Movement Disorders
CLINICAL PRACTICE

RESEARCH ARTICLE

# Quantitative Measurement of Akinesia in Parkinson's Disease

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**Abstract:** **Background:** There is great interest in developing simple, user-friendly, and inexpensive tools for the quantification and elucidation of motor deficits in patients with Parkinson's disease (PD). These systems could help to monitor the clinical status of patients with PD, to develop better treatments, and to identify individuals who have subtle motor signs that might pass unnoticed in the conventional neurological examination.

**Methods:** Mememtum, a smartphone application that allows for the quantification of several parameters of movement, such as regularity, rhythm, and changes in the number of taps while taping with a single finger and with alternating fingers, was developed and then tested in a pilot study in Madrid and in an extensive study in Quito, Ecuador.

**Results:** Almost all patients could successfully perform single-finger tapping, but approximately 10% of patients with severe parkinsonism had problems taping with alternating fingers. The results revealed changes in the regularity of the pressure applied while tapping and a reduction in the number of taps on the device screen when alternating tapping among patients who had idiopathic PD and vascular parkinsonism compared with controls and individuals who had prediagnostic motor abnormalities of PD.

**Conclusion:** Applications available in smartphones could be used for investigation and treatment of patients with PD, but much research is needed to optimize the ideal parameters to be investigated and the potential usefulness of this technique for patients with PD in different stages of the disease.

Parkinson's disease (PD) is a common neurodegenerative disorder that affects millions of patients in the developed world, with an estimated prevalence of more than 3 in 1000 of the population older than 65 years of age.[1] Patients with PD present with motor and nonmotor symptoms, but motor deficits are considered characteristic of this disease.[2,3] Akinesia, muscle rigidity, postural abnormalities, and tremor at rest are considered the most important motor abnormalities and the most important reasons for disability in patients with PD.[2,3]

There are effective treatments for motor symptoms in PD, including pharmacotherapy, physical therapy, and deep brain stimulation. However, it is difficult to quantify the motor changes, because the tools used to measure these responses in PD are semiquantitative motor scales[4] or entail semi-invasive procedures.[5] The need for simple, inexpensive and user friendly quantitative tests for the evaluation of patients with PD is specially critical in developing countries where clinical man power is less abundant than in the first world.

Finger tapping is an item included in the Unified Parkinson's Disease Rating Scale (UPDRS) and is used to evaluate akinesia.[4] Finger tapping entails the semiquantitative evaluation of several components of akinesia, including speed, amplitude, fatigue, and regularity of finger movements. Recent studies have shown that programs available in smartphones could be used to collect data related to motor function in patients with PD and that there is a significant correlation between 5 subscores on the

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Movement Disorder Society UPDRS (rest tremor, postural tremor, pronation-supination, leg agility, and finger tapping) and 8 parameters of the data collected with the smartphone.[1] However, there is a need for studies of the different features of motor performance characteristics of PD in large groups of patients to evaluate the potential usefulness of these tools in large populations with difficult access to highly specialized medical care. Here, we report 1 such study focused on the use of an application for smartphones and tablets that mostly measures akinesia.

# Materials and Methods

## Patients

The first study took place in Madrid, Spain. We investigated 19 individuals with PD from the PD associations and 22 healthy individuals (controls) who voluntarily performed the tests. All patients were cognitively normal and at stages I through III of the Hoehn and Yahr scale.[6] All participants performed the following tests: (1) repetitive tapping for 20 seconds of a square with 1 finger of both hands (finger tapping); and (2) alternative tapping with 2 fingers of each hand of 2 color switching (red and green) rectangles on the cellular phone screen (for simplicity, designated as "typing").

The second study took place at the Department of Neurology, Hospital Eugenio Espejo, Quito, Ecuador. We studied 290 patients with idiopathic PD (I-PD), 51 patients with the initial prediagnostic motor abnormalities characteristic of PD (IMA-PD), 32 with vascular parkinsonism (V-PD), and 51 controls without neurological abnormalities. As described elsewhere, patients with IMA-PD[7] were members of families with hereditary PD or individuals attending the Movement Disorders Clinic with complaints compatible with early PD (shoulder pain, tremor at rest, constipation, orthostatic hypotension, etc.,) but with scores on the Unified Parkinson's Disease Rating Scale (UPDRS) part III (motor part) (UPDRS-III) from >3 to <10 (in patients with predominant tremor, the UPDRS-III score could be up to 20). The limit of 20 points for individuals who had tremor-dominant clinical features was established to avoid including those who had essential tremor and other types of tremors; however, the actual mean ± standard deviation UPDRS scores were 9.137 ± 1.96 (95% confidence interval, 8.816–9.458). The criteria for V-PD and I-PD have been published elsewhere.[8,9] Patients with IMA-PD were included in the study to investigate whether we could demonstrate features of akinesia in patients who had symptoms compatible with PD of insufficient severity for the diagnoses of this disease.[10] The controls were healthy volunteers. Patients with dementia were excluded from this study.

## Cellular Phone Applications

The programs used for the analysis of motor performance were obtained from Mememtum (Taniwa Solutions, Madrid, Spain), which is a software tool based on smartphone devices to measure motor performance in neurological diseases. For this study, Mememtum was installed in android devices, connected to the cloud, in which the algorithms processed the data. Before performing the test, the patients provided signed informed consent. The program produced a pseudonymization code, which was used for further data treatment. The motor tests preloaded with Mememtum were: (1) finger "tapping" and (2) finger "typing."

### Finger Tapping

*Description*. This test is a quantitative modification of the "tapping" test used in the UPDRS-III. The patient is instructed to tap using the index finger on the colored zone in the smartphone screen for 20 seconds. This test should be performed as fast as possible but not so much as to produce errors. After a couple of training trials, tapping should be performed twice: once with each hand. In controls, the dominant hand is considered the "good" hand, and the nondominant hand is considered the "bad" hand. In patients who have clinical evidence of motor disorders, the "good" and "bad" hands are those least and most severely affected, respectively.

*Scoring*. The finger tapping score is based on 3 features of the signal generated by the patient: the temporal rhythm of tapping, the regularity of the pressure applied on the screen, and the number of successful taps produced in 20 seconds. The signal is cloud-processed to generate the scores (Table S1).

### Finger "Typing"

*Description*. This test is a modification of the tapping test and is performed by alternative beating of 2 color-changing rectangles, which switch their color in response to the tap. We call this test "typing" for brevity, because it involves the alternative use of 2 different fingers, resembling typing on a keyboard, instead of repetitive tapping with only 1 finger. The patient is instructed to use the index finger to press a green rectangle, which switches to red after a successful tap, whereas the red rectangle, positioned in front of the middle finger, turns green and it is ready to be pressed. "Typing" should be performed as fast as possible without producing errors. After a couple of training trials, the test must be performed with both hands, considering the "good" and "bad" hands based on the same criteria used for tapping.

*Scoring*. The scoring for finger typing is performed as in tapping, but the number of successful taps is divided by one-half. This signal is cloud-processed to generate the scores, as shown at Table S2.

## Statistical Methods

Statistical analyses were performed using Graph Pad Prisma software package (version 6; GraphPad Software, Inc., La



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Jolla, CA). Differences were considered significant when $P < 0.05$.

The pilot study, which included only patients with I-PD and controls, was analyzed using the unpaired Student *t* test for age, which has a Gaussian distribution, and the Mann-Whitney test for the remaining parameters, which did not have a Gaussian pattern. For the final study, which included 4 groups of patients for comparison, we performed a 1-way analysis of variance (ANOVA) followed by the Fisher's test.

We checked the correlation between the results obtained with both hands from the motor tests of tapping and typing and the correlation between tapping and typing with each hand. For these analyses, we used Spearman's correlation. We also studied the relative asymmetry of motor performance for tapping and typing between both hands in controls and patients with IMA-PD, V-PD, and I-PD. In addition, we subtracted the results obtained with 1 hand from the results obtained with the other, elevated this difference to the square, and compared the results with an ANOVA followed by the Fisher's test.

For the evaluation of repeatability, we analyzed the number of taps produced by control participants using both the right and the left hand while typing. Because we worked with a quantitative variable, the measurement of concordance was the intraclass correlation coefficient. This analysis was based on an ANOVA of repetitive measures of our paired data. Previously, we compared the 2 series of data using a 2-tailed Student *t* test to rule out the possibility that there was a difference between the number of taps with both hands. In addition, we performed a Bland-Altman test of these 2 series of data obtained in controls to evaluate the agreement of the number of strokes between both hands (Fig. S1).

## Ethical Issues

The procedures used in this study were approved by the Ethical Review Committees of the Hospital Ramón y Cajal, Madrid, and the Hospital Eugenio Espejo, Quito. The individuals who participated in this study provided written informed consent.

# Results

## Pilot Study

The pilot study was performed in Madrid, Spain, and included 19 individuals with PD and 22 controls of similar age. The patients with PD were in stages I through III according to the Hoehn and Yahr scale.[7] These patients performed under strong supervision and were allowed to train with the device as many times as they needed to feel confident. All participants in the pilot study were able to complete all tests.

The most important results from the pilot study are summarized in Table 1. The number of taps, during finger tapping, was reduced in patients with I-PD with respect to controls, from 19% to 25% of baseline, although these differences were not significant due to the small size of the sample and to the great variability of the results. With regard to "typing," the differences observed between controls and patients with PD increased more in the worst hand (68% reduction compared with controls; $P < 0.01$) than in the best hand, in which there was a 35% reduction; however, these differences were not significant. There was more irregularity of "typing" in patients with I-PD than in controls. The differences were significant ($P < 0.05$) when "typing" with the best hand. There was also more irregularity in patients with I-PD, although the difference was only between 10% and 20% and did not reach significance.

**TABLE 1** Pilot study of quantitative methods for the analysis of motor performance in Parkinson's disease in Spain

| Variable | Mean ± SD | | *P* value |
|---|---|---|---|
| | Controls (n = 22) | Idiopathic PD (n = 19) | |
| Age, y | 71.65 ± 16.33 | 66.37 ± 24.69 | 0.8119 |
| Gender: No. of women/men | 15/7 | 10/9 | 0.3522 |
| Tapping, best hand | | | |
| Rhythm | 44.5 ± 26.2 | 59.3 ± 22.4 | 0.0598 |
| Regularity of force | 17.8 ± 8.2 | 21.4 ± 9.2 | 0.1432 |
| No. of taps | 86.7 ± 29.7 | 75.4 ± 29.3 | 0.2024 |
| Tapping, worse hand | | | |
| Rhythm | 43.6 ± 22.5 | 46.9 ± 22.7 | 0.3670 |
| Regularity of force | 19.6 ± 11.4 | 20.5 ± 8.3 | 0.6467 |
| No. of taps | 80.9 ± 27.9 | 65.3 ± 28.6 | 0.1197 |
| Typing, best hand | | | |
| Rhythm | 53.3 ± 18.3 | 68.7 ± 18.1 | 0.0220* |
| Regularity of force | 29.9 ± 31.0 | 33.4 ± 30.1 | 0.0863 |
| No. of taps/2 | 39.8 ± 30.7 | 25.8 ± 24.7 | 0.1758 |
| Typing, worse hand | | | |
| Rhythm | 60.1 ± 22.1 | 67.8 ± 27.3 | 0.2648 |
| Regularity of force | 35.4 ± 29.3 | 38.4 ± 38.4 | 0.6461 |
| No. of taps/2 | 34.2 ± 27.2 | 11.0 ± 11.7 | 0.0044** |

*$P < 0.05$ (2-tailed *t* test).
**$P < 0.01$ (2-tailed *t* test).

## Confirmative Study in Ecuador

The individuals with V-PD (32 patients) and I-PD (290 patients) in the study were in the following stages according to the Hoehn and Yahr scale[7]: stage I, 71 patients; stage II, 75 patients; stage III, 118 patients; stage IV, 34 patients; stage V, 14 patients; and unknown, 10 patients. All participants, with the exception of 3 who had I-PD, could perform tapping; 34 patients, including 6 with V-PD and 28 with I-PD, were unable to perform "typing." The most common reasons for inability to perform were (1) large-amplitude tremor, producing inability to consistently touch the screen of the phone; (2) excessive adherence to the screen with inability to lift up the hand from the screen; (3) repetitive tapping instead of alternative touching of the 2 rectangles shown on the screen while typing; or (4) simultaneous pressing of both rectangles.

The results of this substudy are summarized in Table 2. Controls and individuals with IMA-PD were slightly older than those with I-PD and V-PD, which rules out the possibility that



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**TABLE 2** Confirmative study of abnormalities of voluntary repetitive finger movements in idiopathic and vascular parkinsonism in Ecuador

| Variable | Mean ± SD | | | | *P* value |
|---|---|---|---|---|---|
| | Controls (n = 49) | IMA-PD (n = 51) | Vascular PD (n = 32) | Idiopathic PD (n = 290) | |
| Age, y | 75.5 ± 49.2 | 77.2 ± 47.6 | 71.0 ± 10.6 | 69.0 ± 12.0 | |
| Age at disease onset, y | | | 66.6 ± 8.8 | 61.3 ± 12.7 | Control vs. IMA-PD, $P < 0.05$; control vs. V-PD, $P < 0.001$; control vs. I-PD, $P < 0.001$ |
| Gender: No. of women/men | 34/17 | 32/19 | 20/12 | 195/95 | |
| Tapping, best hand | | | | | |
| Rhythm | 50.7 ± 27.3 | 52.9 ± 28.7 | 54.5 ± 26.3 | 55.3 ± 21.9 | |
| Regularity of force | 23.3 ± 14.5 | 22.2 ± 7.8 | 26.4 ± 11.4 | 26.3 ± 12.6 | Control vs. V-PD, $P < 0.05$; control vs. I-PD, $P < 0.05$ |
| No. of taps | 87.6 ± 26.6 | 83.4 ± 24.5 | 71.1 ± 27.6 | 76.8 ± 23.8 | Control vs. V-PD, $P < 0.05$; control vs. I-PD, $P < 0.001$ |
| Tapping, worse hand | | | | | |
| Rhythm | 51.4 ± 23.1 | 45.1 ± 23.9 | 48.6 ± 26.0 | 50.4 ± 21.9 | |
| Regularity of force | 24.3 ± 10.9 | 23.7 ± 7.9 | 32.5 ± 17.3 | 28.1 ± 12.9 | Control vs. V-PD, $P < 0.05$; control vs. I-PD, $P < 0.05$; IMA-PD vs. V-PD, $P < 0.05$; IMA-PD vs. I-PD, $P < 0.05$ |
| No. of taps | 82.2 ± 21.5 | 82.6 ± 21.0 | 71.2 ± 22.3 | 71.0 ± 24.8 | Control vs. V-PD, $P < 0.05$; control vs. I-PD BH and WH, $P < 0.001$; IMA-PD vs. I-PD, $P < 0.05$ |
| Typing, best hand | | | | | |
| Rhythm | 55.1 ± 16.5 24.3 | 59.9 ± 16.2 | 52.1 ± 21.5 | 55.5 ± 17.0 | |
| Regularity of force | 24.8 ± 11.8 | 24.9 ± 7.5 | 26.4 ± 13.1 | 25.9 ± 8.5 | |
| No. of taps/2 | 37.0 ± 17.5 | 38.4 ± 22.2 | 20.4 ± 16.1 | 23.4 ± 19.1 | Control vs. V-PD, $P < 0.001$; control vs. I-PD, $P < 0.001$ |
| Typing, worse hand | | | | | |
| Rhythm | 48.6 ± 21.5 | 52.8 ± 19.4 | 55.4 ± 21.0 | 52.6 ± 19.1 | |
| Regularity of force | 25.8 ± 9.30 | 23.8 ± 6.20 | 27.9 ± 11.4 | 26.5 ± 8.50 | |
| No. of taps/2 | 31.5 ± 18.2 | 34.6 ± 22.7 | 23.4 ± 13.6 | 22.2 ± 14.7 | Control vs. V-PD, $P < 0.001$; control vs. I-PD, $P < 0.001$ |

SD, standard deviation; IMA-PD, initial prediagnostic motor abnormalities characteristic of Parkinson's disease; PD, Parkinson's disease; V-PD, vascular Parkinson's disease; I-PD, idiopathic Parkinson's disease; BH, best hand; WH, worse hand.

the findings were related to aging. In this study of 422 patients, we concentrated on tapping and typing.

There were no significant differences between the patients with IMA-PD and the controls, indicating that, in this study, we could not demonstrate subclinical features of akinesia in patients with IMA-PD. The irregularity of tapping increased and the number of taps decreased in patients who had I-PD and V-PD compared with controls and patients who had IMA-PD (Table 2). The differences in irregularity and the number of taps among these groups, although significant, were modest at approximately 12% to 15% of baseline. Patients with IMA-PD were no different from controls in tapping.

With respect to typing, there was a significant difference in the number of valid cycles of alternative tapping between the V-PD and I-PD groups compared with the control and IMA-PD groups. This difference in "typing" was greater (approximately 30–35%) than the difference in tapping. However, we did not observe significant differences in the levels of irregularity between the groups while typing.

There was good correlation ($r = 0.7703$; $P = 0.0043$) between the performance of motor tests, evaluated as the number of strokes obtained while tapping and typing in both hands. The comparison of tapping and "typing" in each hand yielded significant results ($P < 0.05$; $r = 0.2644$).

The index of asymmetry revealed significantly increased asymmetry for "typing" only in the I-PD group and not in the V-PD or IMA-PD groups (Table 3). There was no change in the index of asymmetry for tapping in any of the groups included in this study.

We indirectly evaluated the repeatability of the results from this study. The correlation obtained between the number of taps produced by control participants in both hands was 0.791 ($P < 0.001$). The 2-tailed Student *t* test did not indicate any significant differences between the 2 measurements, and the intraclass correlation coefficient indicated a good correlation ($\rho = 0.78$). The Bland-Altman analysis of differences versus average (bias ± SD) was 4.411 ± 17.44 (95% confidence interval, −29.77 to 38.60). A representation of the Bland-Altman analysis is presented in Figure S1.

# Discussion

Finger tapping is an item on the UPDRS-III that is considered an index of akinesia.[4] However, it is evaluated semiquantitatively in clinical practice. In this study, we tested a new, quantitative, examiner-independent method for the evaluation of finger tapping. Other quantitative systems of evaluation of motor performance in PD include online monitoring systems[5]



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**TABLE 3** Asymmetry of motor performance in Parkinson's disease

| Variable | Control | Prediagnostic PD | Vascular PD | Idiopathic PD |
|---|---|---|---|---|
| Tapping, rhythm | 255 ± 569 | 1047 ± 1208 | 817 ± 1065 | 933 ± 1316 |
| Tapping, force | 30.0 ± 23.4 | 76.5 ± 129 | 297 ± 715 | 147 ± 410 |
| Tapping, no. of taps | 85.6 ± 59.7 | 191 ± 343 | 950 ± 1885 | 537 ± 1259 |
| Tapping, rhythm | 26.5 ± 13.8 | 58.3 ± 72.4 | 184 ± 441 | 82.3 ± 200 |
| Tapping, force | 46.5 ± 70.8 | 106 ± 283 | 120 ± 267 | 226 ± 1522* |

PD, Parkinson's disease.
*$P$ = 0.0075 (idiopathic PD vs. control). The remaining comparisons were nonsignificant. Statistical analyses were performed using 2-way analysis of variance followed by the Kruskal-Wallis test and the Dunn's multiple comparisons test.

and laboratories for the analysis of movement.[11,12] Most of those systems are relatively invasive and time consuming and do not differentiate normal movement from tremor and high activity from dyskinesia.[13–24] In the past few years, great interest has arisen in the use of smartphones application for the evaluation and treatment of patients with PD.[25–30]

We developed a system for the evaluation of different features of tapping, such as rhythmicity, regularity of pressure, and speed of tapping (represented by the number of taps per 20 seconds), which are features of movement-related akinesia. Changes in regularity were greater while tapping, but the reduction of the number of taps was greater while "typing," suggesting that several tests should be performed to test different types of patients who have different degrees of severity.

The data obtained in the 2 studies reported here are complementary. In the pilot study, which was performed in patients who had PD in stages I to III,[5] there was a difference in the number of taps between controls and patients with PD. The difference, as expected, became highly significant for the most severely affected hand of the patient, consistent with the asymmetrical character of I-PD.

The confirmative study reproduced the findings observed in the pilot and yielded additional results, such as increased irregularity and reduction in the number of taps among patients with V-PD and I-PD compared with controls and patients with IMA-PD. There was also a very pronounced reduction of the number of taps, but no increase in the irregularity of pressure applied, in patients with I-PD while typing.

There is great interest in developing quantitative methods for analyzing the clinical features of movement disorders. With regards to akinesia, which is the core symptom of PD, several groups have developed different systems of analysis. Taylor Tavares and colleagues[31] demonstrated that repetitive finger tapping could be measured by quantitative digitography using a computer-interfaced musical keyboard. Those authors found that quantitative digitography correlated well with UPDRS scores, especially those related to bradykinesia, and improved with dopaminergic treatment and deep brain stimulation. Louie and colleagues[32] used the same methodology to investigate the slope of the curve of akinesia in both hemibodies and a steeper course in the least affected side. Espay and colleagues[33] used an electromagnetic device to investigate changes in amplitude and speed in PD and found that amplitude was disproportionately affected in the state OFF stimulation and was correlated with UPDRS scores. Heldman and colleagues[34] evaluated a modified scale for bradykinesia, which separately assessed speed, amplitude, and rhythm and their correlation with kinematic measures from motion sensors. Those authors found a good correlation between the new bradykinesia scale and the kinematic measures, with the best correlation observed for amplitude.

All of the above-mentioned studies demonstrate that bradykinesia is a complex phenomenon that can be subdivided into several components. There is also good correlation between the clinical and instrumental measurements. However, the quantitative methods described above are tools designed to be used in the setting of clinical research laboratories. The step we took in this study was to transfer the quantitative methods to commercially available smartphones and to the patient environment.

There are very few studies of akinesia that include smartphone devices. Arora and colleagues[35] performed a pilot study in 20 patients with PD who were provided smartphones with an android operating system that assessed voice, posture, gait, finger tapping, and response time 4 times daily for 1 month and who also participated in 1 weekly teleconference. Those authors reported that these tests allowed for discrimination of PD patients and controls with high sensitivity and specificity. Sharma and colleagues[36] proposed a system comprised of a smartphone and a smartwatch that could analyze facial tremors and speech and could monitor active movements. In our study, Mememtum provided useful, quantitative online information about motor performance in patients with PD that could be stored in the cloud for future analysis or for clinical studies. The system is free, does not require invasive procedures, and is fully operated by the patient. In addition, Mememtum does not need assistance from health care providers and is free, which could be 2 important features in developing countries. On the other hand, Mememtum is prepared to store the raw information of each test in an anonymous, real-life evidence database, allowing the extraction of analytical information and the use of machine-learning algorithms to automatically infer UPDRS scores.

However, our system has limitations. Approximately 10% of patients, mostly those with severe parkinsonism, were unable to perform "typing." This probably could be improved, at least in part, by using larger and more stable devices, such as tablets, which are easier to operate. Our system requires more formal validation to define its accuracy, agreement with a reference standard, and responsiveness. In addition, the system could be improved by adding a battery of tests of different lengths, to



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monitor irregularity and fatigue, and of different complexity, such as "typing" with more than 2 fingers. In any case, it appears that online, self-operated, free motor performance tests will have a role in the management of patients with PD.

# Author Roles

1. Research Project: A. Conception, B. Organization, C. Execution; 2. Statistical Analysis: A. Design, B. Execution, C. Review and Critique; 3. Manuscript Preparation: A. Writing the First Draft, B. Review and Critique.

L.L.: 1C, 3B
M.L.: 1C, 3B
A.M.: 1C, 3B
F.A.: 1C, 3A, 3B
M.F.: 1A, 1B, 3B
J.P.: 1A, 1B, 3B
J.L.M.: 1A, 1B, 3B
M.Á.M.: 1C, 3B
J.L.L.S.: 1C, 3A, 3B
J.G.d.Y.: 1C, 2A, 2B, 3A, 3B

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# Supporting Information

Additional Supporting Information may be found online in the supporting information tab for this article:

**Table S1.** Score and description of tapping test

**Table S2.** Score and description of typing test

**Figure S1.** Bland and Altmann analysis of repeatability of the number of taps of both hands in the control groups while "typing" for 20 seconds.



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