
Home-Based Physical Behavior in Late Stage Parkinson Disease Dementia: Differences between Cognitive Subtypes.

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Home-based physical behavior in late stage Parkinson’s disease dementia: differences between cognitive subtypes

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Abstract

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

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

Methods: Fifty five patients with mild to severe Parkinson’s disease (PD) participated in this cross-sectional study. Based on comprehensive neuropsychological testing, PD patients were classified as cognitively non-impaired (PD-NC), PD-MCI or PDD. For physical behavior assessments, patients wore the accelerometer DynaPort® (McRoberts) for three days.

Ordinal logistic regression models with continuous Y were applied to correct results for motor impairment and depressive symptoms.

Results: After excluding 7 patients due to insufficient wearing time, 48 patients with a mean of 2 recorded days were analyzed (17 PD-NC, 22 PD-MCI, 9 PDD). ADL-impaired PDD patients showed fewer sedentary bouts than non-ADL-impaired PD-MCI \( [P=0.01 \text{ odds ratio (OR)}=8.9, 95\% \text{ confidence interval (CI)}=1.8-45.2] \) and PD-NC \( (P=0.01, \text{ OR}=10.3, \text{ CI}=1.6-67.3) \) patients, as well as a longer sedentary bout length (PD-NC: \( P=0.02, \text{ OR}=0.1, \text{ CI}=0.02-0.65; \) PD-MCI: \( P=0.02, \text{ OR}=0.14, \text{ CI}=0.03-0.69 \)). These differences were mainly caused by fewer (PD-NC: \( P=0.02, \text{ OR}=9.6, \text{ CI}=1.5-62.4; \) PD-MCI: \( P=0.01, \text{ OR}=8.5, \text{ CI}=1.5-37.3 \)), but longer sitting
bouts (PD-NC: \( P=0.03, \) OR=0.12, CI=0.02-0.80; PD-MCI: \( P=0.04, \)
OR=0.19, CI=0.04-0.93). Tests assessing executive function, visuo-
construction and attention correlated significantly with specific activity
parameters (\( \rho \geq 0.3; P<0.05 \)).

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

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

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

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

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

The aim of this pilot study was to test whether objectively assessed physical behavior parameters could contribute to the discrimination of
cognitive subtypes of PD, especially between PDD and mild cognitive impairment (PD-MCI).

2. Methods

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

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

2.2 Cognitive and motor examination
Each individual underwent a clinical assessment that included the Unified Parkinson Disease Rating Scale part III (UPDRS III) [17], and the Hoehn & Yahr staging scores [18]. Demographical data and medication intake was also assessed. Intake of dopaminetics is expressed as the levodopa equivalent daily dose (LEDD) [19]. All participants underwent a
comprehensive neuropsychological assessment that included the MMSE, the Parkinson Neuropsychometric Dementia Assessment (PANDA) [20], and the Geriatric Depression Scale (GDS) [21], among others. Details are provided in Table 1 and in the supplementary Table A.

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

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

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

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

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

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

2.3.2 Pattern

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

2.3.3 Intensity

Intensity, as the mean vector magnitude of dynamic acceleration per day for each behavior (e.g. lying intensity) or in total (total movement intensity), was detected and expressed relative to gravitational acceleration by the unit g (m/s²).

2.3.4 Energy expenditure

Energy expenditure was calculated using an algorithm based on a validation study with indirect calorimetry [26] and demographic characteristics of the participants. The following energy expenditure
parameters were calculated: (i.) Activity related Energy Expenditure per day (AEE); (ii.) Total Energy Expenditure per day (TEE); (iii.) Physical Activity Level per day, as the relative energy expenditure to basal metabolic rate (PAL); (iv.) Physical Activity Ratio, as the relative energy expenditure to basal metabolic rate for each behavior (PAR) (e.g. PAR of lying).

2.4 Data processing

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

2.5 Statistical Analysis

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

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

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

3.1 Physical behavior outcomes

In both PD-NC and PD-MCI groups, the largest proportion of the day was spent lying (PD-NC: 37%, PD-MCI: 42%), followed by sitting (PD-NC: 36%, PD-MCI: 34%), standing (both 14%), walking (PD-NC: 5%, PD-MCI: 4%), shuffling (PD-NC: 2%, PD-MCI: 1%), and not-wearing (<1%). In the PDD group, the most frequent behavior was sitting (42%), followed by lying (40%) (Figure 1).
Descriptively, median values for active physical behavior were relatively low in the PDD group, but no significant difference in relation to the other cognitive groups was found (P > 0.05, Figure 2 and Table 2). Median activity time was 9% in the PDD group, compared to 21% in both PD-MCI and PD-NC groups (P> 0.05, Table 2). In contrast, median sedentary time was 89% for PDD, 78% for PD-MCI, and 75% for PD-NC (P > 0.05, Figure 2).

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

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

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

(P < 0.05, Figure 3E and 3F).

3.2 Correlation of sitting parameters with parameters of other behaviors

An increase of sitting time correlated significantly with a longer lying time

(rho = 0.55, P < 0.01, supplementary Figure A) but not with the ‘time’
parameter of other behaviors (rho ≤ 0.19, P > 0.05). A higher sitting
intensity correlated with a higher sedentary intensity (rho = 0.84, P < 0.01)
and a higher standing intensity (rho = 0.36, P < 0.05), but not with the
‘intensity’ parameter of other behaviors (rho ≤ 0.19, P > 0.05). An increase
in the number of sitting bouts correlated with a higher number of bouts of all
other behaviors (rho ≥ 0.65, P < 0.01), except for the number of lying bouts
(rho = -0.13, P > 0.05). An increase in mean sitting bout length was
associated with higher ‘mean bout length’ of both sedentary behavior and
shuffling behavior (rho ≥ 0.39, P < 0.01), but not with higher ‘mean bout
length’ of other behaviors (rho ≤ 0.14, P > 0.05).

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

Standing mean bout length only correlated with mean walking bout length
(rho = -0.31, P < 0.05) and mean activity bout length (rho = 0.87, P < 0.01,
supplementary Figure A).
3.3 Correlation of physical behavior outcomes and cognitive tests

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

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

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

To the best of our knowledge, this is the first study to explore the physical behavior profile of cognitive subtypes in PD. Dontje and colleagues [14] reported that 586 PD patients showed a relevant but weak correlation between MMSE score and energy expenditure using actigraphy. Though our study did not reproduce this finding with statistical significance, descriptive values support their findings. The lack of statistical power could
be due to the relatively small PDD cohort or its relatively large heterogeneity.

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

In accordance with previous study results [29–34], our data confirmed that less active physical behavior correlated with lower scores on tests assessing visuo-construction, attention and executive functions, but not verbal fluency, memory and language performance. This indicates that the physical behavior profile can, at least partly, reflect cognitive worsening associated with the domains mentioned above. Linking memory function with physical behavior is controversial, as only one study so far has identified a significant correlation [31]. Therefore, more studies are needed to investigate the relation between cognition and physical behavior in older adults and in dementia.
Limitations of this study were: first, sample size and heterogeneity of the PDD group limited the generalization of our results. Second, no statistical correction for multiple testing was applied. To reduce the influence of these limitations, we used non parametric testing.

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

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

It should also be noted that because of the abilities of current sensor technology and data analysis techniques, the presented output parameters cannot serve as absolute descriptions of daily physical behavior, but rather enable the comparison of group performances.
Strengths of our study are the inclusion and successful assessment of patients with later disease stages, as well as the use of modern wearable technology, which allowed us to evaluate a comprehensive and detailed range of physical behavior outcomes.

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

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Declaration of Conflicting Interests. Rob C. van Lummel is a PhD student at the Faculty of Human Movement Sciences (Vrije Universiteit Amsterdam) and the owner of McRoberts. Jos Prinzen is an employee of McRoberts. This company is the manufacturer of the DynaPort.

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References


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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.

<table>
<thead>
<tr>
<th>Variable</th>
<th>PD-NC (n=17)</th>
<th>PD-MCI (n=22)</th>
<th>PDD (n=9)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>71 (44/80)</td>
<td>68 (57/78)</td>
<td>72 (67/75)</td>
<td>0.18</td>
</tr>
<tr>
<td>Male gender, n (%)</td>
<td>10 (59%)</td>
<td>17 (77%)</td>
<td>9 (100%)</td>
<td>0.09</td>
</tr>
<tr>
<td>Age of onset</td>
<td>64 (43/72)</td>
<td>61 (43/71)</td>
<td>65 (55/69)</td>
<td>0.43</td>
</tr>
<tr>
<td>Disease duration (years)</td>
<td>6 (1/13)</td>
<td>6 (1/20)</td>
<td>6 (5/18)</td>
<td>0.11</td>
</tr>
<tr>
<td>Hoehn &amp; Yahr Stage, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>6 (35%)</td>
<td>3 (14%)</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>10 (59%)</td>
<td>13 (59%)</td>
<td>3 (33%)</td>
<td>0.03</td>
</tr>
<tr>
<td>3</td>
<td>1 (6%)</td>
<td>4 (18%)</td>
<td>3 (33%)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td>2 (9%)</td>
<td>2 (22%)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
<td>1 (11%)</td>
<td></td>
</tr>
<tr>
<td>UPDRS-III score</td>
<td>20 (11/58)</td>
<td>24 (10/62)</td>
<td>36 (14/56)</td>
<td>0.01</td>
</tr>
<tr>
<td>LEDD</td>
<td>620 (160/2420)</td>
<td>763 (210/3738)</td>
<td>496 (100/1139)</td>
<td>0.16</td>
</tr>
<tr>
<td>Geriatric Depression Scale (GDS)</td>
<td>2 (0/6)</td>
<td>5 (0/10)</td>
<td>8 (3/15)</td>
<td>0.001</td>
</tr>
</tbody>
</table>

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.
Table 2 Group comparisons adjusted for depression (GDS) and motor impairment (UPDRS-III) scores.

<table>
<thead>
<tr>
<th></th>
<th>Median (Minimum/Maximum)</th>
<th>PD-NC vs. PDD</th>
<th>PD-MCI vs. PDD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PD-ND</td>
<td>PD-MCI</td>
<td>PDD</td>
</tr>
<tr>
<td><strong>Activity time [%]</strong></td>
<td>0.21 (0.03/0.41)</td>
<td>0.21 (0.08/0.39)</td>
<td>0.09 (0.01/0.26)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Activity intensity [g]</strong></td>
<td>0.08 (0.03/0.13)</td>
<td>0.07 (0.03/0.11)</td>
<td>0.07 (0.03/0.13)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>PAR of activity</strong></td>
<td>2.29 (1.35/3.13)</td>
<td>2.16 (1.43/2.87)</td>
<td>2.20 (1.39/3.08)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Number of activity bouts</strong></td>
<td>1555 (58/6385)</td>
<td>1470 (364/5011)</td>
<td>859 (49/2329)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mean activity bout length [s]</strong></td>
<td>8.50 (0/41.24)</td>
<td>11.03 (6.06/23.91)</td>
<td>12.02 (7.22/19.84)</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sedentary time [%]</strong></td>
<td>0.75 (0.51/0.97)</td>
<td>0.78 (0.61/0.92)</td>
<td>0.89 (0.74/0.97)</td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
<td><strong>Sedentary intensity [g]</strong></td>
<td>0.01 (0.01/0.04)</td>
<td>0.01 (0.01/0.04)</td>
<td>0.01 (0/0.04)</td>
</tr>
<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td><strong>PAR of sedentary</strong></td>
<td>1.18 (1.14/1.66)</td>
<td>1.21 (1.12/1.58)</td>
<td>1.17 (1.13/1.64)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Number of sedentary bouts</strong></td>
<td>134 (63/219)</td>
<td>129 (43/711)</td>
<td>97 (22/159)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mean sedentary bout length [s]</strong></td>
<td>506 (208/1344)</td>
<td>515 (83/1441)</td>
<td>727 (402/3869)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Steps</strong></td>
<td>5778 (43/14164)</td>
<td>4742 (167/10181)</td>
<td>2362 (15/13346)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total movement intensity [g]</strong></td>
<td>0.03 (0.02/0.06)</td>
<td>0.03 (0.01/0.06)</td>
<td>0.03 (0.006/0.04)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Activity Type</td>
<td>% Time Spent with Intensity Levels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>----------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sedentary</td>
<td>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</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light</td>
<td>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</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>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</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vigorous</td>
<td>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</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Units</th>
<th>Estimate (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEE [MJ/d]</td>
<td>832 (514/1477)</td>
</tr>
<tr>
<td>TEE [MJ/d]</td>
<td>2621 (1898/3500)</td>
</tr>
<tr>
<td>PAL</td>
<td>1.47 (1.32/1.90)</td>
</tr>
</tbody>
</table>

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.
**Table A** Correlations between selected neuropsychological tests and physical behavior parameters

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

**Correlation level of significance**: **P < .01; *correlation level of significance P < .05; PANDA, Parkinson Neuropsychometric Dementia Assessment; MMSE, Mini-Mental 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.