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Relation between Event Segmentation and Memory Dysfunction in Parkinson's Disease

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Abstract

The perception of everyday events is thought to imply the segmentation into discrete sub-events. Involvement of dopaminergic networks in this process could relate to particular problems of persons with Parkinson's disease (PD) to recall recent activities. In an event segmentation task, persons with PD and healthy controls had to indicate the beginning of sub-events within three movies showing persons performing everyday activities. In a subsequent recognition task, they should judge whether presented pictures of sub-events were part of the watched movies. In a final order memory task, they had to arrange pictures in the sequence in which they had occurred. With respect to the overall segmentation behavior, persons with PD diverged from healthy controls only in the most familiar of the three demonstrated everyday activities. Moreover, persons with PD compared to healthy controls showed generally worse event recognition and committed more errors in the order memory task. These memory deficits were the higher, the more the segmentation moved away from the 'normative' segmentation pattern identified in healthy controls. The findings suggest that dysfunctional structuring of sensory event information contributes to deficient event representations of ongoing everyday activities and recall problems of these recently perceived events in persons with PD.

Keywords. Event segmentation, event recognition memory, event order memory, Parkinson's disease

Relation between Event Segmentation and Memory Dysfunction in Parkinson's Disease

Parkinson's disease (PD) is a chronic neurological condition characterized by progressive loss of nigrostriatal cells in the sustantia nigra (SN) with subsequent dopamine decline in basal ganglia as well as frontal brain regions (Demakis, 2007). Besides typical motor symptoms, such as bradykinesia, tremor, rigidity, and postural instability, persons with PD often suffer from cognitive problems which may, amongst others, include particular deficits in processing frequently occurring everyday events (Kehagia et al., 2010; Zacks & Sargent, 2010). According to the event segmentation theory (EST), the continuous perception of everyday activities is segmented into successions of sub-events and, through event models in working memory, compared to available long-term memory event representations (i.e., scripts) (Zacks, 2020; Zacks et al., 2007). Event models are assumed to maintain a representation of currently experienced scenarios, containing information about human and non-human beings, objects, their relations to each other, locations, and actions therein. They enable probabilistic predictions about upcoming events, so that accurate plans of actions can be made and accomplished. Towards the perception of event boundaries, predictions are presumed to become less accurate as uncertainty increases about how the next sub-event will unfold. This attenuation leads to the integration of follow-up information, for example when the new sensory input is perceived, implying updating operations in working memory (Zacks et al., 2007). Indeed, the perception of event boundaries has been shown to be associated with transient activity changes of widespread cortical, amongst others, frontal regions (Kurby & Zacks, 2018; Schubotz et al., 2012). For updating event models, midbrain dopaminergic structures including the SN projecting to the cortex were discussed to play a key role (Zacks et al., 2011). As PD strongly affects respective areas, it could be assumed that persons with PD experience particular difficulties in event processing (Zacks & Sargent, 2010).

Moreover, event segmentation relies on the knowledge about the sub-events belonging to specific activities (i.e., event knowledge; Zacks, 2020). These semantic representations are

primarily associated with frontal-parietal networks, presumed to be comparably spared from PD pathology (Schiffer et al., 2015). Indeed, a recent study of Schiffer and colleagues (2015) showed a mostly preserved event segmentation behavior in persons with PD with some increase of the temporal variability in determining event boundaries as compared to healthy persons. The authors used an analysis based on a classifier, which finally could not distinguish between the segmentation pattern of persons with versus without PD, which let them conclude that the segmentation patterns of the groups were altogether similar. In the present study, we aimed to test the robustness of this result by analyzing the segmentation of different everyday scenarios in persons with PD compared to healthy controls, applying generalized linear mixed models (GLMMs). A particular advantage of this approach might be that GLMMs allow to infer the probability with which a normative segmentation pattern can predict the segmentation behavior in the distinct groups, while simultaneously accounting for individual variance in event segmentation behavior (e.g., through random effects, see Data analysis section for details). Thus, we assume that this approach might provide insights into potential deficits of event segmentation in PD.

As various studies have shown, declines in event segmentation could have a number of far-reaching consequences. For instance, normative segmentation of everyday events, defined as high interindividual agreement on points in time defining sub-event boundaries, is conducive for recalling the overall event later on (Flores et al., 2017; Gold et al., 2017). Thus, impairments in the primary segmentation process could not only affect immediate aspects of action planning and execution, but also the memory for the perceived everyday events (Swallow et al., 2009; Zacks et al., 2006; Zacks & Tversky, 2001). Therefore, the current study aimed to investigate the agreement of event segmentation between persons with PD and healthy controls, positing that dopaminergic striatal-frontal processing is involved in updating operations at event boundaries. Further, we sought to analyze potential relations of the segmentation behavior to subsequent event memory performance.

In the event segmentation task, participants were presented with movies showing a person performing everyday activities. They were asked to divide the movies into meaningful segments by pressing a button, indicating when one sub-event had ended and the next one was about to begin (Newtson, 1973). We assumed that a normative segmentation pattern (c.f. Data analysis section) predicted the task performance of healthy controls better than that of persons with PD (Schönberger et al., 2015). Further, we assumed that persons with PD memorize seen sub-events worse than healthy controls and that a decreased event segmentation behavior was associated with lower event memory performance.

2. Method

2.1 Participants

Thirty-eight medicated persons with PD (mean age = 68.61, *SD* = 11.05) and 25 healthy persons as the control group (mean age = 67.16, *SD* = 7.86) were recruited for the current study. Exclusion criteria were cognitive impairment and psychiatric disorders (e.g., depression). Eight persons with PD were excluded from analyses because they did not reach the PANDA (Parkinson Neuropsychometric Dementia Assessment; Kalbe et al., 2008) cut-off score for cognitive non-impairment (i.e., 18 of 30 points). Two persons with PD and one healthy control subject were excluded because they showed symptoms of depression (i.e., over 17 of 51 points in the Hamilton Rating Scale for Depression [HRSD]). Thus, 28 persons with PD and 24 healthy persons were included in final analysis (see Table 1). Both groups neither differed regarding their mean age ($t(50) = -.32$, $p = .748$) nor in their gender distribution ($U = 316$, $z = -.44$, $p = .663$). The academic background was similar for both groups ($U = 320{,}5$, $z = -.27$, $p = .767$) and all participants were German native speakers. Persons with PD were recruited via the neurological outpatient clinic of Charité Campus Benjamin Franklin and healthy controls were recruited via the recruitment platform (PESA) of the department of psychology of the Humboldt-Universität. The Ethics Committee of the

Charité Campus Benjamin Franklin approved the study in accordance with the Declaration of Helsinki (EA4/022/18).

Table 1

Demographic information of persons with PD and healthy controls

	Persons with PD (*N*=28)	Healthy controls (*N*=24)
Mean age in years	65.96 (10.98 [40-89])	66.83 (7.85 [54-78])
Gender	10 females, 18 males	10 females, 14 males
Academic background (number of participants)		
Apprenticeship	7	5
Professional school degree	3	2
University of applied science degree	6	7
University degree	11	8
Others	1	2
UPDRS (motor part)	19.58 (7.02 [9-33])	
Mean disease duration in years	5.88 (4.18 [1-17])	
Hoehn & Yahr disease stage	2.23 (0.67 [1-4])	
Affected body side (number of participants)	17 left, 8 right, 3 no clear side preponderance	
L-DOPA equivalent doses	813.17 (401.44 [226-1977])	

Note. Standard Deviation (SD) and range are displayed in parentheses. UPDRS = Unified Parkinson's Disease Rating Scale; maximum 108 points.

2.2 Procedure and stimulus material

Participants were informed about the study procedure and gave their written consent to their participation. After filling out a demographic questionnaire, participants completed the event segmentation and recognition memory task, both presented with the Presentation® Software (Version 14.9, www.neurobs.com) on a 15" monitor screen. In the event segmentation task, persons with and without PD watched three movies[1] of ongoing everyday activities and segmented the movies into meaningful sub-events by button presses (Newtson, 1973). All three movies showed a single actor or actress performing an everyday activity: preparing breakfast (BF, 329 seconds), working in the garden (GA, 354 seconds), and preparing a party (PA, 375 seconds). A fourth practice movie showed an actress ironing a shirt (298 seconds). All movies were shot without cuts at a fixed camara angle. After the participants read the standardized instructions, they segmented the practice movie (e.g., ironing a shirt) and the instructor made sure that they understood the task correctly. Participants were asked to segment the movies purely on their subjective judgement and no instruction regarding the length of the sub-event units were given. Then, the three movies were shown in randomized order, each directly followed by the recognition memory task related to the movie which just had been watched. Here, two images were displayed side by side on the screen in 20 trials, one image showing a scene of the movie the participants had just watched and the other image showing a similar scene which has not been part of the movies. Participants had to decide which images occurred in the movies by pressing one of two buttons. Thereafter, participants completed the order memory task. Twelve hard copy pictures, respectively for each movie, were presented on a table all showing scenes of the movies. The investigator arranged the pictures in a random order and asked the participants to sort the pictures into the correct temporal order in which they occurred in the movies.

[1] The stimulus material was kindly provided by Jeffrey M. Zacks, Washington University in St. Louis and was used, for example, by Gold et al. (2017) and Sargent et al. (2013).

As previous studies suggested that general cognitive functions may contribute to event segmentation processes (Sargent et al., 2013; Zacks et al., 2006), participants finally completed a comprehensive psychometric battery to determine the functional specificity of potential event segmentation deficits in the PD group and to explore whether they are related to general cognitive abilities. The PANDA assesses symptoms of dementia in persons with PD and its final score is an indicator for overall cognitive functioning. In the HRSD, symptoms of depression are queried. The Multiple-Choice Vocabulary Intelligence Test (MWT) was administered to estimate the crystallized intelligence of both groups. To assess executive functions, participants completed the Trail Making Test (TMT) and the STROOP test. The total study duration was approximately two hours.

2.3 Data analysis

For the event segmentation analysis, we divided each movie into 1-sec bins (see Kurby & Zacks, 2011). Whenever a participant identified an event boundary in the respective second (i.e., pressed the button), the value 1 was submitted to this bin (we will refer to this variable as 'click-behavior'). Otherwise, the bin contained the value 0. As event segmentation is a purely subjective judgment, we calculated a normative segmentation pattern based on the click-behavior of the healthy control group. For this, we calculated how many healthy control subjects segmented each movie in each 1-second (sec) bin on average (we will refer to this variable as 'proportion'). Moreover, for each healthy control subject we calculated a sub-proportion variable by omitting the respective subject's click-behavior (i.e., *N*-1). Healthy participants whose number of segments was over two standard deviations above the mean or did not segment the movies at all, were excluded from the proportion calculation (exclusion of two participants in BF and GA movies and exclusion of three participants in the PA movie). In order to analyze if the normative segmentation performance predicts the segmentation pattern of persons with PD differently (i.e., worse) than that of healthy controls,

we computed a generalized linear mixed model (GLMM) with a binomial link function with the lme4 (Bates, Mächler, et al., 2015) and lmerTest packages in R-Studio (version 1.2.5033, R Core Team, 2014). We excluded all participants, whose number of segments exceeded two standard deviations above the mean within each group and movie from GLMM analyses to secure that no extreme deviant segmentation behavior would distort the results[2]. We defined the click-behavior as the dependent variable and analyzed the main effects of *group* (two levels: persons with PD, healthy controls), *proportion* (continuous variable; z-transformed for GLMM analysis), *movie* (three levels: BF, PA, GA) and the interaction between these variables. For predicting the click-behavior of the healthy controls, we used the proportion variable which omitted the respective subject's click-behavior (i.e., *N*-1) to avoid predicting one own's click-behavior. For predicting the click-behavior of persons with PD, we used the proportion variable which was calculated as the average over all healthy participants who clicked in the respective bin. For the *group* and *movie* effects we used sliding difference contrasts, hence resulting estimates can be understood as the difference between neighboring factor levels (Schad et al., 2020). We included the by-subject intercepts and slopes for the effect proportion, movie, and their interactions. When convergence problems occurred, we simplified the random effect structure by removing correlation parameters and by using Principal Component Analysis to remove random effects stepwise from the model when they explained zero variance (Bates, Kliegl, et al., 2015). Once the random effect structure was determined (e.g., the model converged), non-significant main effects and interaction terms of the GLMM were identified and reduced by comparing models using the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC, both decreasing with increasing model fit), and Likelihood Ratio Test (LRT). If the removed term did not influence model fit, that is,

[2] Exclusion of two persons with PD and two healthy control subjects in the BF and PA movie, respectively, and exclusion of one healthy control subject in the GA movie.

if the simpler model explained the data as good as or better than the more complex model (e.g. non-significant Chi-Square test), the simpler model was kept (Meteyard & Davies, 2020). Additional nested models were computed to resolve significant interactions relevant to the research questions. The nested models were specified identically to the non-nested model (expect for the nesting) resulting in identical results regarding the random effect structure and model fit indices.

To assess whether persons with PD differed in their number of segments from persons without PD, we computed the mean number of segments of each participant in each movie and performed a mixed model design analysis of variance (ANOVA) including the within-subject factor *movie* (BF, GA, PA) and the between-subject factor *group* (persons with PD, healthy controls). We report Effect sizes η_p^2 and use Greenhouse-Geiser corrections. When interactions reached significance ($p < 0.05$), post-hoc pairwise comparisons were computed, for which *p*-values were Bonferroni corrected.

For recognition memory analysis, means of reaction times (RTs) in milliseconds (ms) and error rates (ER) in percent were computed for each participant in each movie and submitted to an ANOVA with similar factor levels as described above. One person with PD and one healthy person were excluded from the recognition memory analysis due to an error rate over 50%. For the order memory task, RTs in seconds and an error score, defined as the mean deviation from each placed card from the correct position, were submitted to according ANOVAs.

To further analyze how the segmentation behavior relates to event memory, we calculated segmentation agreement scores by correlating the individual segmentation behavior (click-behavior) to the normative segmentation pattern (e.g., to the variable proportion. See Kurby & Zacks, 2011 for a similar approach). We scaled all relevant variables and conducted multiple regression analyses within each group to determine how much variance is explained

by the event recognition and order memory RTs and error rates to the segmentation agreement scores.

Finally, psychometric variables (i.e., PANDA, MWT, TMT, STROOP, and HRSD) were compared between groups with independent *t*-tests and multiple regression analyses were performed within each group to assess whether the psychometric variables explain variance to the segmentation agreement scores.

3. Results

The GLMM analysis (see Table 2 for details) for the event segmentation task revealed a main effect of *proportion* indicating that proportion significantly predicted the click-behavior in both groups. Further, we found significant two-way interactions between *proportion* and *movie* (PA-BF and BF-GA, respectively) and a significant three-way interaction between *proportion*, *movie* (PA-BF), and *group* (see Table 2). To reveal potential group differences within each movie, we nested the interaction of *proportion* and *group* within the factor *movie*. Results of the nested model showed that for persons with PD, proportion predicted the click-behavior in the movie 'preparing breakfast' (BF) significantly worse than for healthy controls ($b = 0.21$, $SD = 0.09$, $z = 2.23$, $p = .026$) (see Figure 1). No significant group differences were found within the other movies (all $p > .90$).

Table 2

Generalized Linear Mixed Model results predicting the click-behavior

Term	b	SE	z	p
Intercept	-3.50	0.13	-27.67	<.001
Proportion	0.55	0.04	13.31	<.001
Movie: PA-BF	-0.27	0.10	-2.73	.006

Proportion * Movie: PA-BF	0.11	0.04	2.74	.006
Proportion * Movie: BF-GA	-0.13	0.04	-3.58	<.001
Proportion * Movie: PA-BF * Group	-0.16	0.07	-2.22	.027

Variance components (SD)		**Goodness of fit**
Intercept	0.77 (0.88)	Log Likelihood: -8387.6
Proportion	0.07 (0.26)	REML deviance: 50044
Movie: PA-BF	0.25 (0.50)	
Movie: BF-GA	0.19 (0.45)	

Note. PA = "Preparing a Party", BF = "Preparing Breakfast", GA = "Working in the Garden". Non-significant fixed effects were excluded from the model as they did not improve model fit. Variance components show the by-subject random effects. Further, please note that we changed the order of the *movie* factor levels in a second GLMM analysis so that the movies 'preparing a party' and 'working in the garden' were also compared. No interaction between *proportion* and *movie* (PA-GA) or *proportion*, *movie* (PA-GA), and *group* was found (all $p > .362$).

The analysis for the number of segments revealed a main effect of movie ($F(2, 100) = 4.03$, $p = .021$, $\eta_p^2 = .08$) with more identified event boundaries in the movie BF than in the movie GA. The main effect of group and the interaction between movie and group did not reach significance ($p > .130$) indicating that persons with PD did not differ regarding their mean number of segments (14.79, $SD = 9.67$) from healthy controls (20.31, $SD = 15.26$).

In the recognition memory task, RT analysis revealed a main effect of movie ($F(2, 96) = 11.09$, $p \leq .001$, $\eta_p^2 = .19$) with higher RTs in identifying the correct events in the movie BF than in the movies GA and PA. Moreover, the main effect of group reached significance ($F(1, 48) = 8.75$, $p = .005$, $\eta_p^2 = .15$) indicating that persons with PD showed overall higher RTs than healthy controls (see Figure 2). The interaction between movie and group was not

significant ($p > .660$). Regarding the ER analysis in the recognition memory task, results showed a significant main effect of movie ($F(2, 96) = 9.43$, $p \leq .001$, $\eta_p^2 = .16$) indicating that both groups showed higher ERs in recalling the correct events in the movie BF than in PA. Moreover, persons with PD showed overall higher error rates compared to healthy controls as indicated by a significant effect of group ($F(1, 48) = 8.21$, $p = .006$, $\eta_p^2 = .15$) (see Figure 2). The interaction between movie and group was not significant ($p > .274$).

In the order memory task, RT analysis revealed a main effect of movie ($F(2, 100) = 33.94$, $p \leq .001$, $\eta_p^2 = .41$) with lower RTs in the movie PA than in the movies BF and GA. Further, the main effect of group reached significance ($F(1, 49) = 9.06$, $p = .004$, $\eta_p^2 = .17$), indicating that persons with PD were significantly slower than healthy controls (see Figure 2). The interaction between movie and group was not significant ($p > .085$). The error analysis revealed a main effect of movie ($F(2, 100) = 60.52$, $p \leq .001$, $\eta_p^2 = .55$) with fewer errors in the movie PA than in the movies BF and GA and fewer errors in the movie GA than in BF. Moreover, the main effect of group reached significance ($F(1, 50) = 4.38$, $p = .041$, $\eta_p^2 = .08$), indicating that persons with PD made overall more errors in the order memory task than healthy controls (see Figure 2). The interaction between movie and group was not significant ($p > .152$).

The regression models for investigating potential associations between event segmentation and related event memory processes (e.g., recognition and order memory) showed that the overall number of errors in the order memory task predicted the event segmentation performance (i.e., segmentation agreement score) for persons with PD ($b = -0.43$, $p = .031$, $R^2 = .37$, $F(4, 23) = 3.39$, $p = .025$), but not for healthy controls ($b = -0.01$, $p = .952$; $R^2 = .07$, $F(4, 19) = 0.70$, $p = .599$) (see Figure 3). No other predictors reached significance in the regression models (all $p > .239$).

Finally, the analyses of the psychometric variables showed that persons with PD and healthy controls did not differ significantly in their PANDA and MWT scores (see Table 3),

indicating comparable general cognitive functioning and crystallized intelligence between groups. However, persons with PD showed lower scores in their executive functions (TMT and STROOP) and scored higher in their depression ratings (HRSD), which are two characteristic findings in the clinical context of PD (Chaudhuri et al., 2011; Lewis et al., 2003). The regression analyses showed that no psychometric variable was a significant predictor for the segmentation agreement score in neither group (all $p > .112$).

Table 3

Psychometric results of persons with PD and healthy controls

	Persons with PD		Healthy controls		
	Mean	SD	Mean	SD	Statistics
PANDA	26.07	2.99	27.04	2.99	$t(50) = -1.24$, $p = .223$
MWT	117.19	12.78	118.04	11.85	$t(48) = -0.24$, $p = .809$
TMT	50.44	27.459	28.54	13.45	$t(49) = 3.54$, $p \leq .001$
STROOP	59.22	4.69	64.58	6.30	$t(49) = -3.47$, $p \leq .001$
HRSD	7.59	4.42	3.08	3.34	$t(50) = 4.05$, $p \leq .001$

Note. SD = Standard Deviation; PANDA = Parkinson Neuropsychometric Dementia Assessment; MWT = Multiple-Choice Vocabulary Intelligence Test; TMT = Trail Making Test (difference RT in seconds between TMT A and TMT B is displayed); HRSD = Hamilton Rating Scale for Depression

Figure 1

Proportion of participants indicating event boundaries in the movie 'preparing breakfast' per second in either group

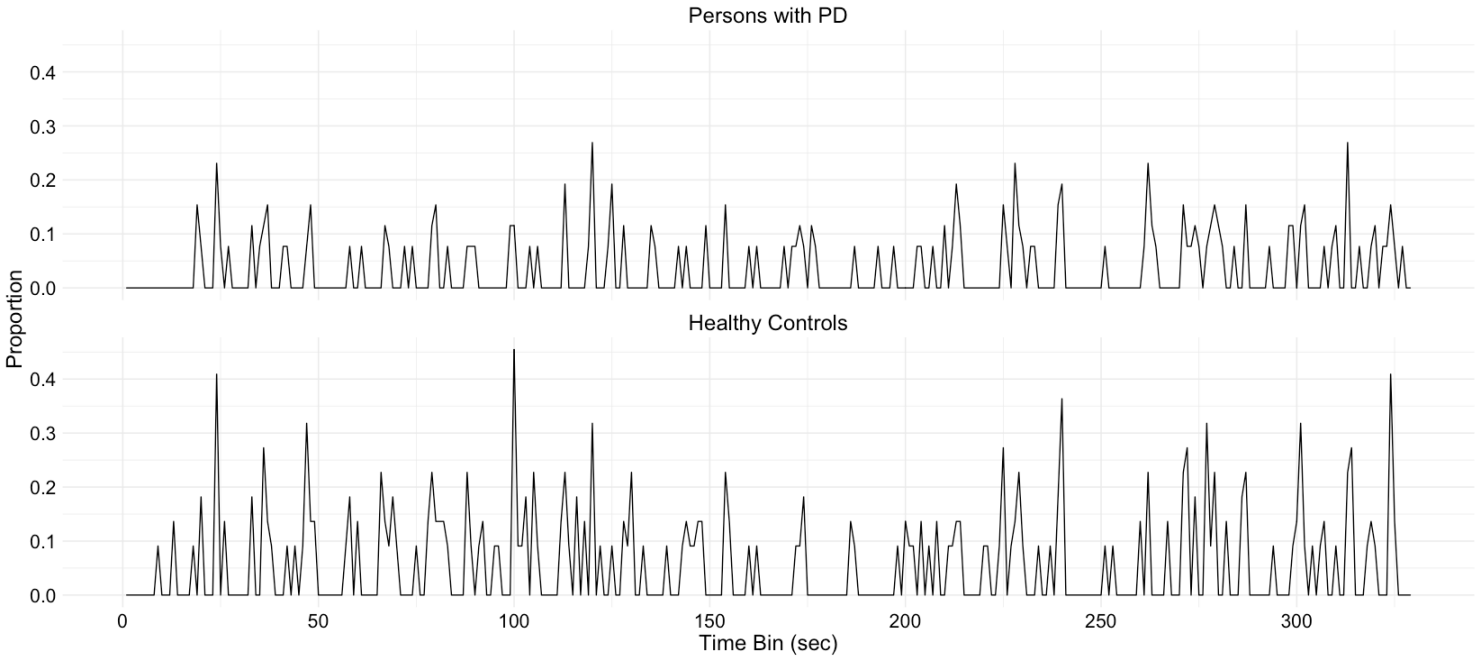
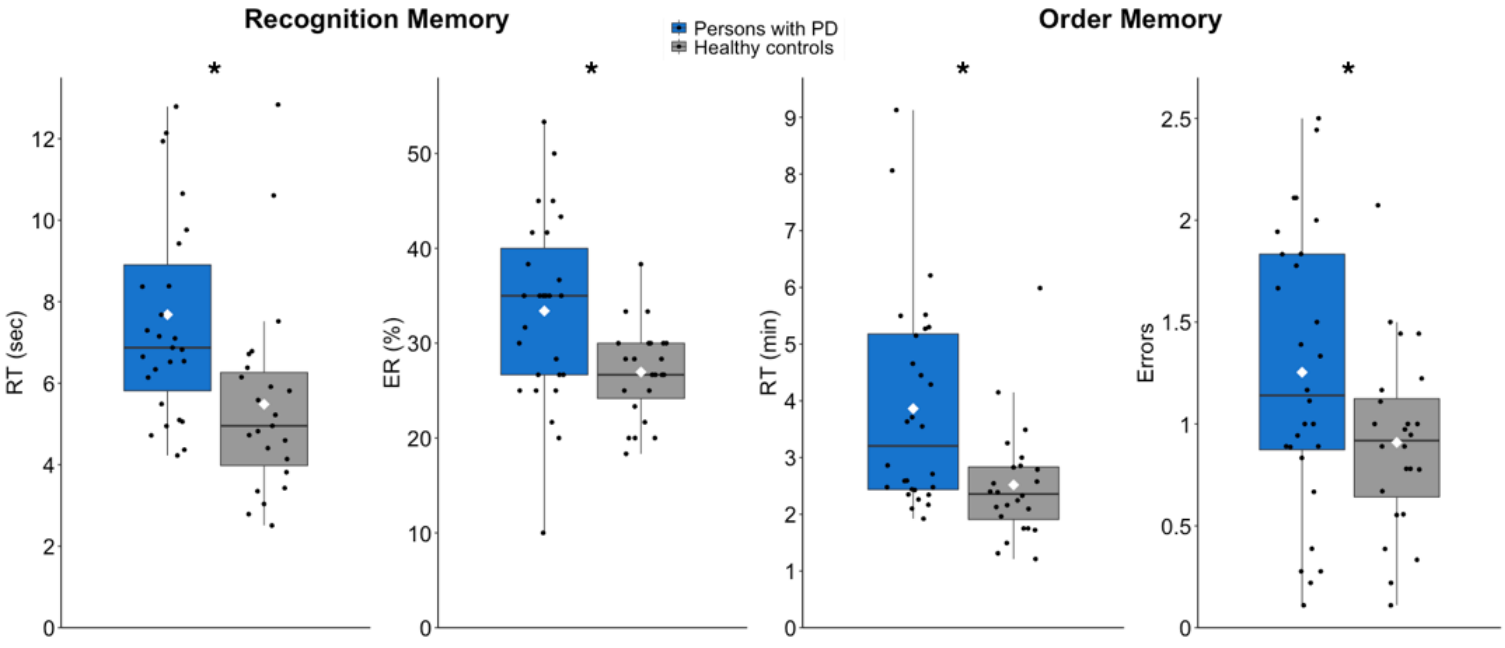


Figure 2

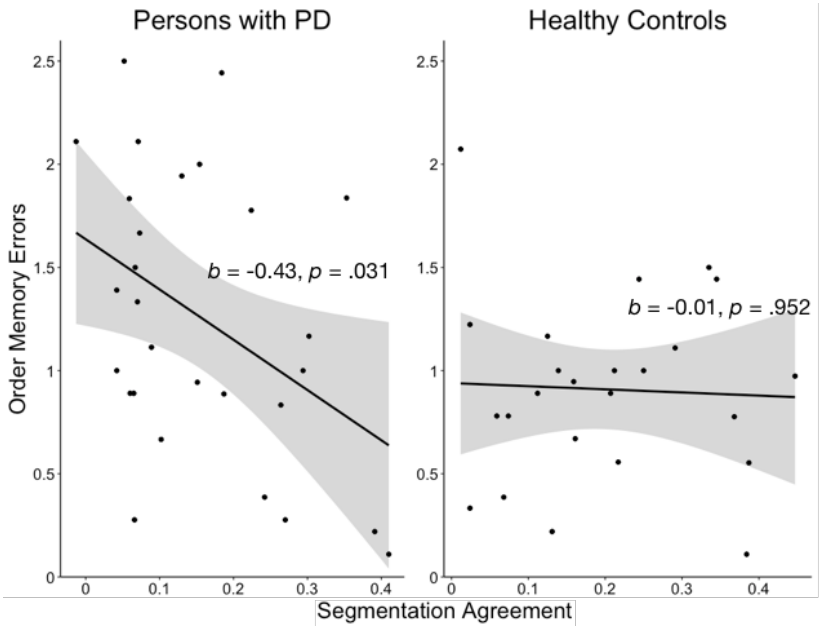
Reaction times (RT) and error rates (ER) for the recognition and order memory tasks across movies for persons with PD and healthy controls



Note. Box plots show the mean, the upper and lower quartiles, and range. Dots show individual means. Errors in the order memory task indicate the absolute mean deviation from each placed card from the correct position. Asterisks mark significant differences (*$p < .05$) between groups.

Figure 3

Order memory errors predict segmentation agreement for persons with PD, but not for healthy controls



Note. Errors in the order memory task indicate the absolute mean deviation from each placed card from the correct position.

4. Discussion

In the present study, persons with PD and healthy controls performed three tasks. First, participants were asked to segment movies of particular everyday activities into sequences of sub-events. After that, they should judge whether presented pictures had appeared in the movies previously shown and, finally, they were asked to order pictures chronologically as they had occurred. Indeed, measures for the prediction of segmentation performance showed diverging behaviors between persons with PD and healthy controls.

However, with respect to the three scripts 'preparing a party', 'working in the garden' and 'preparing breakfast', persons with PD only deviated from the normative segmentation pattern with respect to the latter everyday activity. Generally, event memory deficits prevailed in persons with PD and became apparent as overall worse picture recognition, more errors with respect to the correct order of pictures, and slowed task performance compared to the healthy controls. The regression analysis results indicated that the more the segmentation differed from the 'normative' pattern of healthy controls, the more order memory errors persons with PD made. These main findings are of interest with respect to disturbed event processing and its behavioral consequences in the clinical context of PD and will be discussed in the following.

In a recent functional imaging study (Reagh et al., 2020), age-dependent activity changes in posterior parts of the hippocampal-neocortical network were found at event boundaries which were correlated with memory performances. Thus, difficulties to decompose perceived everyday events into meaningful sub-events seem to be an implication of healthy ageing, involving brain structures related to mnestic functions. Yet, in the present study the recall and sequence problems in persons with PD went beyond aged-matched levels. Moreover, the regression analysis showed that the higher these memory deficits were, the more the segmentation behavior deviated from the 'normative' pattern of healthy controls. Interestingly, this connection was group specific, that is, no relation of segmentation behavior and memory performance was identified in the healthy control group. Thus, the current results appear to indicate PD-specific impairments in event processing. Also, as no associations between event segmentation and various cognitive functions were found, altered segmentation behavior seems to reflect a specific impairment rather than an aspect of further cognitive decline in the PD group (Zacks et al., 2006).

The event segmentation theory (EST) proposes that based on the sensory input of the ongoing situation and long-term memory scripts, event models in working memory enable

predictions about imminent events. When event boundaries are perceived, these predictions are thought to become unstable as uncertainty rises about how the next event will unfold. Once the new sensory input is perceived, it is integrated into the event model which will then return to its stable state (i.e., the event model is updated). These updating processes in working memory are assumed to be mediated through dopaminergic projections form the basal ganglia (BG) to the cortex (Zacks et al., 2007). For instance, functional imaging results demonstrated midbrain dopaminergic network activity and BG involvement in event prediction, e.g., in the context of model updating, and in sequencing event information (Saint-Cyr, 2003; Tinaz et al., 2006; Tinaz et al., 2008; Zacks et al., 2011). For persons with PD, who show decreased dopaminergic network functions, segmentation should therefore be distorted, compatible with the present findings (Schiffer et al., 2015; Zacks & Sargent, 2010). However, as persons with PD were investigated only on their regular medication and no tests were performed after drug withdrawal, the role of the dopaminergic replacement therapy for the present results eventually remains unclear.

Interestingly, activation of hippocampal, frontal and parietal-temporal brain regions during the perception of event boundaries suggests the relevance of stored event representations for the segmentation of continuous information streams into sub-events (Baldassano et al., 2017; Reagh et al., 2020; Schubotz et al., 2012; Zacks, 2020). Our findings support this notion, in that the segmentation behavior depended on the specific activity perceived. In particular, only in the script 'preparing breakfast' persons with PD showed worse event segmentation performance than healthy controls. Of note, whereas 'preparing breakfast' can be reasonably considered as highly familiar, the other activities (e.g., 'working in the garden', 'preparing a party') are probably performed less frequently and are further away from daily routines (Raisig et al., 2009; Rosen et al., 2003). In this regard, different, but not mutually exclusive explanations referring to different mechanisms of aberrant event segmentation behavior in persons with PD are conceivable.

For instance, one could assume that stable knowledge templates of highly familiar activities (i.e., preparing breakfast in our study) may support the generation of a 'normative' behavior, from which, however, persons with PD would diverge due to impaired event knowledge organization and its top-down retrieval. That is, *knowing* when one sub-event ends and the next one is about to begin might be compromised and, thus, could affect the normative identification of event boundaries in persons with PD. Indeed, some studies indicate altered, that is, less structured event representations and retrieval in PD potentially contributing to the observed segmentation differences between both groups in the present study (Godbout & Doyon, 2000; Wyrobnik et al., 2022). In turn, the segmentation of less familiar activities (e.g., 'working in the garden', 'preparing a party') based on comparable less established event representations is generally more heterogeneous resulting in similar segmentation patterns in both groups. Here, the segmentation deficit in persons with PD could have still remained undetected, but might be determined when semantic, and hence, event knowledge processing and corresponding temporal-parietal brain networks continue to decline as the disease progresses (Angwin et al., 2017; Braak et al., 2003).

An alternative explanation involves the assumption of deficient updating processes of event models in PD. Highly familiar activities are assumed to entail high associative strength and predictive power between sub-events (Drummer et al., 2016; Schiffer et al., 2013). For example, the script 'preparing breakfast' will activate own, that is, interindividual variable experiences and associations of successive action steps leading to strong individual expectations about upcoming sub-events. The presented movie, however, could violate one's own predictions and hence, will force participants to update their model representations accordingly. As previously mentioned, model updating in case of prediction errors is assumed to be impaired in PD, possibly leading to the aberrant segmentation behavior in the familiar activity. In contrast, for unfamiliar scripts sub-event predictions about next action steps and respective updating processes are less established (Schiffer et al., 2013), resulting in similar

segmentation performance between groups. Thus, it could be argued that in case of high routine, but interindividual variable activities, persons with PD show particular deficits in adopting to changes of own predictions and subsequently have difficulties to remember the experienced events.

Finally, a bottom-up perceptual segmentation deficit of sensory information may be involved in the identified PD-related performance pattern (Schönberger et al., 2015; Tiedt et al., 2017). In the current context, this could mean that insufficient segmentation of sensory information streams hampered the establishment of meaningfully structured short-term templates of ongoing events, for which memory then became faulty. In particular, persons with PD may be impaired in identifying movement-related sensory cues typically marking event boundaries in observed actions (Baldwin et al., 2008; Schubotz et al., 2012; Schubotz & von Cramon, 2002). For example, changing the direction of a movement is often indicative of a change in a person's goal or intention, implying an event boundary. As persons with PD were shown to have altered motion perception, group differences of the segmentation behavior could be explained by differences in motion characteristics in the presented activities (Kloeters et al., 2017). Possibly, the frequency and complexity of moves differed across the movies shown here, which might have influenced event segmentation behaviors independently from the degree of event familiarity.

In future studies, neural correlates of event segmentation in persons with PD could be investigated, additionally controlling for the degree of familiarity as well as for the particular movement properties (e.g., number, diversity, complexity, and velocity of movements) to further delineate mechanisms underlying event segmentation and memory. Also, as pharmacological treatment might have influenced the present findings, future studies comparing persons with PD on and off their medication might shed further light on the role of dopaminergic processes in event segmentation.

In sum, the present results are suggestive of dysfunctional segmentation of event information in persons with PD for highly familiar activities and of an association between deviance from normative segmentation behavior and deficits in memorizing corresponding events. As structuring and remembering ongoing streams of (sub-)events are ubiquitously important for action planning and execution, such deficits could contribute to difficulties in everyday routines prevalent in persons with Parkinson's disease.

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Author contributions

MW: Conceptualization, Investigation, Formal analysis, Data curation, Writing – Original draft, Visualization. **EvdM:** Conceptualization, Writing – Review & Editing, Supervision. **FK:** Conceptualization, Formal analysis, Resources, Writing – Review & Editing, Supervision.