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Research report

Retention of touchscreen skills is compromised in Parkinson's disease

Evelien Nackaerts[a,*], Pieter Ginis[a], Elke Heremans[a], Stephan P. Swinnen[b,c], Wim Vandenberghe[d,e], Alice Nieuwboer[a,c]

[a] Research Group for Neurorehabilitation (eNRGy), Department of Rehabilitation Sciences, KU Leuven, Tervuursevest 101, box 1501, Leuven, Belgium
[b] Movement Control & Neuroplasticity Research Group, Department of Movement Sciences, KU Leuven, Tervuursevest 101, box 1501, Leuven, Belgium
[c] Leuven Brain Institute (LBI), KU Leuven, Leuven, Belgium
[d] Department of Neurology, University Hospitals Leuven, Herestraat 49, Leuven, Belgium
[e] Laboratory for Parkinson Research, Department of Neurosciences, KU Leuven, O&N IV Herestraat 49, box 602, Leuven, Belgium

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ABSTRACT

Fine motor skill impairments likely have a severe impact on the use of touchscreens in Parkinson's disease (PD). Although recent work showed positive effects of intensive writing training, many questions remained regarding the consolidation of motor learning in PD. The current study examined the effects of PD on practicing the manipulation of touchscreen technology and whether this can lead to 24h-retention and transfer. We developed the Swipe-Slide Pattern (SSP)-task, similar to handling a touchscreen unlock-trace. On day 1, 11 patients and 10 healthy, age-matched controls underwent two consecutive runs of early and late learning (9 × 36 s SSP and 36 s rest). This was followed by a retention test after 24 h, including the assessment of transfer. Movement time (MT, s), Euclidean distance (ED) and a performance index (PI = MT/ED) were compared across the learning phases (early, late, retention and transfer) for both groups. Additionally, a learning, retention and transfer index were compared between groups and correlated to clinical characteristics. Both groups significantly improved in MT and PI across practice. However, while healthy adults showed further improvements after a 24h-retention period, patients presented with impaired retention indices. This was correlated with disease duration, disease severity and performance on a daily life mobile phone task. Finally, transfer to a similar, but untrained pattern was comparable between both groups. Overall, short-term practice of the SSP-task results in improvements for PD patients, albeit with impaired retention. Future work should investigate whether prolonged touchscreen skill training can be retained in motor memory in PD.

1. Introduction

Rehabilitation forms an important part of therapy for patients with Parkinson's disease (PD) [1], a neurodegenerative disorder mainly affecting the basal ganglia. However, as the basal ganglia, and particularly the striatum, are involved in motor learning, it is not surprising that the ability to learn and refine motor skills is impaired in PD [2,3]. In healthy adults the associative striatum and its connections are recruited during the early phase of learning [4–8]. In contrast, the sensorimotor network involving dorsolateral putamen is engaged in the consolidation of motor learning [4–8]. This sensorimotor network is already impaired early on in PD [9–11], suggesting that consolidation may be affected. Retention and transfer are two aspects of consolidation, resp. defined as the ability to sustain improvements over time without practice and the capacity to apply the learned skill to a similar but untrained motor task. So far, researchers in PD investigated motor learning abilities mostly using either visuomotor adaptation or motor sequence learning (MSL) paradigms yielding differing results. For visuomotor adaptation tasks, studies consequently showed that retention is impaired in PD despite preserved initial learning [3,12–15]. For MSL, the literature is less consistent. The majority of studies confirmed that initial learning is relatively intact in PD [16–23]. Some difficulties are

Abbreviations: COV, coefficient of variation; DextQ-24, dexterity questionnaire; ED, euclidean distance; HC, healthy control; H&Y, Hoehn & Yahr stage; LED, levodopa equivalent dose; MDS-UPDRS-III, movement disorders society unified Parkinson's disease rating scale part III; MMSE, mini-mental state examination; MoCA, Montreal cognitive assessment; MSL, Motor sequence learning; MT, movement time; MWU, mann-whitney U test; PD, Parkinson's disease; PI, performance index; SSP-task, swipe slide pattern task; VAS, visual analogue scale

* Corresponding author at: Department of Rehabilitation Sciences, KU Leuven, Tervuursevest 101, box 1501, B-3000, Leuven, Belgium.
E-mail addresses: evelien.nackaerts@kuleuven.be (E. Nackaerts), pieter.ginis@kuleuven.be (P. Ginis), elke.heremans@uhasselt.be (E. Heremans), stephan.swinnen@kuleuven.be (S.P. Swinnen), wim.vandenberghe@uzleuven.be (W. Vandenberghe), alice.nieuwboer@kuleuven.be (A. Nieuwboer).

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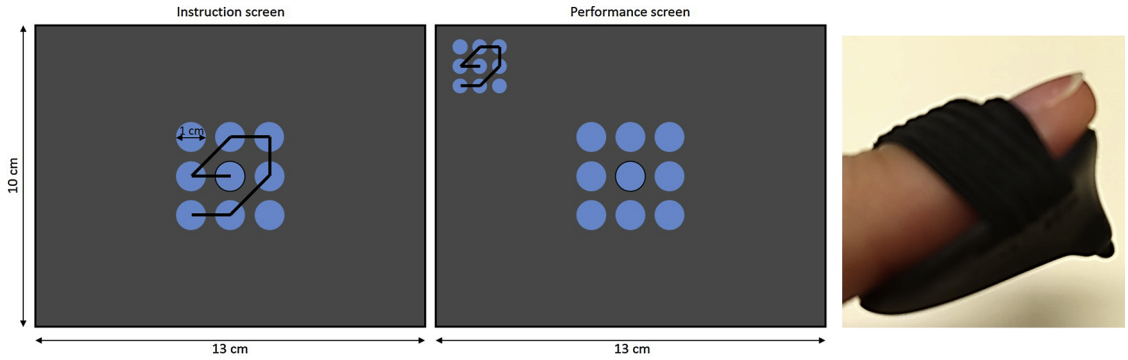

Fig. 1. The Swipe-Slide Pattern task. Participants first looked at an instruction screen for 3 s, showing the pre-defined to-be-learned pattern. When the pattern disappeared, participants started producing the pattern for the remaining 33 s using the provided finger stylus. During this period, the pattern remained visible in the upper left corner of the screen.

present in early learning [24,25], though this is likely the result of the degree of cognitive demand required for the MSL task. Contrary to visuomotor adaptation, retention of MSL was maintained in both patients and healthy controls when tested after 24 h [21,24]. However, approximately 1 year after training, retention was impaired in PD, specifically in those with further striatal degeneration [26]. Skill transfer has been shown to be successful in PD patients, though to a smaller extent as for healthy elderly and primarily when the transfer test occurs under the same conditions as training [27,28]. Overall, these results illustrate the task-specificity of motor learning.

In this study, we investigated the impact of PD on the retention and transfer of a novel motor skill directly relevant for daily life, namely performing a task on a touchscreen, which resembles smartphone or tablet use, thereby requiring dexterity. We defined dexterity in accordance with the International Classification of Functioning, Disability and Health (ICF) as “fine hand use, performing the coordinated actions of handling objects, picking up, manipulating and releasing them using one's hand, fingers and thumb, such as required to lift coins off a table or turn a dial or knob” [29]. The preservation of dexterity is not trivial for PD patients [30,31] and becomes more vital with the increasing importance of smartphone applications for both patient follow-up [32–35] and rehabilitation [36,37]. Though the ability to use smartphones in PD is often assumed [38], it was shown that impaired dexterity hinders the interaction of patients with touchscreen handheld devices [39]. Moreover, if PD patients will need to use mobile-health technology successfully in the future, the robust acquisition of these skills needs to be addressed in rehabilitation programs. Hence, we aimed to understand the impact of PD on touchscreen skill learning. Therefore, we developed the Swipe-Slide Pattern (SSP)-task, in which participants have to learn a sequence of continuous swiping/sliding movements. We hypothesized that both healthy adults and PD patients would be able to learn the SSP-task, but that 24h-retention and transfer would be more compromised in PD. We also predicted that disease severity would be associated with these difficulties.

2. Methods

2.1. Participants

Eleven PD patients and 10 healthy, age-matched controls (HC) were tested. Inclusion criteria for PD patients were: diagnosis of PD according to the United Kingdom PD Society Brain Bank criteria [40]; Hoehn and Yahr (H&Y) stage I to III in the on phase of the medication cycle, with right-sided impairment for patients in H&Y I [41]; and Mini-Mental State Examination (MMSE) ≥ 24 [42]. The exclusion criteria for both groups were: upper-limb problems other than those related to PD; other medical of psychiatric disorders that could interfere with the protocol; and people who play games on a touchscreen-operated device on a daily basis. All patients were tested in the on phase of the medication cycle (±1 h after medication intake). The study design and protocol were approved by the local Ethics Committee of the KU Leuven and were in accordance with the code of Ethics of the World Medical Association (Declaration of Helsinki, version 2013). After complete explanation of the study protocol, written informed consent was obtained from all participants prior to participation in the study.

2.2. Experimental procedure

All participants underwent a two-day testing procedure with practice of the Swipe-Slide Pattern (SSP) task. On day 1, two consecutive runs were performed, each consisting of nine task blocks (each 36 s) and an equal amount of rest. On day 2, all participants had a 24h-retention test, consisting of: (i) a run containing the learned pattern (6 blocks); and (ii) a run including a new pattern to assess transfer (9 blocks). All participants were tested at the same time of day on both test days. At the end of each day, participants indicated fatigue caused by the SSP-task on a visual analogue scale (VAS).

On day 1, all participants additionally underwent a set of cognitive and motor skill tests, including the MMSE, Montreal Cognitive Assessment (MoCA) [43], Dexterity questionnaire (DextQ-24) [44] and a mobile phone task. For the latter, participants had to tap a pre-defined telephone number on a standard smartphone and the required amount of time to complete the task was measured. Three trials were performed. Disease characteristics were evaluated using H&Y staging [41] and the Movement Disorders Society Unified Parkinson’s Disease Rating Scale part III (MDS-UPDRS-III) [45] while on medication. Finally, the levodopa equivalent dose (LED) was calculated.

2.3. Swipe-Slide Pattern (SSP) task

The SSP-task required finger movements to unlock a touchscreen device. Participants learned a pre-defined pattern that remained visible in the upper left corner of the screen during actual task performance to reduce cognitive load (Fig. 1). Additionally, participants were able to see the lines they were drawing. The pattern began in the middle of a nine-circle configuration and consisted of connecting six different circles. Participants were instructed to form the patterns as quickly and accurately as possible. To avoid over-emphasis on accuracy and to obtain fluent movements, the minimal requirement was to touch the within-circle surface. Hence, participants were not required to make movements from the exact center of one circle to the exact center of the next circle. Also, participants were told to move their hand without lifting the finger stylus from the screen to maintain the online trace and to return to a fixed starting point (i.e. the middle circle) when the pattern was completed. After reaching the starting point again, the pattern was erased and participants could continue with making the

Table 1
Demographics and clinical characteristics.

	PD (N = 10)	HC (N = 10)	P-value
Age (years)	67.5 ± 6.2	63.6 ± 6.7	0.194
Gender (M/F)	4 / 6	6 / 4	0.800
MMSE (0-30)	28.2 ± 1.6	29.2 ± 0.9	0.107
MoCA (0-30)	28.0 (24.5, 29.3)	28.0 (27.0, 29.0)	0.739
DEXTQ-24 (24-96)	29.0 (25.8, 32.0)	24.0 (24.0, 24.0)	< 0.001
Disease duration (years since diagnosis)	5.9 ± 4.0	–	–
H&Y (II/III)	8 / 2	–	–
Disease dominance (R/L)	8 / 2	–	–
LED (mg/day)	358.7 ± 172.4	–	–
MDS-UPDRS-III (0-132)	25.8 ± 10.9	–	–
Mobile phone task (s)	9.0 (8.1, 12.0)	7.4 (6.5, 8.3)	0.019
Baseline SSP performance			
- MT (s)	7.41 ± 3.43	7.79 ± 4.23	0.828
- COV_{MT} (%)	27.23 ± 17.96	29.31 ± 10.09	0.766
- ED	3.53 ± 1.05	3.41 ± 0.97	0.791
- COV_{ED} (%)	13.92 ± 8.42	17.70 ± 9.72	0.391
- PI (%)	2.16 ± 0.99	2.24 ± 0.86	0.830

Mean ± Standard deviation or median (IQR) are displayed depending on normality of the data.
Abbreviations: PD = Parkinson's disease; HC = healthy controls; M = male; F = female; MMSE = Mini-Mental State Examination; MoCA = Montreal Cognitive Assessment; DEXTQ-24 = Dexterity questionnaire; H&Y = Hoehn and Yahr stage; LED = Levodopa Equivalent Dose; MDS-UPDRS-III = Movement Disorders Society sponsored revision of the Unified Parkinson's Disease Rating Scale part III; SSP = Swipe Slide Pattern; MT = movement time; COVMT = coefficient of variation of movement time; ED = Euclidean distance; COVED = coefficient of variation of Euclidean distance; PI = performance index.

same pattern for the duration of the trial (36 s). The SSP-task was performed on a custom-made tablet, incorporating a resistive touchscreen in a 4-wire set-up (Fujitsu Components Europe, Hoofddorp, The Netherlands), to allow MRI compatibility for future study. Unpublished pilot work in healthy young adults revealed measurement errors when using the set-up without a finger stylus. Hence, a commercially available finger stylus (Nintendo®) was used to standardize performance (Fig. 1).

2.4. Data processing and statistical analysis

A touch-sensitive tablet (13 x 10 cm) was used to record xy-coordinates at a sampling rate of 200 Hz and with a spatial resolution of 32.5 μm. Patterns were filtered at 7 Hz with a 4th-order Butterworth filter and further processed using MATLAB R2016b (The Mathworks, Natick, Massachusetts, USA). Visual inspection between raw data and MATLAB processing was implemented according to standard lab procedures. Our primary outcome measure was the time necessary to complete the pattern, i.e. movement time (MT, s). In addition, the Euclidean distance (ED), i.e. the deviation between the ideal pattern and the pattern formed, was calculated as a measure of accuracy. For both MT and ED, a coefficient of variation (COV, %) was determined by dividing the within-subject standard deviation by the average. Secondly, a performance index (PI), taking into account both movement time and accuracy, was computed, with a lower PI indicating better performance. Finally, to capture the learning process across time, three metrics were calculated for MT, ED and PI in analogy with the work of Manuel et al. [13].

1 The learning index, representing the acquisition phase: $\frac{(Late - Early)}{Early} \times 100$
2 The retention index, characterizing 24h-offline learning: $\frac{(Retention - Late)}{Late} \times 100$
3 The transfer index, signifying transfer of learning: $\frac{(Transfer - Late)}{Late} \times 100$

For all three indices, a negative value indicates improvements.

We excluded one patient from further analysis, as this patient regularly touched the screen with the other fingers while performing the task with the right index finger, rendering the data inadequate for processing.

Data were analyzed using SPSS software (version 24 SPSS, Inc., Chicago, IL, USA) with significance levels of $\alpha < 0.05$. Depending on the data distribution and equality of variances, either a parametric independent samples *t*-test or non-parametric Mann-Whitney U (MWU)-test was performed to compare general characteristics, baseline performance on the SSP-task (i.e. block 1) and baseline performance on the mobile phone task between both groups. For gender, a Chi-squared test was performed. Spearman correlations were used to correlate baseline performance on the SSP-task and mobile phone task with each other and with clinical characteristics (age, MoCA, DEXTQ-24, disease duration, LED and MDS-UPDRS-III). The learning, retention and transfer index of MT, ED and PI were compared between patients and controls using a MWU-test and Spearman correlations were used to correlate these to clinical characteristics (age, MoCA, DEXTQ-24, disease duration, LED and MDS-UPDRS-III) and to baseline performance on the mobile phone task. Finally, a repeated measures ANOVA was performed, with group as a between-subject factor (PD or HC) and time as a within-subject factor (early learning (block 1–9), late learning (block 10–18) and retention (block 19–24)) to assess retention effects. For transfer, a mixed model ANOVA was performed with between-subject factor group (PD or HC) and within-subject factor test (retention or transfer). Both analyses were done for MT, ED, COV_{MT}, COV_{ED} and PI. As the sphericity assumption was violated for the repeated measures ANOVA, Greenhouse-Geisser corrected p-values are reported. In case of significant differences, post hoc analyses were carried out using Bonferroni tests.

3. Results

3.1. Participants

Demographics and clinical characteristics are specified in Table 1. Patients and healthy controls did not differ significantly, except for a higher score on the DEXTQ-24 in PD patients, indicating worse fine motor skills ($Z = -3.732$; $p < 0.001$).

3.2. Baseline performance

Baseline performance on the SSP-task did not differ between PD patients and HC (Table 1). Performance on the mobile phone task, however, was worse in PD patients ($Z = -2.345$; $p = 0.019$) (Table 1). Exploring the validity of the touchscreen outcomes, there was a trend towards a correlation between a slower performance (i.e. higher MT) on the SSP-task and a slower performance of the mobile phone task across participants ($r_s = 0.403$; $p = 0.078$). Moreover, in PD patients, a slower performance and worse accuracy of the SSP-task correlated with a higher score on the MDS-UPDRS-III (i.e. worse disease severity) (*resp.* $r_s = 0.788$; $p = 0.007$; $r_s = 0.652$; $p = 0.041$).

3.3. Learning the SSP-task in PD and HC

3.3.1. From early learning to retention

Repeated measures ANOVA revealed a main effect of time for MT, COV_{MT} and PI (*resp.* $F = 22.635$, $p < 0.001$; $F = 12.103$, $p = 0.001$; $F = 18.288$, $p < 0.001$) (Fig. 2). Post hoc analyses revealed that both from early to late learning and from early learning to retention participants showed a decrease in MT (both $p < 0.001$), COV_{MT} (*resp.* $p < 0.001$ *and* $p = 0.095$) and PI (both $p < 0.001$), suggesting better performance. There were no further changes from late learning to retention.

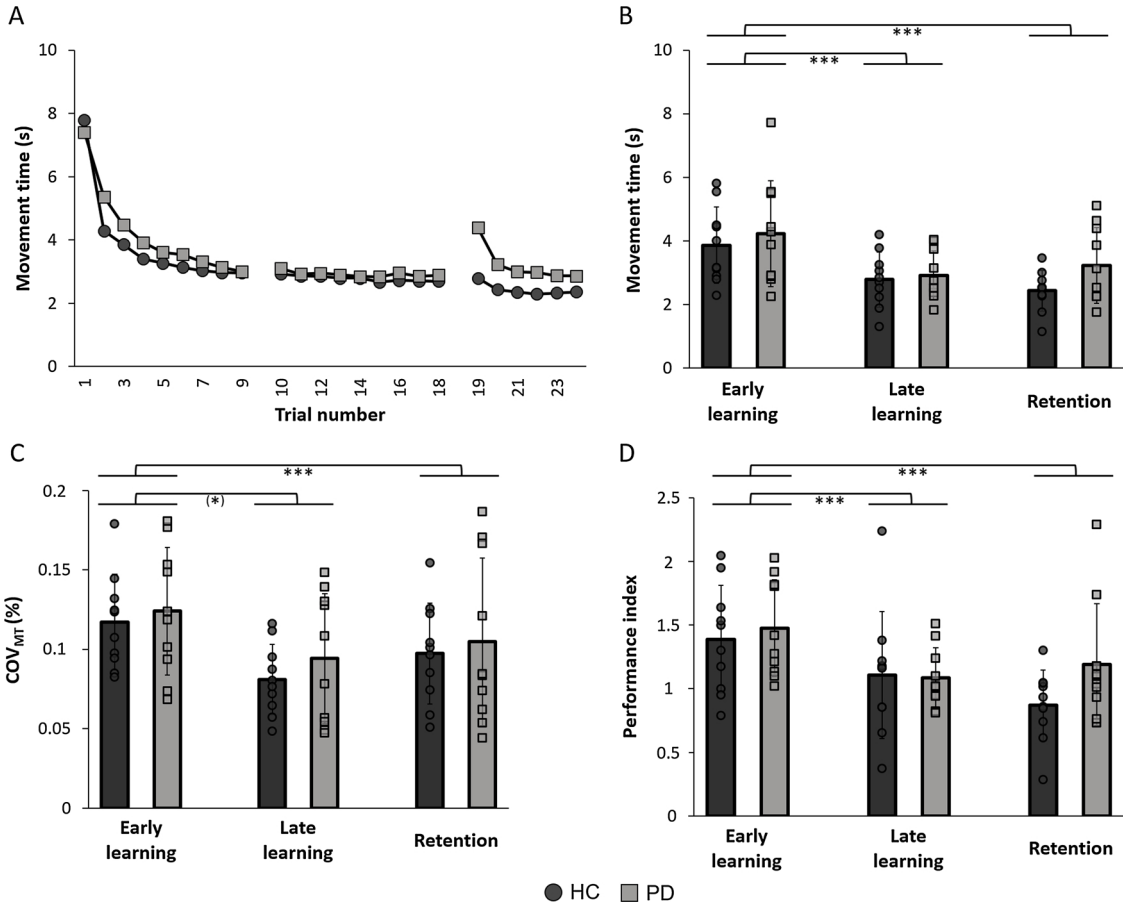

Fig. 2. Performance on the Swipe-Slide Pattern task during early learning, late learning and retention. (A) Trial by trial learning curve for movement time; (B) Changes in movement time; (C) Changes in variability of movement time; and (D) Changes in performance index. Data are presented as group means (± standard deviation), as well as individual data points. (*) $p < 0.10$; *** $p < 0.001$.

For PI, there was a strong tendency towards an interaction between group and time ($F = 3.075$; $p = 0.063$). Exploratory post hoc analyses showed a decrease in PI in HC from early to late learning ($p = 0.013$) and from early learning to retention ($p = 0.001$), with a tendency to further decrease from late learning to retention ($p = 0.099$), all suggesting better performance. In PD patients, PI decreased from early to late learning ($p = 0.001$), though there was only a tendency towards a decrease from early learning to retention ($p = 0.059$) and no difference between late learning and retention ($p = 0.952$). Additionally, only at retention PD patients tended to have a higher PI than HC ($p = 0.082$). Details on all non-significant main and interaction effects can be found in **Suppl. Table A1**.

The number of patterns formed throughout training and fatigue at the end of training on day 1 did not differ between groups (resp. **Suppl. Table A2 & A3**).

3.3.2. From retention to transfer

The mixed model ANOVA revealed a main effect of test for ED, COV_{ED}, COV_{MT} and PI (*resp.* $F = 7.853$, $p = 0.012$; $F = 6.351$, $p = 0.021$; $F = 9.352$, $p = 0.007$; *and* $F = 6.221$, $p = 0.023$) (Fig. 3). Results revealed that participants performed the pattern more accurately and with less variability in MT and ED during retention compared to transfer. However, the PI was higher during the retention test, suggesting worse overall performance. Details on all non-significant main and interaction effects can be found in **Suppl. Table A1**.

3.4. The SSP-task across time - indices

The MWU-test comparing PD patients and HC revealed no significant difference for either the learning or transfer index (see **Suppl. Table A4**). For the retention index on the other hand, a deterioration was found for both MT and PI in PD patients compared to HC (*resp.* $Z = -2.343$, $p = 0.019$; $Z = -2.343$, $p = 0.019$) (Fig. 4**A-B**), confirming the above described difficulties with retention in PD. For ED no significant differences were found (see **Suppl. Table A4**).

The correlation analysis revealed that a slower performance on the mobile phone task correlated with a higher retention index for both MT (Fig. 4C) and PI, suggesting worse retention, across participants (*resp.* $r_s = 0.531$; $p = 0.016$; $r_s = 0.513$; $p = 0.021$). In patients, a longer disease duration correlated with a higher MT-retention index ($r_s = 0.884$; $p = 0.001$). Additionally, a higher score on the MDS-UPDRS-III, suggesting worse disease severity, correlated with a higher PI-retention index ($r_s = 0.720$; $p = 0.019$) (Fig. 4D).

For the transfer index, similar correlations were found. A slower performance on the mobile phone task correlated with a higher transfer index for MT and PI, i.e. worse transfer, across participants (*resp.* $r_s = 0.670$; $p = 0.001$; $r_s = 0.457$; $p = 0.043$). Additionally, a higher score on the MDS-UPDRS-III correlated with a higher MT-transfer index ($r_s = 0.770$; $p = 0.015$).

No correlations were found with age, cognitive test outcomes, manual dexterity or LED.

4. Discussion

We investigated whether PD patients were able to perform and learn a swiping pattern similarly to age-matched healthy controls. Overall, both groups were equally able to perform the SSP-task and showed similar early learning. However, patients presented with impaired

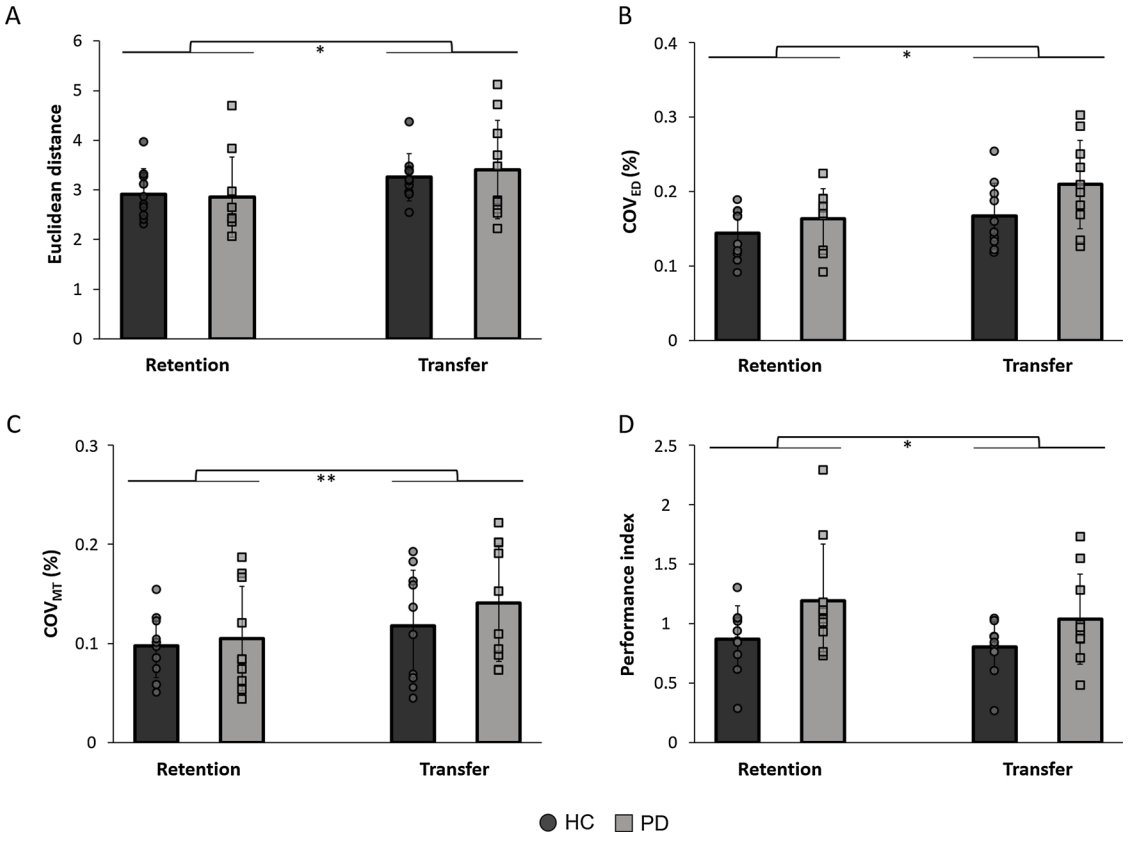

Fig. 3. Comparison of the Swipe-Slide Pattern task between retention and transfer test. (A) Euclidean distance; (B) Variability in Euclidean distance; (C) Variability in movement time; and (D) Performance index. Data are presented as group means (± standard deviation), as well as individual data points. * $p < 0.05$; ** $p < 0.01$.

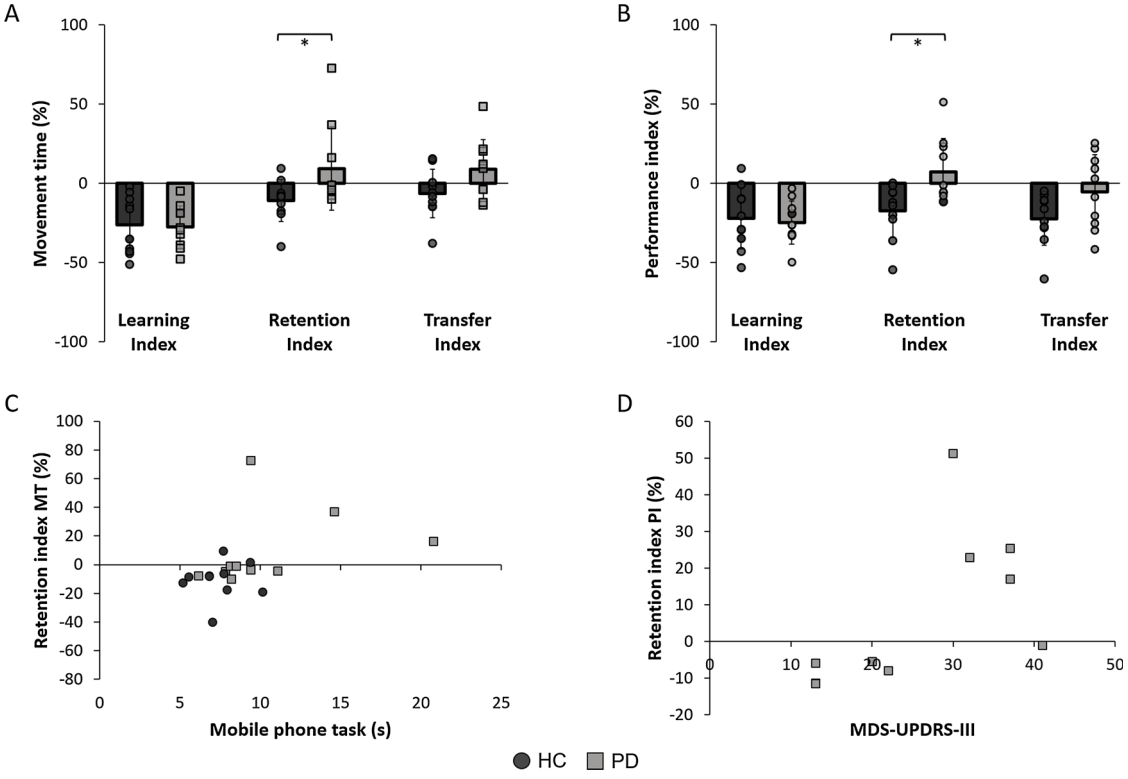

Fig. 4. The learning, retention and transfer index. (A) Differences between PD and HC for movement time (MT); (B) Differences between PD and HC for performance index (PI); (C) A positive correlation between the retention index for MT and performance on the mobile phone task; and (D) A positive correlation between the retention index for PI and the MDS-UPDRS-III. Data are presented as group means (± standard deviation), as well as individual data points. * $p < 0.05$.

retention indices, while HC showed further improvements after a 24h-retention period. The retention deficits in PD were correlated with disease duration, disease severity and performance on the mobile phone task, i.e. tapping a telephone number. Surprisingly, transfer to a similar, but untrained pattern, was comparable between groups. Worse transfer was, however, related to a more severe disease and compromised performance on the mobile phone task.

4.1. Impaired retention in PD

The current study revealed that while healthy elderly maintained and even improved their performance on the SSP-task after 24 h, PD patients did not. This is in line with previous studies investigating visuomotor adaptation learning in PD [3,12–15]. Moreover, difficulties with retention were related to a longer disease duration and worse disease severity, similar to what was found by Manuel et al. [13]. Contrary to other MSL studies [21,24,26], retention was compromised in our study. This can be attributed to the difference in task specifications, as the SSP-task combined characteristics from MSL with a strong visuomotor coupling, as is required in visuomotor adaptation studies. As such, participants did not learn a sequence of discrete finger movements, but rather a pattern requiring a continuous finger movement while making use of visuomotor processing. Hence, the SSP-task reflected a degree of complexity relevant for daily life touchscreen use. Despite its relative complexity, it is unlikely that the observed retention difficulties can be attributed to cognitive load, as the required pattern was visible at all times during task performance and therefore not dependent on memory. Moreover, no correlations were found between the retention index and cognitive tests, though this may be attributed to the fact that we did not include patients with cognitive impairments. Future research should include a broader patient sample to investigate the influence of cognition on the SSP-task to increase its clinical relevance. Worse retention was correlated with a poorer baseline performance of the mobile phone task, supporting the idea that the SSP-task is relevant for picking up learning deficits of smartphone use. Importantly, differences in retention between PD and HC cannot be ascribed to a difference in amount of training or fatigue at the end of practice on day 1, as the number of patterns during learning and VAS scores did not differ significantly between groups.

4.2. Preserved acquisition and transfer in PD

In line with our hypothesis and some previous studies [13–23], we found that both PD patients and HC were equally able to learn the SSP-task. Research has shown that patients likely use compensatory attentional networks to achieve this [22,23]. Moreover, both patients and HC exhibited transfer to an unknown pattern, though this was accompanied by greater variability in performance. This greater variability may have prevented us from obtaining significant differences, as our study was at risk for generating false negatives due to the small sample size. So far, the literature mainly documented impairments of transfer in PD, indicating loss of flexible application of what was learned [27,28]. However, PD patients did show transfer for a functional reach task depending on the context [27] and from cued to uncued handwriting [46]. However, transfer from practiced writing exercises to daily life was limited and no comparison was made with healthy elderly [46]. Overall, these differences in the literature are likely the result of the type of transfer that was tested. Finally, our correlation analysis revealed that transfer is more limited in patients with a worse disease severity and poorer baseline performance on the mobile phone task, as possible markers of reduced flexibility to adapt motor skills. This is analogous to what we found for retention and suggests consolidation problems as the disease progresses. Future research is therefore necessary to clarify transfer capacities in PD and how basal ganglia pathology contributes to this.

4.3. Impaired touchscreen use in PD

Finally, we explored difficulties in using touchscreens in PD. Patients performed worse on the mobile phone task compared to healthy elderly. Although the SSP-task assesses different aspects of touchscreen use, there was a strong tendency towards a correlation between both tasks. The use of the finger stylus during the SSP-task may have improved movement accuracy and fluency for PD patients, thereby concealing difficulties experienced in daily life. Nevertheless, SSP performance was related to disease severity, though a larger sample size across disease stages is required to substantiate our findings and assess the impact of these deficits in daily use of touchscreens. What is more, it will be interesting to capture these deficits in future generations of patients, who have learned and automatized touchscreen skills at an earlier age.

4.4. Study limitations

The results of this study need to be interpreted against the risk of type II errors due to sample size. Nevertheless, we found significant and consistent results pointing to retention deficits in an ecological task. Patients were tested in the optimally medicated state. While this best reflects daily life situations, research has shown that dopaminergic medication can influence motor learning [47–49]. The used touchscreen technology required the adoption of a finger stylus to reproduce the same fluidity of the sliding movement normally produced on a smartphone or tablet with a finger. Use of the stylus may therefore not be exactly comparable to daily sliding movements. Finally, the SSP-task focused on the motor skills required to navigate an unlock-trace screen of a smartphone. However, many more skills are required for daily use such as finger pressure, repetitive sliding, cognitive switching and multitasking. All of these skills need careful future study to truly understand the impact of PD on touchscreen utilization.

5. Conclusion

Overall, results of the current study support previous findings that the initial stages of motor learning are relatively preserved in PD and further extend the knowledge on retention impairments using a task that is relevant for daily use of a smartphone. Future work should address whether prolonged touchscreen skill training can improve retention capacities in PD.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.bbr.2019.112265.

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