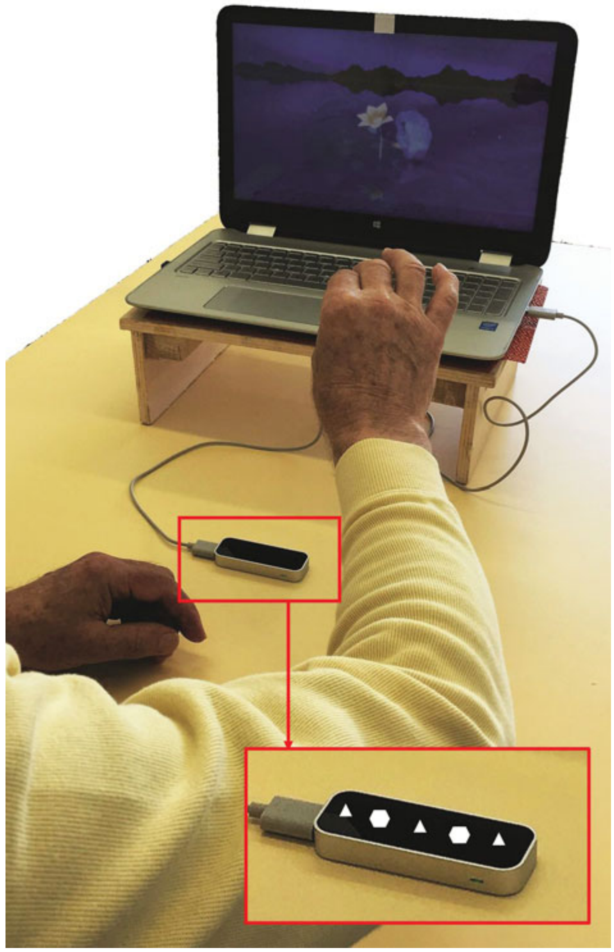

Figure 1. Setup of the exergaming dexterity intervention. Triangles indicate infrared light emitters; hexagons indicates charge-coupled device cameras.

During training sessions, participants sat at a table with a laptop positioned approximately 1 m away. The exergaming device was located between the participant and the laptop, which was placed on a small box of approximately 10 cm (see also the Video, Supplemental Digital Content 1, available at: http://links.lww.com/JNPT/A270, which demonstrates the setting). A pillow was used to support the arms if needed.

The dexterity exergames were selected to target fundamental elements of dexterity, as previously defined[3]: finger independence, finger coordination, pointing, and wrist extension/flexion. Based on expert consensus of 3 of the authors (J.v.B., T.V., and S.B.), 5 exergames were downloaded free from the manufacturer's Web site (Leap Motion Gallery: Cut the Rope, Dots, Blocks, Flower, and ASL Digits, see also: https://gallery.leapmotion.com/). One of the games is illustrated at the end of the Video Abstract (see Supplemental Digital Content 1, available at: http://links.lww.com/JNPT/A270, for a demonstration of the game "Flowers") and a description of the played games is given in supplementary PDF file 1 (see Supplementary Digital Content 2, available at: http://links.lww.com/JNPT/A271). The level of difficulty was progressively modified over the course of the intervention. This modification was done during gameplay by the therapist.

To make sure that participants fully understood the training before the first training session, participants practiced each of the 5 dexterity exergames for approximately 6 minutes, in a random order using computerized randomization by the function "randperm" using MATLAB R2013b (Mathworks, Natick, Massachusetts). Each game was played starting with the less affected hand. Both hands were trained equally and bilateral games were also included.

Outcome Measures

All outcome measures at T0 and T1 were collected and rated by a single expert clinician (J.v.B.) to achieve optimum standardization of outcome measurement.

Primary Outcomes

Feasibility was comprehensively measured by (1) the adherence rate: the ratio of the total time spent on intervention (TT) and planned time (PT; ie, TT / PT × 100%), (2) the level of motivation, measured with the Pittsburgh Rehabilitation Participation Scale (PRPS),[20] (3) the subjective opinion of the participants, evaluated by open-end questions in an interview form, and (4) usability of the exergaming device with the System Usability Scale (SUS).[21]

To determine the adherence rate, the time spent on every training session was recorded by the expert clinician (J.v.B.). The TT was compared to the PT (5 games × 6 minutes × 8 sessions = 4 hours) to evaluate whether participants were conformant to the intervention. An adherence rate of 80% was defined as good.[14,22] Participants' participation (as defined by the level of effort and motivation) during the training sessions was measured by the PRPS.[20] This measure is a 6-point scale whereby participants' participation is scored by the therapist from 1 (no) to 6 (excellent). During every game, the clinician scored the interest, independence, and motivation of the participants. Subsequently, the average score of the 8 sessions was calculated. With respect to the open-end questions, the participants were asked about (1) their overall impression of the therapy, (2) the duration of the therapy, (3) the potential home use of exergaming, (4) the most favorite, and (5) the least favorite game. The answers were scored as either positive (1 point), negative (0 point), or neutral (no score).

The SUS is a questionnaire, consisting of a 10-item Likert scale—each item is scored from 0 (strongly disagree) to 4 (strongly agree)—which takes 3 usability criteria into account: effectiveness, efficiency, and satisfaction.[21,23] The total score is obtained by multiplying the mean sum value by 2.5. The SUS score has a range of 0% to 100%, where a higher value indicates better system usability. A score of 60% up to a maximum 100% represents acceptable to excellent usability.[21,23]

Secondary Outcomes

Two validated dexterity measures were used to obtain an estimation of the value of the intervention. First, the Nine-Hole Peg Test (9-HPT), which is a standardized, well validated capacity measure for dexterity in persons with PD.[24] The time to complete the task was recorded for each hand separately. Second, the Dexterity Questionnaire-24 (DextQ-24) was used, a standardized patient self-rated outcome measure for evaluating dexterity-related ADL in individuals with PD (for more details see Vanbellingen et al[3]).

To assess QoL we used the 39-item Parkinson's Disease Questionnaire (PDQ-39).[25] The questionnaire consists of 39 questions, which collapse into 8 subscales (mobility, ADL, emotional well-being, stigma, social support, cognition, communication, and bodily discomfort). The total score is given by the sum of all items and is then transformed in a range from 0 to 100. A lower value corresponds to a better perception of the subject's QoL.

The severity of motor deficits was measured using a modified version of motor examination part III from the Movement Disorders Society Unified Parkinson's Disease Rating Scale (MDS-UPDRS),[26] which consisted of the upper limb items 3.3 to 3.6, 3.15 to 3.18. To further improve the reliability of scoring, the participants' performance on all items of part III was videotaped.

Statistical Analysis

Descriptive statistics were used to present baseline and clinical characteristics of all participants. For missing data, the last value observed was carried forward. Normality of distribution of all outcome measurements (primary and secondary) was checked by Shapiro-Wilk tests. In addition, skewness and kurtosis of the residuals were used to further check for normal distribution of outcome scores. For the whole group analysis, depending on the normality of distribution of outcome scores, either parametric-repeated measures analysis of variance (ANOVA) or nonparametric statistics (Friedman's ANOVA) were done as a primary analysis (T0 vs T1) for all outcome measures. Because in PD discrepancies between subjective self-reports and objective performance rating can occur,[27] we performed a secondary analysis. We subdivided participants in 2 groups based on established normative cut-off values for the 9-HPT (ie, those having pathological or no pathological dexterity at T0).[28] Subsequently, we performed between-group analyses for all demographic and clinical outcomes measures by means of either the 1-way ANOVA or the nonparametric Kruskal-Wallis test, depending on normality of distribution. In case of significant interactions, post hoc paired t tests were done to compare means (T0 vs T1) within the groups. To explore relationships between clinical parameters (such as disease severity, disease duration, cognition, and dexterity) and usability scores, Pearson or Spearman correlations were done.

All statistical analyses were performed using Statistical Package for Social Science (SPSS for Windows, version 24.0;

Table 1. Participant Clinical and Demographic Characteristics[a]

Characteristics	Data
Age, y	65.40 ± 7.01 (55-75)
Gender (male/female), n	7/3
Disease duration, y	8.50 ± 4.38 (2-14)
Hoehn and Yahr stage	2.40 ± 0.699 (2-4)
(II/III/IV), n	7/2/1
Levodopa equivalent	670 ± 388 mg/d
MoCA	25.20 ± 2.44 (22 - 29)
Handedness (right/left), n	7/3
More affected side (right/left), n	4/6

Abbreviation: MoCA, Montreal Cognitive Assessment.
[a]Total sample: n = 10. All values are presented as mean ± standard deviation (range) or otherwise stated.

SPSS Inc, Chicago, Illinois). The level of significance was set at $P < 0.05$.

RESULTS

Recruitment took place between February and June 2017 (see the Flowchart, Supplemental Digital Content 3, available at: http://links.lww.com/JNPT/A272).

All 10 participants completed the exergaming-based dexterity training, indicating 100% adherence to the training protocol. In addition, there were no reported adverse effects or complications. Detailed clinical and demographic characteristics are presented in the Table 1.

Primary Outcomes

Adherence rate with regard to the average total time spent on the exercises was 3 hours 57 minutes (standard deviation [SD] = 24 minutes) compared with the planned time (SD = 4 hours), being 99%.

Motivation, as measured with the PRPS, significantly increased from 3.9 at T0 to 4.8 at T1 ($F_{[1,9]} = 6.90$, $P = 0.03$; $\eta^2 = 0.43$, $P = 0.03$). For more details see Figure 2.

The open-end questions revealed that the overall impression of participants was positive. All participants reported that dexterity training might be helpful for improving or maintaining dexterity. Moreover, participants reported that they enjoyed the interactive nature of the exergaming intervention. Eight of 10 participants were positive about the duration of exercise. Two participants would have liked to play longer. Six participants reported that they would buy the exergaming device in its present form, and to use it for home purposes. Some critical feedback concerned (1) the difficulty of the exercises, some requiring a high level of concentration throughout the whole gameplay (such as for the game Dots), and (2) the exergaming device having occasional difficulty reconstructing the fingertip trajectories, when finger movements were very fast. This qualitative feedback of the open-end questions was also reflected in the usability scores at T1, in which 6 of 10 participants rated the exergaming device above 60%, indicating good usability, 1 participant rated approximately 58%, meaning acceptable usability, and 3 participants below 50%, meaning poor usability. For more details see Figure 3.

We did not find significant correlations between MoCA, disease duration, severity (Hoehn and Yahr), dexterity, and usability scores ($r = -0.12$, $P = 0.9$; $r = -0.45$, $P = 0.2$; $r = -0.54$, $P = 0.1$; $r = -0.34$, $P = 0.3$).

Secondary Outcomes

The whole group analyses revealed no significant differences between T0 and T1 for the secondary outcomes (9-HPT, DextQ-24, PDQ-39, and MDS-UPDRS III). The comparison of the 9-HPT performance of the participants with established normative cutoff values revealed that 6 participants performed within normal range at T0 (good dexterity) and 4 were above cutoff (poor dexterity). Taking this into account, the secondary between group analysis revealed a significant time×group interaction effect, $F_{[1,8]} = 5.99$, $P = 0.04$, $\eta^2 = 0.43$, for the left hand 9-HPT performance (see also Figure 4).

Thus, while participants with poor dexterity at T0, dexterity significantly improved (T0 = 39.59, SD = 23.61 vs T1 = 35.04, SD = 20.88, $P = 0.04$), participants with good dexterity did not improve (T0 = 19.78, SD = 2.07 vs T1 = 19.60, SD = 3.69, $P = 0.82$). For the right-hand 9-HPT, secondary analysis revealed no time×group interaction effect, $F_{[1,8]} = 2.55$, $P = 0.15$, $\eta^2 = 0.24$. Participants with PD with poor dexterity did not improve (T0 = 29.27, SD = 4.30 to T1 = 31.15, SD = 8.09, $P = 0.38$), and this was also the case for participants with good dexterity (T0 = 19.33, SD = 2.33 to T1 = 17.79, SD = 1.93, $P = 0.18$).

A significant time×group interaction effect was found for the PDQ-39 ($F_{[1,8]} = 8.53$, $P = 0.02$, $\eta^2 = 0.52$). QoL significantly improved for the participants with poor dexterity (PDQ values at T0 = 36.66, SD = 11.64 vs T1 = 23.20, SD = 5.16, $P = 0.03$), while for the participants with good dexterity

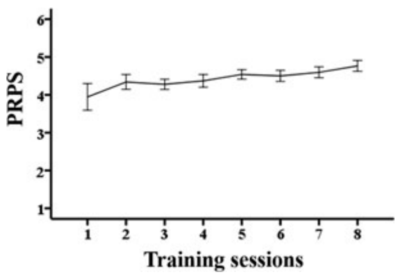

Figure 2. Mean PRPS scores of all participants after each training session. Error bars indicate standard error of the mean. PRPS, Pittsburgh Rehabilitation Participation Scale.

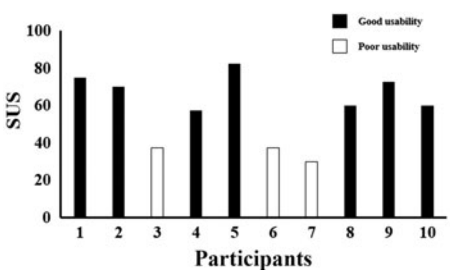

Figure 3. SUS scores for each participant. SUS, System Usability Scale.

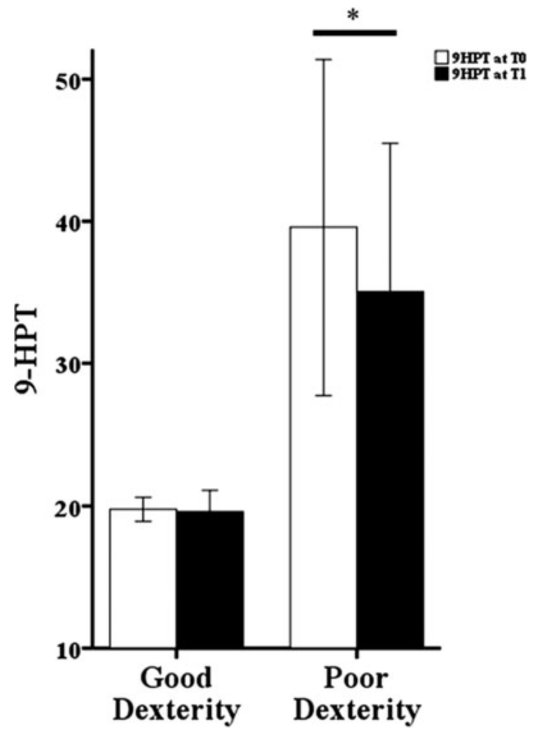

Figure 4. Significant between-group interaction effect for left 9-HPT. Error bars indicate standard error of the mean. There were no significant differences between groups for age ($P = 0.4$), disease severity ($P = 0.2$), disease duration ($P = 0.5$), and cognition ($P = 0.3$). 9-HPT, Nine-Hole Peg Test.

there was no improvement (PDQ values at T0 = 21.35, SD = 13.34 vs T1 = 21.58, SD = 17.36, $P = 0.93$)

For the DextQ-24, no significant time×group interaction effects were found, $F_{[1,8]} = 0.95$, $P = 0.36$, $\eta^2 = 0.11$, which means that, although average scores decreased, subjective dexterity did not improve for participants having either poor (T0 = 35.00, SD = 3.65 to T1 = 29.00, SD = 4.24, $P = 0.13$) or good dexterity (T0 = 36.17, SD = 7.31 to T1 = 34.17, SD = 8.04, $P = 0.50$). Also, for upper limb motor parkinsonian symptoms, there were no time×group interaction effects, $F_{[1,8]} = 0.10$, $P = 0.76$, $\eta^2 = 0.01$, which means that for both participants with poor (T0 = 8.25, SD = 5.12 to T1 = 7.50, SD = 3.70, $P = 0.65$) or good dexterity (T0 = 6.33, SD = 7.94 to T1 = 6.00, SD = 7.80, $P = 0.47$) no improvements were found.

DISCUSSION

The aim of the present pilot study was to comprehensively evaluate the feasibility of a 4-week Exergaming-based dexterity training in participants with PD. The high adherence rate of 99% confirms the feasibility of exergaming-based dexterity training. This is also expressed by the evidence that the participants were well motivated throughout the 4-week exergaming-based dexterity training and showed high adherence to the training protocol. In addition, overall, most participants rated the exergaming device with its videogames as a usable tool to improve dexterity. Especially, participants with poor dexterity at the start of the exergaming training program significantly improved their dexterous performance, which also transferred to an improved QoL.

In contrast to a previously published small feasibility study in participants with PD,[29] our study comprehensively demonstrates excellent feasibility, by a high adherence rate (99%) to the training protocol, and a high level of active participation rates. The latter expresses good effort and high motivation of the participants, which are crucial components of optimal training and were not reported previously.[29] In fact, during the 4-week exergaming-based dexterity training, participation rates even further improved, meaning that the training stimulated motivation, which is in line with other exergame training.[10,11] It is likely that users are challenged by the exergames, because they experience for the dexterity training in the novel VR environments. In contrast to traditional dexterity training, where real objects are used,[5] the subject matter now is presented in a visual 3-dimensional format, which is new for all participants. The exergames trained different aspects of dexterity, such as finger coordination, pointing, and wrist flexion/extension, therefore attributing to a high degree of variety to the training. In addition, the exergaming software provided feedback regarding progression in difficulty and performance, thereby further contributing to the high level of motivation. Variability in exercise, augmented feedback, progression in difficulty—are all important aspects, which may facilitate motor learning.[9]

Most participants enjoyed the training and indicated that they would continue the training at home. Whether a home-based exergaming dexterity training intervention could also improve dexterity needs further study. Recently, a home-based exergame step training program demonstrated improved self-reported mobility in some participants with PD.[30] It is possible that in future studies a similar outcome will be found for home-based exergaming dexterity intervention. Finally, a recent case report suggests that a telehealth approach is also associated with improved adherence to a home exercise program developed for persons with PD.[31] Since our results indicate exergaming dexterity training is associated with high levels of adherence, there may be a value in combining exergame-based dexterity training with a telehealth program for home-based rehabilitation.

With regard to the usability of the exergaming device, participant ratings ranged from acceptable to very good for 7 out of the 10 participants and are comparable with previous studies.[29] Three participants rated low on satisfaction with the exergaming dexterity training. One reason might be that rapid finger movements during the games (such as for Cut the Rope) were sometimes not well traced by the device sensors, leading to glitches in visual feedback, which may have caused some frustration. This observation has been described previously.[15] Another participant's feedback concerned the amount of attention and planning, which were needed, besides the performance of finger movements to complete the task (especially for the game Dots). Both are higher executive cognitive functions and it is known that training in VR environments may require motor-cognitive dual tasking, which may lead to cognitive overload,[32,33] even in participants having largely preserved cognitive skills, as in our study.

Although this feasibility study was not designed or powered to investigate efficacy with respect to dexterity, comparison of pretraining to posttraining performance and QoL scores in those participants with PD with greater impairment of dexterity suggests that the exergaming-based dexterity training may have value for improving dexterity. The pretraining to posttraining differences were only found for the left, and not for the right hand. This might be explained by the fact that more participants had more impaired dexterity in the left hand (6 of the 10 participants) therefore having greater margin for more improvement. Moreover, 3 of the 4 participants belonging to the poor dexterity group were also more affected on the left side. Handedness did not play a role since only 1 of these 4 participants (of the poor dexterity group) was left handed. Participants having no impairment of dexterity at the start of the training, according to an objective capacity measure being the 9-HPT, did not demonstrate change in performance, which may be explained by ceiling effects.

A limitation of the present study is that we included a small sample of participants with PD who had relatively good cognitive function. Therefore, we cannot generalize our findings to individuals with more severe cognitive impairment. It might be expected that individuals with PD who have greater cognitive impairment will be more dependent on therapists' support during exergaming dexterity training. In addition, it might be questioned whether, due to cognitive overload of VR training, individuals with significant cognitive impairment will benefit from the exergaming dexterity training approach. For these individuals, conventional dexterity training (eg, the HOMEDEXT[5]) might be more beneficial. Finally, due to the pilot nature of this feasibility study, we did not include a control group and so no claims of efficacy can be made. Likewise, since there was only a single group, the investigator providing the outcomes assessments was not masked. Both a control group and assessor masking are needed if the efficacy of exergaming dexterity training is to be investigated.

CONCLUSIONS

The present pilot study is the first to address the feasibility and usability of specific dexterity training in participants with PD using an exergaming-based approach. The intervention may be specifically suitable for individuals with PD in the early stages of dexterity impairment. Future studies should investigate its efficacy for improving impaired dexterity and QoL by a properly powered RCT. Due to its relative affordability, ease of use, and free accessibility of software games, exergaming-based dexterity training could also be tested as home-based dexterity intervention.

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