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1 Home-based physical behavior in late stage 2 Parkinson's disease dementia: differences 3 between cognitive subtypes

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1 **Abstract**

2 Background: For the early diagnosis of Parkinson's disease dementia
3 (PDD), objective home-based tools are needed to quantify even mild
4 stages of activities of daily living (ADL) dysfunction.

5 Objectives: In this pilot study, home-based physical behavior was assessed
6 to examine whether it is possible to distinguish mild cognitive impairment
7 (PD-MCI) from PDD.

8 Methods: Fifty five patients with mild to severe Parkinson's disease (PD)
9 participated in this cross-sectional study. Based on comprehensive
10 neuropsychological testing, PD patients were classified as cognitively non-
11 impaired (PD-NC), PD-MCI or PDD. For physical behavior assessments,
12 patients wore the accelerometer DynaPort® (McRoberts) for three days.
13 Ordinal logistic regression models with continuous Y were applied to
14 correct results for motor impairment and depressive symptoms.

15 Results: After excluding 7 patients due to insufficient wearing time, 48
16 patients with a mean of 2 recorded days were analyzed (17 PD-NC, 22 PD-
17 MCI, 9 PDD). ADL-impaired PDD patients showed fewer sedentary bouts
18 than non- ADL-impaired PD-MCI [$P=0.01$ odds ratio (OR)=8.9, 95%
19 confidence interval (CI)=1.8-45.2] and PD-NC ($P=0.01$, OR=10.3, CI=1.6-
20 67.3) patients, as well as a longer sedentary bout length (PD-NC: $P=0.02$,
21 OR=0.1, CI=0.02-0.65; PD-MCI: $P=0.02$, OR=0.14, CI=0.03-0.69). These
22 differences were mainly caused by fewer (PD-NC: $P=0.02$, OR=9.6,
23 CI=1.5-62.4; PD-MCI: $P=0.01$, OR=8.5, CI=1.5-37.3), but longer sitting

1 bouts (PD-NC: $P=0.03$, OR=0.12, CI=0.02-0.80; PD-MCI: $P=0.04$,
2 OR=0.19, CI=0.04-0.93). Tests assessing executive function, visuo-
3 construction and attention correlated significantly with specific activity
4 parameters ($\rho \geq 0.3$; $P < 0.05$).

5 Conclusion: Objective assessment of physical behavior, in particular the
6 detection of sedentary bouts, is a promising contributor to the
7 discrimination between PD-MCI and PDD.

8 **Key words:** Parkinson's disease; Dementia; Physical activity; Activities of
9 daily living; Cognition; Accelerometer; Sedentary behavior.

1 **1. Background**

2 Dementia is common in Parkinson's disease (PD) [1,2], and objective tools
3 allowing for the assessment of activities of daily living (ADL) function, and
4 thereby an early diagnosis of Parkinson's disease dementia (PDD), are
5 needed, especially as effective therapeutic options are available [3].

6 With the development of wearable and relatively unobtrusive sensor
7 systems during recent years, it has become feasible to assess home-based
8 physical behavior of PD patients over longer time periods[4], and thus
9 indirectly monitor ADL function [5,6]. Since ADL function is essential for the
10 discrimination of PDD from mild cognitive impairment (PD-MCI) patients
11 [7,8], its unbiased assessment is of utmost importance.

12 It is known that both dementia and PD are associated with reduced
13 physical activity, which can be seen even years before the diagnosis can
14 be made [9–12], yet there are few studies that investigate advanced
15 disease stages. Those few studies indicate that late stage PD patients
16 show longer bouts of sedentary behavior [13], and that energy expenditure
17 is related to cognition [14]. However, these studies excluded patients with
18 more advanced cognitive impairment [13,14]. To the best of our knowledge,
19 no study is currently available that has objectively assessed
20 comprehensive physical behavior parameters of PD patients with advanced
21 cognitive impairment or PDD.

22 The aim of this pilot study was to test whether objectively assessed
23 physical behavior parameters could contribute to the discrimination of

1 cognitive subtypes of PD, especially between PDD and mild cognitive
2 impairment (PD-MCI).

3 **2. Methods**

4 **2.1 Participants**

5 A total of 55 PD patients were investigated within the frame of the
6 Dempark/Landscape study [15]. Diagnosis of PD was made according to
7 the adapted United Kingdom Parkinson's Disease Society Brain Bank
8 Criteria. Inclusion criteria included: age between 45 and 80 years, German
9 as a first language, and adequate or corrected hearing/visual abilities. The
10 following exclusion criteria were applied: history of other neurological
11 diseases affecting the central nervous system, onset of dementia within
12 one year after PD diagnosis, prior surgery due to PD, and a Mini-Mental
13 State Examination (MMSE) [16] score < 18 points (a required cut-off, as
14 only individuals with the capacity to give informed consent could be
15 included).

16 The study was approved by the local ethical committee. All participants
17 gave written informed consent.

18 **2.2 Cognitive and motor examination**

19 Each individual underwent a clinical assessment that included the Unified
20 Parkinson Disease Rating Scale part III (UPDRS III) [17], and the Hoehn &
21 Yahr staging scores [18]. Demographical data and medication intake was
22 also assessed. Intake of dopamimetics is expressed as the levodopa
23 equivalent daily dose (LEDD) [19]. All participants underwent a

1 comprehensive neuropsychological assessment that included the MMSE,
2 the Parkinson Neuropsychometric Dementia Assessment (PANDA) [20],
3 and the Geriatric Depression Scale (GDS) [21], among others. Details are
4 provided in Table 1 and in the supplementary Table A.

5 Three groups were classified according to the criteria listed below: non-
6 cognitively impaired (PD-NC), for patients not meeting criteria of other
7 cognitive subtypes, PD-MCI, and PDD.

8 PD-MCI was diagnosed when the following criteria were met: (i.) one or
9 more test scores ≥ 1.5 standard deviations below published group
10 normative values of healthy control subjects in at least one of the following
11 cognitive domains: attention, executive functions, visuo-spatial function,
12 memory, or language ability; (ii.) no significant impairment of ADL reported
13 by either the patient or the proxy; (iii.) no other primary explanations for
14 cognitive impairment or PD-associated symptoms that could significantly
15 influence cognitive testing.

16 Diagnostic criteria for PDD followed the Level-II recommendation of the
17 MDS Task Force for probable PDD [7]: (i.) At least one score ≥ 1.5 standard
18 deviations below published group normative values of healthy control
19 subjects in at least two of the aforementioned five cognitive domains; (ii.)
20 impairment of ADL and cognitive decline with insidious onset and slow
21 progression reported by either the patient or the proxy. Details about the
22 neuropsychological assessment are provided in supplementary Table A.

23 *2.3 Objective physical behavior assessment and parameters*

1 All participants were asked to wear the triaxial accelerometer DynaPort
2 Minimod® sensor (McRoberts, The Netherlands; dimensions: 64 x 62 x 13
3 mm) on their lower back for three consecutive days. Data was collected
4 with a sample frequency of 100 Hz and a resolution of 1 milli g-force (mg),
5 and then stored on a secure digital memory card inside the device [22].
6 Participants were asked to keep a logbook during the measurement. The
7 following time periods were documented: taking the device off (for water-
8 associated tasks), sleeping, out-of-house activities and special occasions.
9 The logbook was used for plausibility analysis in the case of irregular
10 measurements. Raw data was analyzed with algorithms provided by
11 McRoberts.

12 These algorithms differentiated the following behaviors: lying, sitting,
13 standing, walking, and shuffling (defined as an activity in upright position
14 performed with a locomotion-specific intensity, but without a locomotion-
15 specific horizontal acceleration signal) [23,24]. Behaviors were also
16 combined for better interpretation: (i.) sedentary combines lying and sitting;
17 (ii.) activity combines standing, shuffling and walking. Moreover, steps
18 taken during shuffling and walking were identified. Time in which the sensor
19 was not worn by the participant was detected (not-wearing time). Various
20 parameters were identified and calculated, according to the criteria listed in
21 the following sections.

22 2.3.1 Volume

1 Volume was defined by (i.) amount of total time spent in each behavior
2 (e.g. lying time), normalized as a percentage of 24 hours; (ii.) total number
3 of steps per day; (iii.) total amount of time spent in each intensity level
4 (defined using threshold on Metabolic Equivalent of Task category, MET)
5 normalized as a percentage of 24 hours: sedentary activity, ≤ 1.5 METs;
6 light activity, $1.5 < x < 3$ METs; moderate activity, $3 \leq x < 6$ METs; vigorous
7 activity, ≥ 6 METs.

8 2.3.2 Pattern

9 Patterns were defined according to (i.) total number of bouts per day for
10 each behavior (e.g. number of lying bouts); (ii.) mean bout length for each
11 behavior per day (e.g. mean lying bout length), where a bout, similar to
12 other studies [13,25], is defined as any period of time spent in a certain
13 behavior.

14 2.3.3 Intensity

15 Intensity, as the mean vector magnitude of dynamic acceleration per day
16 for each behavior (e.g. lying intensity) or in total (total movement intensity),
17 was detected and expressed relative to gravitational acceleration by the
18 unit g (m/s^2).

19 2.3.4 Energy expenditure

20 Energy expenditure was calculated using an algorithm based on a
21 validation study with indirect calorimetry [26] and demographic
22 characteristics of the participants. The following energy expenditure

1 parameters were calculated: (i.) Activity related Energy Expenditure per
2 day (AEE); (ii.) Total Energy Expenditure per day (TEE); (iii.) Physical
3 Activity Level per day, as the relative energy expenditure to basal metabolic
4 rate (PAL); (iv.) Physical Activity Ratio, as the relative energy expenditure
5 to basal metabolic rate for each behavior (PAR) (e.g. PAR of lying).

6 2.4 Data processing

7 Criteria for data processing were as follows: days with less than 24 hours
8 recorded or with a relative wearing time <80% of 24 hours were excluded.
9 Since no imputation [27] was applied, all results exclude the not-wearing
10 time.

11 2.5 Statistical Analysis

12 Values are reported as median and range. For demographical and clinical
13 variables, Kruskal-Wallis Test or Chi-square statistics were used. To adjust
14 the physical behavior parameter outcomes for motor disability and
15 depressive symptoms, ordinal logistic regression models for continuous Y
16 [28] were applied. Each physical behavior parameter was chosen as the
17 dependent variable, whereas group membership (coded as a dummy
18 variable) and co-variables were included as independent variables, to
19 correct for the confounders GDS and the UPDRS III score (see Table 1 for
20 details). The odds ratio (OR) with its confidence interval of 95% (CI) was
21 used for effect size estimation. The Spearman rho coefficient (rho) was
22 applied for correlation analysis. An alpha level below 0.05 was considered

1 statistically significant. Statistical analyses were performed using SPSS
2 Statistics 22 (IBM, 2011).

3 **3. Results**

4 Seven subjects were excluded from the analysis. Of these, three were
5 excluded due to uncompleted days recorded (2 PD-NC, 1 PDD), and four
6 due to daily wearing time <80% (2 PD-NC, 1 PD-MCI, 1 PDD). After
7 exclusion of incomplete recorded days, recordings with a mean of 2
8 complete days (range 1-4) of 48 PD patients (PD-NC, n=17, 35%; PD-MCI,
9 n=22, 46%; PDD, n=9, 19%) were analyzed.

10 The UPDRS III and the GDS scores differed significantly between the
11 cognitive subtypes (PD-NC < PD-MCI < PDD, Table 1). The ordinal logistic
12 regression model was therefore corrected for these confounders. The
13 registered not-wearing time (median = 4, range 0 – 280 minutes) did not
14 differ significantly between the cognitive subgroups.

15 ----Please insert Figure 1-3 near here-----

16 **3.1 Physical behavior outcomes**

17 In both PD-NC and PD-MCI groups, the largest proportion of the day was
18 spent lying (PD-NC: 37%, PD-MCI: 42%), followed by sitting (PD-NC: 36%,
19 PD-MCI: 34%), standing (both 14%), walking (PD-NC: 5%, PD-MCI: 4%),
20 shuffling (PD-NC: 2%, PD-MCI: 1%), and not-wearing (<1%). In the PDD
21 group, the most frequent behavior was sitting (42%), followed by lying
22 (40%) (Figure 1).

1 Descriptively, median values for active physical behavior were relatively
2 low in in the PDD group, but no significant difference in relation to the other
3 cognitive groups was found ($P > 0.05$, Figure 2 and Table 2). Median
4 activity time was 9% in the PDD group, compared to 21% in both PD-MCI
5 and PD-NC groups ($P > 0.05$, Table 2). In contrast, median sedentary time
6 was 89% for PDD, 78% for PD-MCI, and 75% for PD-NC ($P > 0.05$, Figure
7 2).

8 Walking time was 1.8% in PDD, 3.9% in PD-MCI ($P=0.67$, OR= 1.40, CI=
9 0.30-6.46), and 5.2% in the PD-NC group ($P=0.44$, OR= 2.01, CI=0.34-
10 12.03). Patients with PDD had a median number of 2362 steps, patients
11 with PD-MCI 4742 steps ($P= 0.72$, OR=1.33, CI= 0.29-6.11), and patients
12 with PD-NC 5778 steps ($P= 0.48$, OR= 1.91, CI=0.32-11.42, Figure 2).

13 The PDD group had a tendency to show low values, however, differences
14 in intensity and energy expenditure parameters were not statistically
15 significant between the groups ($P > 0.05$, Table 2). Similarly, time spent in
16 different MET-categories was comparable between the study groups ($P >$
17 0.05, Table 2).

18 The groups deviated in the pattern of sedentary behavior (Figure 3). The
19 parameter mean sedentary bout length was significantly longer in PDD
20 (727 s) than in both PD-MCI (515 s, $P= 0.02$, OR= 0.14, CI= 0.03-0.69) and
21 PD-NC (506 s, $P=0.02$, OR=0.1, CI=0.02-0.65, Figure 3D). Moreover, the
22 PDD group had a reduced number of sedentary bouts (97) compared to the
23 PD-MCI (129, $P= 0.01$, OR= 8.9, CI= 1.8-45.2) and PD-NC groups (134, $P=$
24 0.01, OR= 10.3, CI= 1.6-67.3, Figure 3C). These differences were mainly

1 caused by fewer, but longer bouts of sitting behavior from the PDD group
2 ($P < 0.05$, Figure 3E and 3F).

3 *3.2 Correlation of sitting parameters with parameters of other* 4 *behaviors*

5 An increase of sitting time correlated significantly with a longer lying time
6 ($\rho = 0.55$, $P < 0.01$, supplementary Figure A) but not with the ‘time’
7 parameter of other behaviors ($\rho \leq 0.19$, $P > 0.05$). A higher sitting
8 intensity correlated with a higher sedentary intensity ($\rho = 0.84$, $P < 0.01$)
9 and a higher standing intensity ($\rho = 0.36$, $P < 0.05$), but not with the
10 ‘intensity’ parameter of other behaviors ($\rho \leq 0.19$, $P > 0.05$). An increase
11 in the number of sitting bouts correlated with a higher number of bouts of all
12 other behaviors ($\rho \geq 0.65$, $P < 0.01$), except for the number of lying bouts
13 ($\rho = -0.13$, $P > 0.05$). An increase in mean sitting bout length was
14 associated with higher ‘mean bout length’ of both sedentary behavior and
15 shuffling behavior ($\rho \geq 0.39$, $P < 0.01$), but not with higher ‘mean bout
16 length’ of other behaviors ($\rho \leq 0.14$, $P > 0.05$).

17 For the behaviors standing, shuffling, walking, and activity, higher values of
18 the registered ‘time’, ‘intensity’, and ‘number of bouts’ parameters
19 correlated significantly with each other ($\rho = 0.34$ to $\rho = 1$, $P < 0.05$).

20 Standing mean bout length only correlated with mean walking bout length
21 ($\rho = -0.31$, $P < 0.05$) and mean activity bout length ($\rho = 0.87$, $P < 0.01$,
22 supplementary Figure A).

1 *3.3 Correlation of physical behavior outcomes and cognitive* 2 *tests*

3 Lower scores of cognitive tests assessing visuo-construction (e.g. the
4 praxis subtest of the Consortium to establish a registry for Alzheimer's
5 disease (CERAD), as well as the mental rotation and spatial sense
6 subtests of the Leistungsprüfsystem 50+) were associated ($P < 0.05$) with
7 the following physical behavior parameters (see supplementary Table A for
8 details): less moderate activity ($\rho = 0.31$ to 0.47), less light activity ($\rho =$
9 0.30), fewer steps ($\rho = 0.32$), lower total movement intensity ($\rho = 0.35$),
10 lower number of activity bouts ($\rho = 0.31$), longer mean activity bout length
11 ($\rho = -0.30$), more sedentary activity ($\rho = -0.36$), and lower number of
12 sedentary bouts ($\rho = 0.32$). More impaired attention performance,
13 represented by at least one of the Stroop-test sub scores, word naming or
14 color naming, correlated significantly with longer mean activity bout length
15 ($\rho = -0.34$), less moderate activity ($\rho = 0.34$), lower total movement
16 intensity ($\rho = 0.30$ to 0.34), and more sedentary activity ($\rho = -0.33$,
17 supplementary Table A). Decreased performance on the Trail making test
18 A/B, assessing executive function, was associated with less moderate
19 activity ($\rho = 0.31$) and a lower number of activity bouts ($\rho = 0.30$).
20 Reduced phonematic verbal fluency correlated with shorter sedentary time
21 ($\rho = 0.30$). Worse memory performance (e.g. word-list recall) was
22 associated with higher activity intensity ($\rho = -0.31$) and a higher number
23 of steps ($\rho = -0.30$).

1 **4. Discussion**

2 In this pilot study, PDD patients showed a tendency for low median values
3 of active and intensive physical behavior parameters and high median
4 values for sedentary parameters. These differences were not significant in
5 the statistical model applied to adjust for depressive symptoms and motor
6 impairment. However, statistically significant differences with relatively high
7 effect sizes were observed in the pattern of sedentary physical behavior:
8 PDD patients had fewer, but longer sedentary bouts than both participants
9 with PD-NC and PD-MCI.

10 The dominant role of sedentary behavior is further supported by two
11 interesting observations of this study. First, unlike the other cognitive
12 subgroups, the most frequent behavior of the PDD group was sitting.
13 Second, the results of the correlation analysis showed that most of the
14 sitting behavior parameters were relatively poorly associated with the
15 parameters of other behaviors. These results could indicate a special role
16 of sedentary, especially sitting, parameters among all physical behavior
17 parameters assessed in our study.

18 To the best of our knowledge, this is the first study to explore the physical
19 behavior profile of cognitive subtypes in PD. Dontje and colleagues [14]
20 reported that 586 PD patients showed a relevant but weak correlation
21 between MMSE score and energy expenditure using actigraphy. Though
22 our study did not reproduce this finding with statistical significance,
23 descriptive values support their findings. The lack of statistical power could

1 be due to the relatively small PDD cohort or its relatively large
2 heterogeneity.

3 Our findings do however support the reports of Chastin and colleagues
4 [13], who showed that late stage PD patients had longer sedentary bout
5 lengths. Moreover, Chen and colleagues [5] compared ADL scores,
6 assessed by the Tokyo Metropolitan Institute of Gerontology Index of
7 Competence, with accelerometer data of 1634 older adults. They found a
8 relevant association between ADL disability and greater volume of
9 sedentary behavior, as well as a lower number of sedentary bouts. Taking
10 our findings and the results of the aforementioned studies into account, the
11 hypothesis that alterations in the sedentary physical behavior pattern,
12 specifically fewer but longer sedentary bouts, could be associated with ADL
13 impairment in PD, seems possible.

14 In accordance with previous study results [29–34], our data confirmed that
15 less active physical behavior correlated with lower scores on tests
16 assessing visuo-construction, attention and executive functions, but not
17 verbal fluency, memory and language performance. This indicates that the
18 physical behavior profile can, at least partly, reflect cognitive worsening
19 associated with the domains mentioned above. Linking memory function
20 with physical behavior is controversial, as only one study so far has
21 identified a significant correlation [31]. Therefore, more studies are needed
22 to investigate the relation between cognition and physical behavior in older
23 adults and in dementia.

1 Limitations of this study were: first, sample size and heterogeneity of the
2 PDD group limited the generalization of our results. Second, no statistical
3 correction for multiple testing was applied. To reduce the influence of these
4 limitations, we used non parametric testing.

5 As can be seen in the scatter dot plots, there may be subgroups that
6 specifically drive group differences. Further analysis of these outliers
7 revealed a very heterogenic picture of both participants with only a few
8 extreme values (≤ 4 parameters: 56% of participants), and participants with
9 several extreme values (≥ 4 parameters: 23% of participants). The latter
10 group could be further categorized into participants with very active
11 physical behavior (10%), participants with very sedentary behavior (8%),
12 and participants with very few bouts (4%). Therefore, the exclusion of
13 outliers with an arbitrary cut-off value bears a high risk of excluding patients
14 with heavier disease burden. Moreover, several other studies have
15 reported a considerable heterogeneity in advanced disease stages of both
16 PD [14] and dementia [35-37].

17 Third, a complete separation between motor impact and cognitive/ADL
18 dysfunction impact on physical behavior is currently not possible. However,
19 we did reduce possible confounding effects by statistically correcting for the
20 UPDRS III motor score.

21 It should also be noted that because of the abilities of current sensor
22 technology and data analysis techniques, the presented output parameters
23 cannot serve as absolute descriptions of daily physical behavior, but rather
24 enable the comparison of group performances.

1 Strengths of our study are the inclusion and successful assessment of
2 patients with later disease stages, as well as the use of modern wearable
3 technology, which allowed us to evaluate a comprehensive and detailed
4 range of physical behavior outcomes.

5 Results of this pilot study indicate that there are associations between the
6 sedentary physical behavior pattern and ADL-impairment in PDD. This
7 helps in identifying promising parameters that have the potential to improve
8 the differentiation of PDD from both PD-NC and PD-MCI. To consolidate
9 our findings, further studies with larger study samples, especially the PDD
10 group, are necessary. Our results support the potential of objective physical
11 behavior assessment in further understanding, screening, diagnosing,
12 predicting, and monitoring cognitive impairment in PD.

13

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3 Amsterdam) and the owner of McRoberts. Jos Prinzen is an employee of
4 McRoberts. This company is the manufacturer of the DynaPort.

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7

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Legend

Figure 1 Overview of total time spent in different behaviors for the three study groups; PD-NC, Parkinson's disease with no cognitive impairment; PD-MCI, Parkinson's disease with mild cognitive impairment; PDD, Parkinson's disease dementia. Values were calculated using the ratio of each median with all summed medians of the study group.

Figure 2 Comparisons of physical behavior parameters between the three study groups; PD-NC, Parkinson's disease with no cognitive impairment; PD-MCI, Parkinson's disease with mild cognitive impairment; PDD, Parkinson's disease dementia. Data is presented with median and interquartile range.

Figure 3 Comparisons of the physical behavior pattern between the three study groups: PD-NC, Parkinson's disease with no cognitive impairment; PD-MCI, Parkinson's disease with mild cognitive impairment; PDD, Parkinson's disease dementia. Data is presented with median and interquartile range. Statistically significant differences adjusted for depression (GDS) and motor impairment (UPDRS III) scores are presented with brackets, odds ratio (OR) with 95% confidence interval (CI) and p-values (P).

Table 1 Characterization of the study sample.

Variable	Median (Minimum/Maximum)			p-value
	PD-NC (n=17)	PD-MCI (n=22)	PDD (n=9)	
Age	71 (44/80)	68 (57/78)	72 (67/75)	0.18
Male gender, n (%)	10 (59%)	17 (77%)	9 (100%)	0.09
Age of onset	64 (43/72)	61 (43/71)	65 (55/69)	0.43
Disease duration (years)	6 (1/13)	6 (1/20)	6 (5/18)	0.11
Hoehn & Yahr Stage, n (%)				
1	6 (35%)	3 (14%)	-	0.03
2	10 (59%)	13 (59%)	3 (33%)	
3	1 (6%)	4 (18%)	3 (33%)	
4	-	2 (9%)	2 (22%)	
5	-	-	1 (11%)	
UPDRS-III score	20 (11/58)	24 (10/62)	36 (14/56)	0.01
LEDD	620 (160/2420)	763 (210/2378)	496 (100/1139)	0.16
Geriatric Depression Scale (GDS)	2 (0/6)	5 (0/10)	8 (3/15)	0.001

LEDD, Levodopa equivalence daily dose; n, number; PDD, Parkinson's disease dementia; PD-MCI,

Parkinson's disease with mild cognitive impairment; PD-NC, Parkinson's disease with no cognitive

impairment; UPDRS-III, Unified Parkinson's disease Rating Scale part III.

Sedentary activity [%]	0.83 (0.60/0.93)	0.84 (0.67/0.96)	0.89 (0.56/0.98)	0.63	0.64	0.11/3.84	0.92	1.08	0.24/4.99
Time spent with intensity levels of ≤1.5 METs									
Light activity [%]	0.08 (0.02/0.33)	0.06 (0.02/0.24)	0.05 (0/0.41)	0.72	1.38	0.23/8.19	0.94	0.94	0.20/4.33
Time spent with intensity levels of 1.6 - 3.0 METs									
Moderate activity [%]	0.07 (0.02/0.15)	0.06 (0.01/0.13)	0.02 (0.0/0.07)	0.31	2.52	0.42/15.17	0.43	1.86	0.40/8.64
Time spent with intensity levels of 3.0-6.0 METs									
Vigorous activity [%]	0.0008 (0/0.03)	0.0007 (0/0.03)	0.0001 (0/0.04)	0.86	0.86	0.14/5.08	0.63	0.68	0.15/3.16
Time spent with intensity levels of ≥6.0METs									
AEE [MJ/d]	832 (514/1477)	775 (202/1081)	664 (314/1205)	0.71	1.41	0.24/8.39	0.76	0.79	0.17/3.63
Estimated EE during active behavior									
TEE [MJ/d]	2621 (1898/3500)	2572 (1127/3182)	2306 (1899/3186)	0.68	0.69	0.12/4.11	0.44	0.54	0.12/2.53
Estimated total EE									
PAL	1.47 (1.32/1.90)	1.48 (1.22/1.80)	1.44 (1.19/1.67)	0.75	1.33	0.22/7.91	0.81	1.20	0.26/5.54
Relative EE to BMR of all behaviors									

AEE, activity related energy expenditure; BMR, Basal Metabolic Rate; CI, Confidence Interval; EE, Energy Expenditure; GDS, Geriatric Depression Scale; MET, Mean equivalent of task; OR, Odds Ratio; PAL, physical activity level; PAR, physical activity ratio; PDD, Parkinson's disease dementia; PD-MCI, Parkinson's disease with mild cognitive impairment; PD-NC, Parkinson's disease with no cognitive impairment; TEE, Total energy expenditure; UPDRS-III, Unified Parkinson Disease Rating Scale part III; P values < 0.05 are shown in bold.

Active physical behavior

A.

C.

E.

G.

Sedentary physical behavior

B.

D.

F.

A. **B.** **C.** **D.** **E.** **F.**

Table A Correlations between selected neuropsychological tests and physical behavior parameters

Test	Function	Activity time	Activity intensity	Number of activity bouts	Mean activity bout length	Sedentary time	Sedentary intensity	Number of sedentary bouts	Mean sedentary bout length	Steps	Total movement intensity	Sedentary activity	Light activity	Moderate activity	Vigorous activity
MMSE	Global cognition	-.07	.13	.09	-.17	.09	.09	.04	-.02	.08	.21	-.20	.11	.19	.15
WMS-R: Digit Span forward [#]	Working memory	.16	.17	.16	-.11	-.10	-.09	.20	-.19	.26	-.05	.14	-.20	.18	.20
WMS-R: Digit Span backward [#]	Working memory	-.06	.06	.01	-.10	.07	-.01	.07	-.05	.05	-.11	.11	-.07	-.06	-.02
CERAD: Word-list recall [#]	Verbal memory	-.15	-.31*	-.22	.14	.07	.15	-.18	.14	-.30*	-.05	-.07	.13	-.17	-.26
CERAD: Semantic fluency [#]	Word generation	.13	.01	.16	-.15	-.09	.20	.22	-.22	.05	.22	-.25	.22	.24	-.05
CERAD: Phonematic fluency [#]	Word generation	-.26	-.20	-.20	-.01	.30*	.15	-.25	.26	-.24	.01	-.12	.20	-.09	-.14
Trail Making Test: Part A [#]	Psychomotor speed	-.22	.05	-.10	.01	.27	.15	-.20	.23	-.11	.12	-.18	.25	-.08	-.07
Trail Making Test: Part B [#]	Psychomotor speed/Set shifting	.10	.23	.18	-.19	.00	.02	-.08	.08	.16	.23	-.14	.08	.29	.09
Trail Making Test: A/B [#]	Set shifting	.29	.23	.30*	-.28	-.19	-.14	-.02	-.03	.26	.09	.07	-.16	.31*	.08
CERAD: Praxis [#]	Visuo-construction	.20	.27	.23	-.15	-.13	-.30*	.32*	-.29	.25	-.12	.22	-.27	.20	.13
LPS 50+ 7: Mental Rotation [#]	Visuo-construction	.28	.29	.31*	-.19	-.22	-.08	.09	-.13	.32*	.26	-.17	.02	.47**	.29
LPS 50+ 9: Spatial Sense [#]	Visuo-construction	.13	.18	.21	-.30*	-.02	.23	.11	-.10	.20	.35*	-.36*	.30*	.31*	.14
Stroop: Word naming	Directed attention	.11	.24	.24	-.34*	-.03	.12	.11	-.13	.16	.30*	-.24	.17	.34*	.06
Stroop: Color naming	Directed attention	.18	.24	.28	-.34*	-.12	.21	.19	-.23	.16	.34*	-.33*	.26	.34*	.07
Stroop: Interference condition	Inhibition	.02	.17	.15	-.20	.04	.16	.06	-.07	.06	.24	-.22	.18	.23	.03

**correlation level of significance $P < .01$; *correlation level of significance $P < .05$; PANDA, Parkinson Neuropsychometric Dementia Assessment ; MMSE, Minimental State

Examination; CERAD, Consortium for the Registry for Alzheimer's Disease (CERAD); BTA, Brief test of attention; WMS, Wechsler Memory Scale Revised; mWCST, Modified Card

Sorting Test; LPS 50+, intelligence scale Leistungsprüfsystem for subjects between 50 and 90 years of age; [#]Data referred to standardized scores (e.g. z-scores or percentile rank

scores, indicating the patient's relative position in the norm group with a range between 0 and 100) of healthy German control subjects as published in the manuals. Data are corrected either for age or for age and education (CERAD, TMT, mWCST).

Figure A Correlations between physical behavior parameters.

Spearman's coefficient for the parameter outcomes of Time (A), Movement Intensity (B), Number of Bouts (C) and Mean Bout length (D) between different behaviors over all study groups. **correlation level of significance $P < 0.01$, *correlation level of significance $P < 0.05$.