Journal of Electromyography and Kinesiology 66 (2022) 102695

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

journal homepage: www.elsevier.com/locate/jelekin

Finger dexterity measured by the Grooved Pegboard test indexes Parkinson's motor severity in a tremor-independent manner

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ARTICLE INFO

Keywords:
Fine motor
Dexterity test
Parkinson's
Motor control
Tremors

ABSTRACT

Fine motor impairments are frequent complaints in people with Parkinson's disease (PD). While they may develop at an early stage of the disease, they become more problematic as the disease progresses. Tremors and fine motor symptoms may seem related, but evidence suggests two distinct phenomena. The purpose of our study was to investigate the relationships between fine motor skills and clinical characteristics of PD patients. We hypothesized worse fine motor skills to be associated with greater motor severity that is independent of tremor. We measured fine motor abilities using the Grooved Pegboard test (GPT) in each hand separately and collected clinical and demographics data in a cohort of 82 persons with PD. We performed regression analyses between GPT scores and a range of outcomes: motor severity, time from diagnosis, age and tremors. We also explored similar associations using finger and hand dexterity scores from a standardized PD rating scale. Our results indicate that scores on the GPT for each hand, as measures of manual dexterity, are associated with motor severity and time from diagnosis. The presence of tremors was not a confounding factor, as hypothesized, but age was associated with GPT scores for the dominant hand. Motor severity was also associated with hand and finger dexterity as measured by single items from the clinical Parkinson's rating scale. These findings suggest that the GPT to be useful tool for motor severity assessments of people with PD.

1. Introduction

Impaired finger dexterity is a symptom that most patients with Parkinson's disease (PD) will eventually experience even when dopaminergic replacement medications adequately alleviate other motor symptoms (Norman and Heroux, 2013). This impairment causes difficulties with daily living and impacts overall quality of life (QOL) in this population (Dural et al., 2003). The exact causes of impaired finger dexterity are still unclear, which is probably due to the lack of knowledge regarding the specific pathophysiological mechanisms, but studies have tied this symptom to several overarching motor impairments such as bradykinesia (Berardelli et al., 2001), motor coordination (Brown and Almeida, 2011), and finger interaction (Park et al., 2012). Disorders of deftness regarding hand and finger movements is also called Limb Kinetic Apraxia (LKA) (Apraxia Erbgn der ges, 1920), which have been associated with PD (Quencer et al., 2007) and PD-related QOL (Vanbellingen et al., 2018), but also subject of controversy (Zadikoff and Lang, 2005). Although tremors can also influence the ability to use hands, many people with PD will not develop tremors but still experience impairments with finger dexterity. In fact, the presence of tremors may impair the ability to distinguish fine motor symptoms from an inability to perform certain hand movements due to tremors. Conversely, those who have tremors may or may not experience impairments in finger dexterity (Dan et al., 2019). Evidence suggests impaired finger dexterity in PD to be predominantly apraxic in nature, and especially when disease progresses to advanced stages (Vanbellingen et al., 2011). Specifically, limb kinetic apraxia, which is an inappropriate selection of individual fingers for coordinated and precise movements, is impaired in PD (Vanbellingen et al., 2011) likely due to premotor cortex abnormalities (Foki et al., 2010) and/or an enhanced

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https://doi.org/10.1016/j.jelekin.2022.102695
Received 5 January 2022; Received in revised form 24 June 2022; Accepted 10 August 2022
Available online 22 August 2022

activity in the left praxis network upstream to primary motor areas (Kübel et al., 2017).

There are three commonly used pegboard tests to assess manual dexterity in research settings: the Purdue Pegboard Test (PPT), the Nine-Hole Peg Test (NHPT) and the Grooved Pegboard Test (GPT). Developed by Joseph Tiffin in 1948, the PPT is now used widely by clinicians and researchers as a measure of gross movements of the arm, hand and fingers, as well as fingertip dexterity. The PPT is suitable for patients who have impairments of the upper extremity resulting from neurological and musculoskeletal conditions (Lindstrom-Hazel and VanderVlies Veenstra, 2015). Unfortunately, the level of difficulty makes its administration rather lengthy and often difficult for patients in advanced stages of the disease, and also does not exclusively assess finger dexterity. The NHPT is a simple and efficient manual dexterity test, which has previously been used to measure manual dexterity improvements in the PD population (Vanbellingen et al., 2017). Unfortunately, its low level of complexity leads to a ceiling effect that may not capture subtle changes in finger dexterity (Wang et al., 2011). As the pegs must be rotated into position to be successfully placed into the pegboard, the GPT adds a dimension of complexity not found in the other two tests as well as a correlate to the coin rotation task used in clinical settings as screening tool for dexterity impairments in PD (Hill et al., 2010). The GPT has been found to be a sensitive device in detecting general slowing due to medication or disease progression (Bryden and Roy, 2005).

In PD, the GPT has been used as a motor outcome of clinical trials (Demakis et al., 2002; King et al., 2009). Regarding its validity towards motor symptoms or, more generally, overall PD symptoms is still an ongoing area of investigation. A previous study suggested its relationship with motor severity in the earlier stages of the disease (Sage et al., 2012), calling for inclusion of cohorts with advanced PD. In another study including patients in early to mid-stages, a relationship between GPT scores and nigrostriatal denervation in PD was found between the clinically least affected limb and the least denervated striatum (Bohnen et al., 2007) with ceiling and floor effects in the opposite limb/regions, suggesting a relationship between manual dexterity and underlying pathophysiology. Whether tremors were accounted for or impacted motor outcomes is a common missing piece in these studies.

The purpose of our study was to investigate the relationships between fine motor skills and clinical characteristics of PD patients across a large spectrum of motor severity. We hypothesized that the scores achieved on the GPT are significantly correlated with motor severity, independent of the presence of tremors.

2. Methods

2.1. Participants

Eighty-two people with PD were recruited from the Movement Disorders Clinic at the University of Colorado Anschutz Medical Campus and from campus-wide advertisements. All participants provided informed consent prior to participating in the study, which was approved by the Colorado Multiple Institution Review Board. Inclusion criteria included a diagnosis of probable PD according to the UK Brain Bank Criteria (Hughes et al., 1992). Participants were excluded if they had features suggestive of other causes of parkinsonism cerebrovascular disease or history of major head trauma; or if they had a history of deep brain stimulation or ablation surgery.

All study visits were performed in the best dopaminergic "ON" state: participants were assessed no longer than an hour before and no shorter than a half hour after the next medication intake. We recorded time from diagnosis for each participant, as well as current dopaminergic medications. We preferred the criterion "time from diagnosis" term rather than "disease duration" because it is widely known that patients with PD experience symptoms a long time before they are formally diagnosed. We also determined which hand was dominant by the Edinburgh Handedness Inventory (Oldfield, 1971). Table 1 includes demographic characteristics of the participants.

No power calculations were conducted for this observational study, rather all available and eligible data were included.

2.2. Clinical measures

The Unified Parkinson's Disease Rating Scale (UPDRS) Section III (Motor Examination) provides an overall marker for Parkinson's disease progression and motor severity, as well as a validated measure of treatment-related benefits, with a higher score indicating further disease progression (Goetz et al., 2008). In addition to completing the GPT as a measure of manual dexterity, finger dexterity was quantified with scores from the UPDRS finger tap items 23a and 23b, for right and left hand respectively, as well as the UPDRS hand movement items 24a (right hand) and 24b (left hand). We also measured resting tremors in the right (items 20b) and left (20c) hands as well as action tremors in the right (21a) and left (21b) hands. We used the Hoehn and Yahr scale (Goetz et al., 2004) to obtain a broad-range clinical profile, which comprises a descriptive categorical scale that is used mostly for demographical representation of a PD group. To measure overall cognition, we used the Montreal cognitive assessment (MoCA), a standardized test widely used in the PD population (Gill et al., 2008).

Table 1 includes participants' clinical characteristics.

2.3. Grooved Pegboard test

All participants completed the Grooved Pegboard Test (Lafayette instruments # 32025), a manual dexterity test that involves manipulating 25 keyhole shaped pegs, one at a time, and inserting them into matching holes (Trites, 1989). The person is instructed to insert the pegs, matching the groove of the peg with the groove of the hole, filling the rows in a given direction as quickly as possible, without skipping any slots. Using the right hand, the patient is asked to work from left to right and top to bottom, and with the left hand, in the opposite direction. The dominant hand is tested first. The patient is warned that only one peg should be picked up at a time and that only one hand is to be used. We collected the time taken to complete the GPT with each hand. This measure of hand function is used as the primary outcome for our association analyses.

2.4. Statistical analyses

The primary analysis focused on the association between the motor measures of hand function and motor severity (UPDRS-III) or time from diagnosis using an "a priori approach". Given that age is a confounding factor for both motor severity and time from diagnosis, we adjusted for age during our analyses. We also examined the potential for resting and action tremors scores to serve as predictor variables for the primary

Table 1
Participants' demographics and clinical characteristics. UPDRS = Unified Parkinson's Disease Rating Scale. The high levodopa equivalence standard deviation indicates that the participants were spread out over a wide range of dosages. *MoCA = Montreal cognitive assessment; only 68 out of 82 had available MoCA scores close to study visits.

Demographics	N (%) / Mean (SD)	range
Sex (# Male)	49 (59.8%)	—
Handedness (#Right)	71 (86.6%)	—
Age	68.91 (7.52)	50.14–83.38
Time since diagnosis (months)	65.63 (42.44)	1–180
Education (Years)	16.49 (2.62)	7–20
Levodopa Equivalence	697.73 (745.31)	0–5238
UPDRS-III	25.83 (9.79)	6–56
Hoehn & Yahr	2.3 (0.7)	1–3
MoCA*	26.19 (2.77)	19–30

outcomes.

Demographics are summarized as frequency (percent) for categorical variables as mean (standard deviation) and range for continuous variables. To address our primary question as to whether GPT scores were significantly associated with motor severity, negative binomial regression was used because the assumptions of linear regression were violated and the data were found to be overdispersed. A dispersion parameter is therefore included in the model. To investigate whether finger tap and hand movement scores were associated with motor severity, ordinal logistic regression was used because scores were ordered categories valued from 0 to 3. All analyses were carried out using R version 4.0.2 (Vienna, Austria).

Of note, secondary fine motor outcomes (finger tap and hand movement scores) are sub-items of the UPDRS-III scores, amongst 27 total sub-items assessed. Given the low % variation explained by these scores (Sage et al., 2012), we wanted to include them as additional fine motor assessments, as commonly measured during clinic visits.

3. Results

Participants were spread through age range (50-83yrs), motor severity (UPDRS-III scores: 6-56), and time from diagnosis (1-180 months), representative of the distributions seen in our clinics. These wide distributions allowed to compute our correlative statistics over a large range of values. Demographics and clinical characteristics are provided in Table 1.

Summary statistics for GPT, finger tap, and hand movement scores can be found in Table 2.

GPT times for the dominant hand (129 s (SD = 51 s)) were significantly associated (Table 3) with motor severity ($p = 0.002$), age of participants ($p < 0.001$), and time from diagnosis ($p = 0.007$). These associations were positive, indicating that longer GPT times were associated with more pronounced motor severity, greater age of participants and longer time since PD diagnosis. In addition, no relationship was found between GPT times and either resting or action tremors in the dominant hand ($p > 0.05$). Fig. 1A and B illustrates the dispersion of the data away from the minimal values for GPT time and motor severity as age increased (darker dots). GPT times for the non-dominant hand (150 s (SD = 74 s)) were positively and significantly associated (Table 4) with motor severity ($p = 0.001$) and time from diagnosis ($p = 0.006$), but no relationship was found with age of participants ($p > 0.05$). We also didn't find an association between the GPT times and either resting or action tremors in the non-dominant hand ($p > 0.05$). Fig. 1C and D illustrates an age dispersion that extends across the range for GPT times for the non-dominant hand.

Table 2
Summary statistics: motor outcomes DH: dominant hand; N-DH: non-dominant hand.

		Overall
N		82
Time (sec) DH (mean (SD))		128.56 (50.91)
Time (sec) N-DH (mean (SD))		149.56 (73.95)
Finger taps DH (%)		
	0	11 (13.4)
	1	31 (37.8)
	2	36 (43.9)
	3	4 (4.9)
Finger Taps N-DH (%)		
	0	9 (11.0)
	1	29 (35.4)
	2	37 (45.1)
	3	7 (8.5)
Hands movement DH (%)		
	0	24 (29.3)
	1	33 (40.2)
	2	24 (29.3)
	3	1 (1.2)
Hands Movement N-DH (%)		
	0	21 (25.6)
	1	36 (43.9)
	2	21 (25.6)
	3	4 (4.9)

Table 3
Estimated coefficients: pegboard scores for the dominant hand (AIC = 817.077).

	Estimate	Std. Error	z value	p-value
(Intercept)	2.993	0.279	10.716	<0.001
Disease Motor severity	0.01	0.003	3.171	0.002
Age	0.021	0.004	4.803	<0.001
Time since diagnosis	0.024	0.009	2.705	0.007
Resting tremor DH	−0.032	0.037	−0.877	0.38
Action tremor DH	0.029	0.044	0.651	0.515

Finger tap scores for the dominant hand were significantly associated with motor severity where a one unit increase in severity increased the odds of a lower performing score by 1.07 ($p = 0.005$; Table 5). We did not find a relationship between finger tap scores for the dominant hand and either age, time from diagnosis or any tremor classification ($p > 0.05$). Similarly, finger tap scores for the non-dominant hand were significantly associated with motor severity where a one unit increase in severity increased the odds of a lower performing score by 1.21 ($p < 0.001$; Table 6), but no relationship was found with age, time from diagnosis, or any tremor classification ($p > 0.05$).

Hand movement scores for the dominant hand were significantly associated with motor severity and action tremors ($p < 0.001$ and $p = 0.003$, respectively; Table 7), but no relationship was found with age of participants, time from diagnosis, or resting tremors ($p > 0.05$). The odds of a lower performing dominant hand movement score were 1.14 times higher for each increase in motor severity, whereas a higher action tremor reduced the odds by 0.35 times. Similarly, hand movement scores for the non-dominant hand were significantly associated with motor severity and action tremors ($p < 0.001$ and $p = 0.002$, respectively; Table 8), but no association was found with age of participants, time from diagnosis, or resting tremors ($p > 0.05$). The odds of a lower performing hand movement score for the non-dominant hand were 1.21 times higher for an increase in motor severity and reduced by 0.34 for the action tremors.

Overall cognition, measured using the MoCA, was not significantly associated with the GPT scores from either the dominant hand or those from the non-dominant hand (Supplementary Tables 1 And 2).

4. Discussion

Our main finding was that GPT times for each hand, as measures of manual dexterity, are significantly correlated with Parkinson's disease motor severity and time from diagnosis. As we hypothesized, the presence of tremors was not a confounding influence on this association. In contrast, age was a significant explanatory variable for the GPT times of the dominant hand but not the non-dominant hand. Motor severity was also associated with hand and finger dexterity as measured by single items from the clinical Parkinson's rating scale.

Our findings indicate that problems with finger dexterity increase in people with PD along with disease progression. Standard disease progression assessments are performed by a neurologist, a movement disorders clinical in best cases, within limited clinic visits that are often occurring twice a year, providing a brief picture rather than a continuous appraisal. Accurate outcomes measures, such as the GPT, could hold potential to monitor progression of fine motor symptoms. This would require further exploration and comparison to normative data from healthy controls, without undermining the high likelihood of practice effects (Marmon et al., 2011). The place phase of the GPT has been previously associated with overall UPDRS scores (Sage et al., 2012), confirming some potential relationship between this behavioral measure and a thorough clinical evaluation. Other pegboard tests have

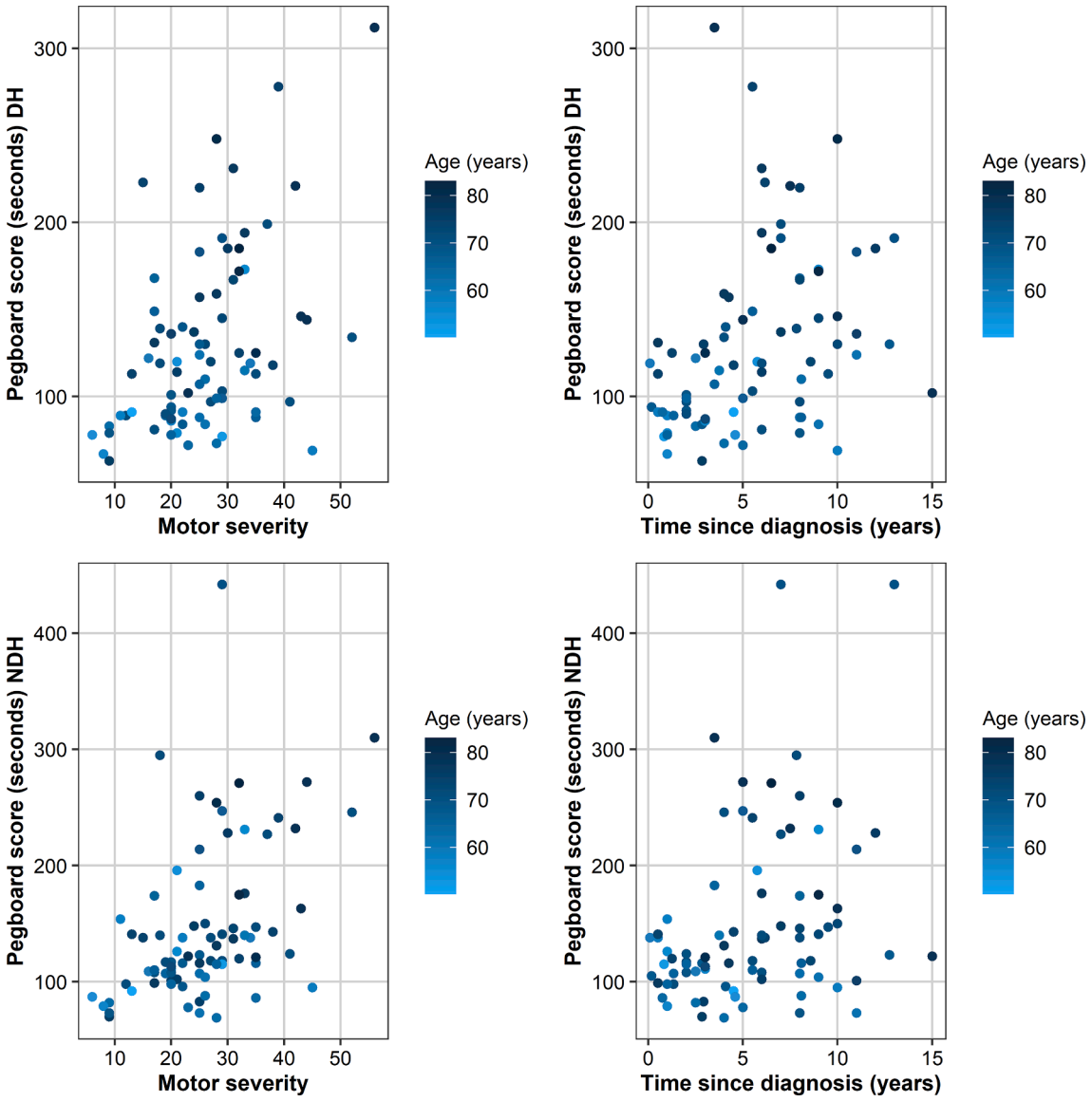

Fig. 1. Demograph.

Table 4
Estimated coefficients: pegboard scores for the non-dominant hand (AIC = 881.713).

	Estimate	Std. Error	z value	p-value
(Intercept)	3.791	0.362	10.478	<0.001
Disease Motor severity	0.015	0.005	3.339	0.001
Age	0.009	0.006	1.549	0.121
Time since diagnosis	0.032	0.011	2.77	0.006
Resting tremor NDH	0.079	0.046	1.72	0.085
Action tremor NDH	−0.051	0.058	−0.877	0.381

Table 5
Estimated coefficients for finger taps of the dominant hand (AIC = 187.127). "0|1, 1|2, and 2|3 represent the intercept terms in the ordinal logistic regression model".

	Value	Std. Error	t value	p-value
Disease Motor severity	0.068	0.024	2.815	0.005
Age	0.038	0.031	1.199	0.23
Time since diagnosis	0.064	0.065	0.984	0.325
Resting tremor DH	0.209	0.27	0.774	0.439
Action tremor DH	−0.166	0.32	−0.518	0.604
0|1	2.566	2.006	1.279	0.201
1|2	4.797	2.072	2.315	0.021
2|3	8.07	2.201	3.666	<0.001

been investigated in the PD population as well and have provided different directions. For instance, PPT scores may be more useful for predicting cognitive changes and ADL dysfunction in PD (Hinkle and Pontone, 2021) but when focused on hand function, it appears that while evidence supports the construct validity of NHPT for measuring more affected hand performance in PD (Proud et al., 2021), its sensitivity to self-reported dexterity issues is lower than the PPT (Proud et al., 2020). In addition, the cognitive component associated with administration of the GPT should be carefully evaluated, since visuospatial skills become problematic as cognitive decline arises and the GPT may also index these impairments as disease progresses along with risks of PD dementia (Bezdicek et al., 2014). In a subset from our cohort (68 out of 82), overall cognitive decline did not explain hand dexterity impairments measured by the GPT.

Although dopamine-replacement medications do not adequately address fine motor symptoms (Schettino et al., 2006; Tunik et al., 2007), symptomatic approaches using complementary and alternative

Table 6
Estimated coefficients for finger taps of the non-dominant hand (AIC = 187.127). "0|1, 1|2, and 2|3 represent the intercept terms in the ordinal logistic regression model".

	Value	Std. Error	t value	p-value
Disease Motor severity	0.189	0.035	5.468	<0.001
Age	−0.042	0.032	−1.302	0.193
Time since diagnosis	0.012	0.065	0.176	0.86
Resting tremor NDH	0.367	0.267	1.374	0.17
Action tremor NDH	−0.41	0.344	−1.193	0.233
0|1	−1.022	2.074	−0.493	0.622
1|2	1.771	2.076	0.853	0.393
2|3	5.514	2.181	2.528	0.011

Table 7
Estimated coefficients for hand movements of the dominant hand (AIC = 172.473). "0|1, 1|2, and 2|3 represent the intercept terms in the ordinal logistic regression model".

	Value	Std. Error	t value	p-value
Disease Motor severity	0.128	0.029	4.482	<0.001
Age	−0.031	0.032	−0.949	0.343
Time since diagnosis	0.08	0.07	1.143	0.253
Resting tremor DH	0.234	0.271	0.864	0.388
Action tremor DH	−1.051	0.356	−2.952	0.003
0|1	−0.272	2.044	−0.133	0.894
1|2	1.981	2.064	0.96	0.337
2|3	6.341	2.323	2.73	0.006

Table 8
Estimated coefficients for hand movements of the non-dominant hand (AIC = 168.87). "0|1, 1|2, and 2|3 represent the intercept terms in the ordinal logistic regression model".

	Value	Std. Error	t value	p-value
Disease Motor severity	0.19	0.033	5.725	<0.001
Age	−0.045	0.032	−1.395	0.163
Time since diagnosis	−0.087	0.067	−1.296	0.195
Resting tremor NDH	0.191	0.254	0.753	0.452
Action tremor NDH	−1.078	0.346	−3.121	0.002
0|1	−1.109	2.041	−0.543	0.587
1|2	1.685	2.042	0.825	0.409
2|3	4.695	2.141	2.193	0.028

methodology, such as Neurologic Music Therapy (Buard et al., 2019), may hold rehabilitative potential. The characterization of fine motor symptoms from neuroanatomical and kinematic perspectives are crucial for effective rehabilitation of symptoms and for possibly staging disease severity. Interestingly, patients with early and untreated PD already experience bradykinesia of fine motor skills in the most-affected side (Koop et al., 2008) as observed during assessment of movement velocity. In contrast, another study noted no slowness or rigidity but evident LKA in a small cohort of mildly affected patients (Quencer et al., 2007). Because GPT times represent a trade-off between movement speed and accuracy (Almuklass et al., 2016), the distinction between slowness and other impairments of fine motor control needs further clarification.

We observed the level of the tremors exhibited by the participants was not associated with either the GPT times or the number of finger taps, but they were associated with worse hand movements (UPDRS items). The neuropathological nature of tremors and fine motor skills seem to indicate two distinct phenomena. Tremors may impair ability to detect and quantify fine motor impairments during standardized clinical assessments, especially when the tremor is severe. According to Gironell et al (Gironell et al., 2018), the several classes of tremors associated with PD are "pure resting tremor (type I); mixed resting and action tremor with similar frequencies (type II) divided, according to action tremor presentation, into II-R when there is a time lag and II-C otherwise; pure action tremor (type III); and mixed resting and action tremor with differing frequencies (type IV)". From a neuroimaging perspective, tremors have been classified as arising in the basal-ganglia, thalamus, or cerebellum, based on responses to dopaminergic medication and distinct neurotransmitter involvement (Madelein van der Stouwe et al., 2020).

In contrast, GPT times in healthy adults are correlated with the amplitude of the force fluctuations during steady, submaximal contractions (force steadiness), which are significantly associated with the variance in the common low-frequency oscillation of motor unit discharge times (Enoka and Farina, 2021). This association needs to be examined in clinical populations, such as people with PD. Nonetheless, the results of our study suggest that it is common synaptic input received by the motor neurons during steady contraction is more strongly associated with motor severity and time from diagnosis, than is oscillatory synaptic inputs that produce the tremors.

Finger dexterity is the planning and execution of finger movements, which links to motor control. The latter can be improved and restored (when lost or weakened) via motor skill learning (Naito et al., 2021), which refers to the increased spatial and temporal movements accuracy with practice. Interestingly, dopamine-replacement medication does improve motor learning during an upper extremity task in people with mild to moderate PD (Paul et al., 2020), although motor learning can be challenging when intentional effort is divided (e.g., dual tasks) (Olson et al., 2019). Finger dexterity improvements may therefore require adequate practice to reach the desired goals. The GPT does include a cognitive component that may impact test proficiency, namely visuo-spatial skills. These are widely affected in people with PD (Levin et al., 1991) amongst other cognitive skills. Some have even proposed GPT scores to reflect cognitive decline associated with postural instability and falls in PD (Bezdicek et al., 2014). Exclusion criteria for our study included dementia but not mild cognitive impairment so it may be possible that cognitive symptoms may have influenced our findings.

5. Conclusion

Our results indicate that the Grooved Pegboard Test represents an effective tool to perform assessments of decline in fine motor skills in people with Parkinson's disease. Importantly, this quantification of manual dexterity is independent of the tremors experienced by a person with the disease.

Funding

National Center for Complementary and Integrative Health (NCCIH) Grant Award #1K01AT009894-01A1 (PI: Buard). University of Colorado Denver Movement Disorders Center Pilot Grant (PI: Buard). National Institute for Neurological Disorders and Stroke Research Award #1R21NS093266-01A1 (PI: Kluger)

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jelekin.2022.102695.

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