

Assessment of Fine Motor Control in Individuals with Parkinson's Disease Using Force Tracking with a Secondary Cognitive Task

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Background and Purpose: Motor symptoms of Parkinson's disease (PD) are typically assessed using clinical scales such as the Unified Parkinson's Disease Rating Scale, but clinical scales are insensitive to subtle changes early in the disease process. The goal of this project was to use current sensing technology to develop a quantitative assessment tool to document fine motor deficits in PD based on the ability to control grip force output. The assessment was designed to challenge deficits commonly encountered as a result of PD, including dual-task performance of a motor task and a cognitive task simultaneously.

Methods: Two force sensors were used to measure the isometric pinch grip force between the thumb and index finger in 30 individuals with PD and 30 control participants of similar age without disability. Participants performed a target force tracking task with each of two different target waveforms (sinusoidal or pseudorandom) under each of three different cognitive load conditions (none, subtract 1, and subtract 3). Dependent variables calculated from the force sensor data included root mean square error, tremor integral, and lag.

Results: In general, individuals with PD showed significantly less accuracy in generating the target forces as shown by larger root mean square error compared with controls ($P < 0.001$). They also showed greater amounts of tremor and lag compared with controls ($P = 0.001$ and <0.001 , respectively). Deficits were more pronounced during the cognitive multitasking component of the test.

Discussion and Conclusions: These results will serve as a preliminary work for the development of a clinical biomarker for PD that may help to identify subtle deficits in fine motor control early in the disease process and facilitate tracking of disease progression with time.

Key words: *Parkinson's disease, force tracking, clinical biomarkers* (JNPT 2010;34: 32–40)

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INTRODUCTION

Parkinson's disease (PD) is a progressive neurodegenerative disorder caused by the degeneration of the nigrostriatal dopaminergic pathways within the basal ganglia. Clinically, the disease is characterized by bradykinesia, akinesia, resting tremor, and rigidity.^{1–4} Pathology studies have shown that by the time the disease is clinically diagnosed, there has been a loss of $>40\%$ of dopaminergic neurons. The disease has a preclinical duration of approximately six years, with the rate of progression being higher in the initial six years.^{5,6} Motor dysfunction of the hand has been documented in the literature,^{7–15} and early involvement of the hand has been subjectively reported by individuals with PD.¹⁶ A majority of the population with PD is high functioning in terms of their activities of daily living, especially when on medication. When the individual is on medication, impairments in hand function are difficult to demonstrate using common clinical measures, such as the Unified Parkinson's Disease Rating Scale (UPDRS), because the UPDRS cannot detect the minute changes in motor function that are observed early in the disease process.¹⁷ An additional disadvantage of the UPDRS is that it relies on self-report for some sections, and early in the disease process, many individuals with PD tend to underestimate their disability.¹⁸ Other clinical tests, such as the Grooved Pegboard Test, provide greater precision but offer little information as to which motor or cognitive parameters contribute to poor test performance.

The goal of this project was to develop a quantitative assessment tool to document fine motor deficits in individuals with PD using current sensing technology. This study describes the development and evaluation of a test, the Advanced Sensing for Assessment of Parkinson's disease (ASAP), to quantify impairments in fine motor control by high-precision force or torque sensors. This preliminary work will provide a foundation for the future development of the test into a clinical biomarker for early diagnosis and to quantify motor symptoms to assess outcomes of rehabilitation or neuroprotective interventions. We hypothesized that individuals with PD would show significant deficits in performance of force tracking tasks, especially when performing a simultaneous cognitive task, compared with control participants of similar age.

METHODS

Participants

Thirty individuals with PD (23 men and seven women) and 30 control participants without PD (12 men and 18 women) enrolled in the study. Demographic characteristics of all participants are reported in Table 1. The mean age of the control participants was within five years of the participants with PD. Individuals with PD were included if they were 18 years or older, were at a mild to moderate level of the disease based on the the Hoehn-Yahr scale,¹⁹ and were willing and able to stay off medications for 12 hours before the testing. Participants with PD were excluded if they had severe involuntary movements that would interfere with the test tasks, had sensory loss or motor weakness in their hand, scored <27/30 on the Mini-Mental State Examination, or had a deep brain stimulator implanted. All participants gave written

TABLE 1. Demographic Characteristics

	PD	Controls
Age, mean (SD); (yr) ^a	65 (10)	70 (10)
Gender (M/F)	23/7	12/18
Handedness R/L	24/6	22/8
No. of years since diagnosis, mean (SD)	6 (1)	NA
Hoehn-Yahr stage	1–3	NA

^a $P = 0.069$.

Abbreviations: PD, Parkinson's disease; SD, standard deviation; M, male; F, female; R, right; L, left; NA, not applicable.

informed consent for participation in a protocol approved by the institutional review board of the University of Pittsburgh.

Instrumentation

Two force sensors (Nano17; ATI Automation Industries, Apex, NC) were used to measure the isometric pinch grip force between the thumb and the index finger. Each sensor was mounted on an aluminum plate fixed to a custom-made arm support (Fig. 1). Each sensor was capable of measuring force and torque along three axes with a resolution of 0.003 N for force and a resolution of 0.01 Nm for torque. Force and torque data from the sensors were recorded at 100 Hz, and each data point represented the mean of ~16 samples. For this study, only the force data were considered.

Computer Display for the Force Tracking Tasks

Sinusoidal Force Tracking Display

A 0.13-Hz sine wave was displayed on the computer screen by a black line surrounded by a white window, indicating 1 N on either side of the target force (Fig. 2A). The horizontal axis of the display corresponded to time, whereas the vertical axis corresponded to force. The target sinusoidal waveform scrolled continuously across the screen from right to left, so that at each time point during the experiment, the current target force was positioned at the horizontal center of the screen. The participants' average resultant force was displayed by a purple point at the horizontal center of the computer screen. The participants were shown the 12.5 seconds of the target wave that had recently passed (along with

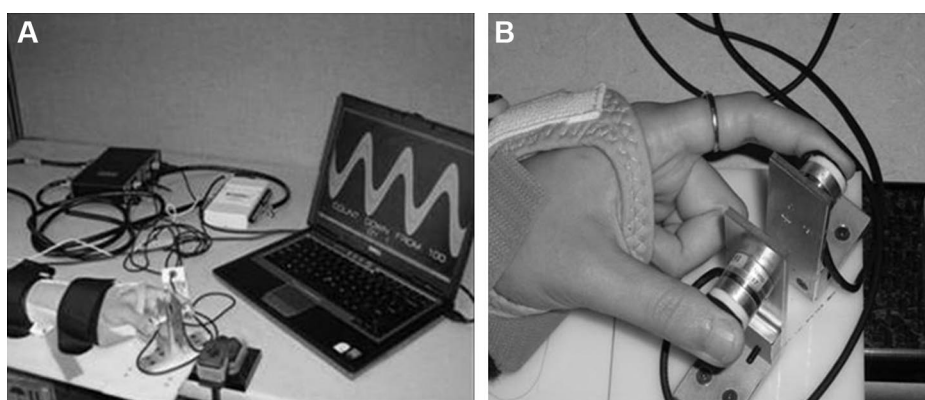


FIGURE 1. Experimental setup. A, Test position for the left arm, with the computer screen showing the sinusoidal tracking task. B, Position of the index finger and thumb grasping the force sensors during the force tracking task.

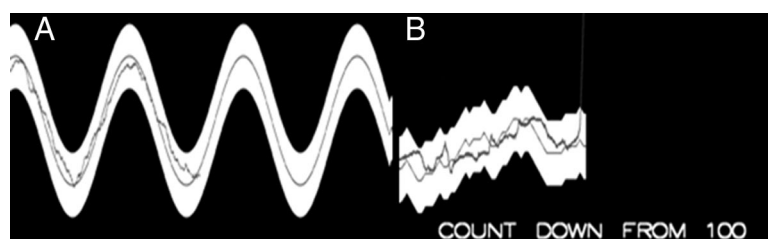


FIGURE 2. Display for the sinusoidal tracking task (A) and the pseudorandom waveform task (B). In both displays, the smooth line in the center of the white band represents the target that the participant was asked to track and the irregular line represents the response force created by the participant.

their tracking performance for that previous period) and the 12.5 seconds of the target wave that was to come.

Pseudorandom Force Tracking Display

The force target in the second task was a pseudorandom waveform (generated using pseudorandom ternary sequence), which made the waveform unpredictable.²⁰ As in the sinusoidal tracking task, the force target was represented on the computer screen as a black line surrounded by a white window, indicating 1 N on either side of the target force (Fig. 2B). This waveform was chosen because its derivative approximated a random noise distribution. The pseudorandom waveform had a frequency of 0 to 2.5 Hz and a period of 60.5 seconds. In this display, the participants were shown a 12.5-second history of the target and their response forces, but were given no information about the shape of the upcoming waveform.

Experimental Tasks and Conditions

Before performing the force tracking tasks, participants were familiarized with the equipment and trained for two minutes by tracking target waveforms that included periods of constant and ramping forces. The training session did not have a simultaneous task component.

Participants performed both the sinusoidal tracking task and the pseudorandom tracking task (described later) with each arm, for a total of four trials per participant. A rest break of five minutes was provided between each trial. Participants performed both force tracking tasks with one arm before proceeding with the other arm. The sinusoidal tracking task was always performed first, followed by the pseudorandom tracking task. For all the participants, the right arm was tested first, followed by the left arm regardless of dominant side or degree of involvement (in participants with PD).

Participants performed the force tracking tasks under each of the following three cognitive load conditions:

- No cognitive load (none) condition: force tracking task performed with no additional cognitive task
- Subtract 1 condition: force tracking task performed while simultaneously counting aloud backward consecutively from 100 (ie, 100, 99, 98, 97, 96 . . .)
- Subtract 3 condition: force tracking task performed while simultaneously counting aloud backward from 100 subtracting 3 each time (ie, 100, 97, 94, 91, 88 . . .)

A simultaneous mental task paradigm was chosen because cognitive distractions or dual-tasking has been shown to increase the difference in motor performance between individuals with and without PD.^{21,22} For this reason, we thought that the dual-task paradigm would be likely to magnify motor impairment in individuals with PD and may be valuable in improving the ability to detect small changes in performance early in the disease process. In addition, the dual-task paradigm increased the functional relevance of the assessment because most daily activities require individuals to function efficiently as they multitask, such as talking on the phone while walking or opening a door with a key.

Sinusoidal Tracking Task

Participants were asked to track the sinusoidal waveform (display as described in the Instrumentation section); the display of the target waveform provided an opportunity for the participants to observe their recent and current tracking performance and to see a portion of the upcoming waveform. The range of force required to track the target wave was 2 to 6 N, which is within the range of force necessary for everyday activities involving precision grip.²³ The sinusoidal tracking task required a total time of three minutes and 20 seconds to complete, with time allocated as follows. In preparation for tracking the sinusoidal waveform in the three cognitive load conditions, the participant tracked a flat line corresponding to a constant force of 4 N for 20 seconds. After this, the participant tracked the target sinusoidal waveform under the no cognitive load condition for one minute. The participant was then prompted to continue the tracking task while simultaneously counting aloud backward from 100 to one for the next one minute. Subsequently, the participant was prompted to continue the tracking task while simultaneously counting aloud backward from 100 to three for one minute. The timeline for the sinusoidal tracking task is shown in Table 2. To determine whether fatigue may contribute to deterioration over time in performance of the tracking task, five participants with PD engaged in an additional three minutes of sinusoidal force tracking under the no cognitive load condition.

Pseudorandom Tracking Task

Participants were asked to track the pseudorandom waveform (display as described in the Instrumentation section). The target force and the participant's force response were shown at the horizontal center of the screen, and a 12.5-second history of the target and response forces was also shown. However, the participant was unable to predict how much force should be used as the right side of the computer screen was blank (unlike the sinusoidal tracking task in which the upcoming 12.5 seconds of the ensuing waveform was displayed). During the pseudorandom tracking task, the participant experienced the same cognitive load conditions, in the same order and time duration, as in the sinusoidal tracking task.

Data Analysis

For each of the force tracking tasks, the data were separated into three consecutive one-minute sections corresponding to the cognitive load condition: no cognitive load, subtract 1, and subtract 3. Comparisons were made between data acquired from participants with and without PD, with dominant and nondominant sides considered separately. Three main response variables, tremor integral (TR), root mean square error (RMSE), and lag, were used to characterize the data.

TABLE 2. Timeline of Test Task

Minute 1	Minute 2	Minute 3
Force tracking without cognitive task	Force tracking + count backward by 1 (100, 99, 98, 97 . . .)	Force tracking + count backward by 3 (100, 97, 94, 91 . . .)

Tremor Integral

The force fluctuations associated with tremor in participants with PD were quantified. Quantification was based on the integral (area under the curve) of the power spectral density function (which describes how the force signal is distributed with frequency) between the force frequencies of 2 and 8 Hz. This value was defined as the TR. In subsequent analyses, it was assumed that the tremor was superimposed on the desired force output. Therefore, to mitigate the influence of the tremor on the other computed variables, after quantification of the TR, the force data were filtered with a Butterworth low-pass filter (second order, cutoff frequency 2 Hz, dual pass). All other dependent variables were calculated from the filtered data.

RMSE

To quantify force tracking accuracy, the RMSE was computed between the target force F_T and the observed force F :

$$\text{RMSE} = \sqrt{\frac{1}{N} \sum_{i=1}^N (F_i - F_{Ti})^2}$$

where N represents the number of data points measured during the time period considered.

Lag

The peak covariance between the target force and the response force (a measure of how these two variables changed together) was used to determine the time lag of the participant's response. A very small covariance value indicated that the subject followed the target so poorly that calculating the lag was not meaningful. For this reason, if the covariance was <0.35 , then the trial was assigned the maximum lag value of 2.5 seconds for the sinusoidal tracking task and 5 seconds for the pseudorandom tracking task. The covariance threshold of 0.35 was conservative and chosen empirically with the intent to minimize the number of cases being artificially assigned the maximum lag value. The maximum lag values were also chosen empirically based on the visual inspection of data.

Finally, data from five individuals with PD who performed the sinusoidal force tracking task for three minutes

under the no cognitive load condition were evaluated. Repeated-measures analysis of variance was performed to examine the effect of minutes of tracking on TR, RMSE, and lag.

Statistical Analysis

Repeated-measures analysis of variance was performed on the three response variables (TR, RMSE, and lag) with presence of PD as the between-group variable. The following three repeated measures were included in the analysis: dominant side, waveform type (sinusoidal or pseudorandom), and cognitive load condition (no cognitive load, subtract 1, and subtract 3). The significance level was set at $\alpha < 0.05$. The Mauchly test indicated that the assumption of sphericity was violated for the main and interaction effects. Therefore, the degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity.

The primary analyses of interest were the main effect of group (presence or absence of PD), which would indicate a significant effect of disease on the variables of interest, and the interaction of group and cognitive load condition, which would indicate whether individuals with versus without PD performed differently when simultaneously executing a cognitive task. Post hoc tests were performed when appropriate across the levels of cognitive load using the Bonferroni correction.

RESULTS

The average performance of 30 controls and 30 individuals with PD for the sinusoidal and pseudorandom tracking task are illustrated in Figures 3 and 4, respectively. The majority of participants with PD were men (23/30), whereas men composed the minority of control participants (12/30); thus, preliminary analyses were carried out using gender as a covariate. As there was no main effect of gender, and there was no interaction between gender and any of the other variables, the analyses reported below are without the covariate of gender. The findings related to the three response variables as a function of group, cognitive load, and waveform type are illustrated in Figures 5–7, respectively. Because there was no main effect of dominant side in any of the

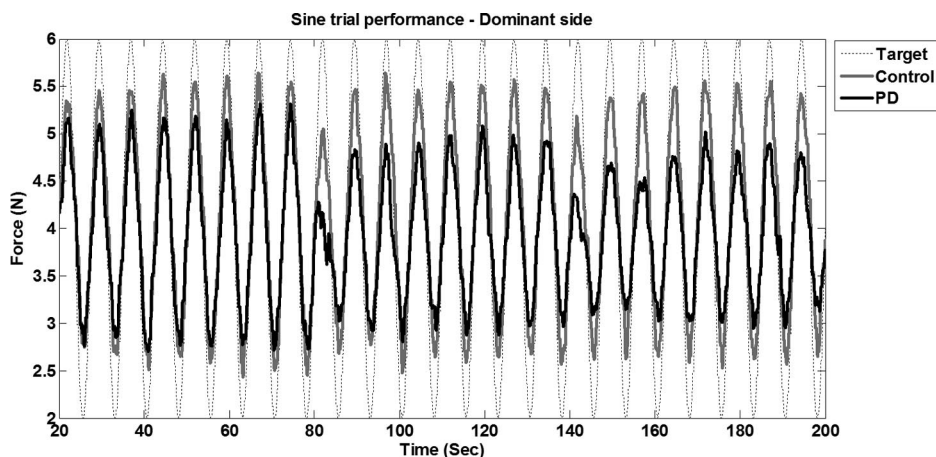


FIGURE 3. Ensemble plot of force traces from 30 participants with Parkinson's disease, 30 controls, and the target during the sinusoidal tracking task.

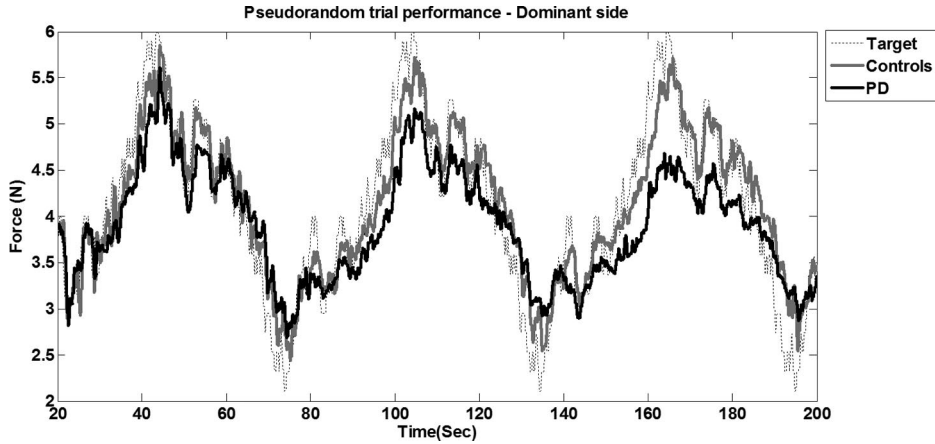


FIGURE 4. Ensemble plot of force traces from 30 participants with Parkinson's disease, 30 controls, and the target during the pseudorandom wave trial.

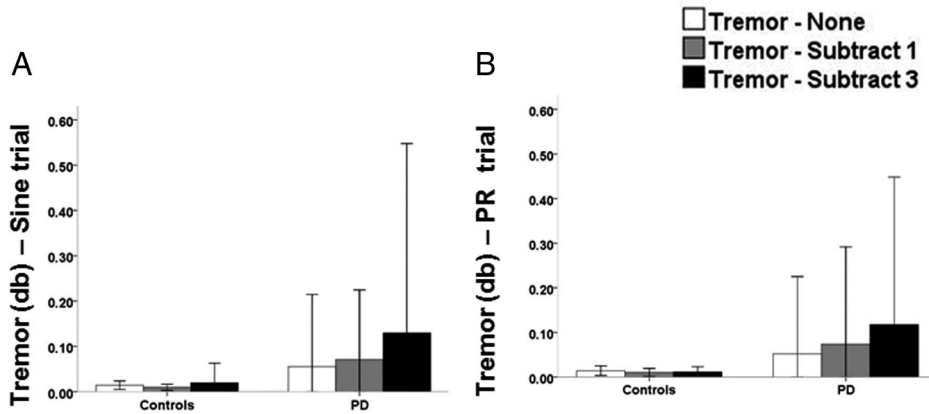


FIGURE 5. Sum of power of the force signal in the characteristic frequency range for parkinsonian tremor during the sinusoidal tracking task for the dominant side. Sinusoidal tracking task (A) and pseudorandom tracking task (B) for 30 controls and 30 participants with Parkinson's disease during each of the three cognitive load conditions. Error bars represent one standard deviation.

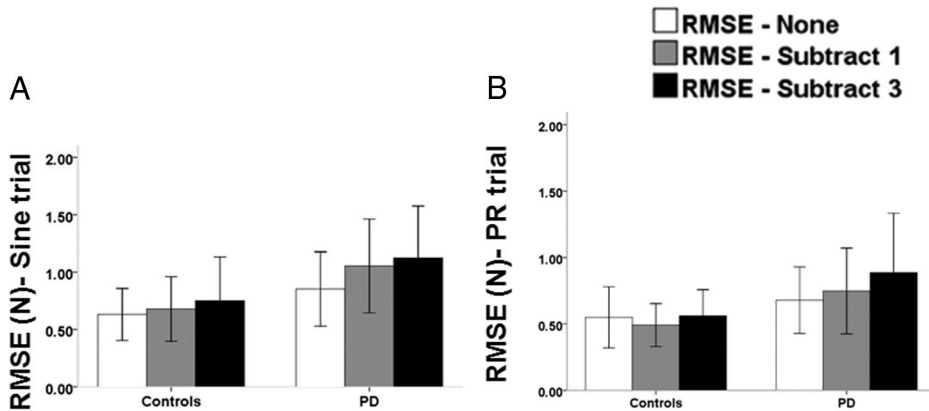


FIGURE 6. Root mean square error between the target force and the pinch force during the sinusoidal tracking task for the dominant side. Sinusoidal tracking task (A) and pseudorandom tracking task (B) for 30 controls and 30 participants with Parkinson's disease during each of the three cognitive load conditions. Error bars represent one standard deviation.

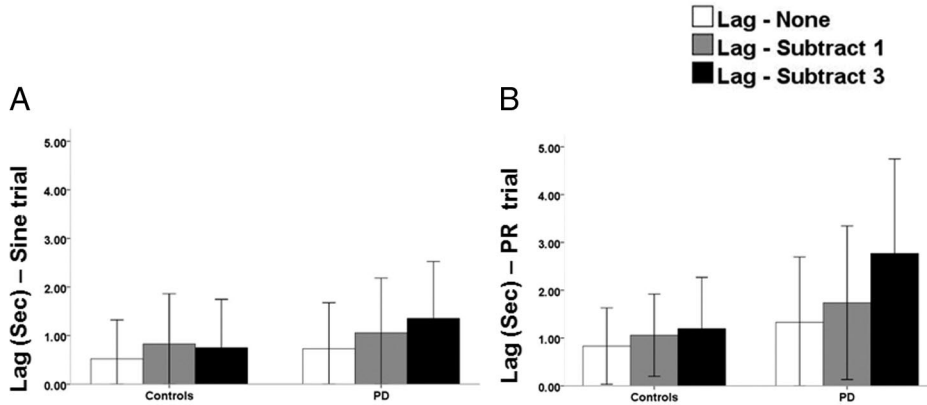


FIGURE 7. Lag between the target force and the pinch force during the sinusoidal tracking task for the dominant side. Sinusoidal tracking task (A) and pseudorandom tracking task (B) for 30 controls and 30 participants with Parkinson’s disease during each of the three cognitive load conditions. The error bars represent one standard deviation.

response variables, these figures show data for the dominant side only.

Tremor Integral

As expected, the force fluctuations during the force tracking task (as quantified by the TR) were significantly greater for participants with PD than for controls ($F_{1,58} = 4.22, P = 0.04$; Fig. 5). There was no main effect of cognitive load, waveform type, or dominant side on TR. There were no significant interactions among these variables. After analysis of TR, the force data were filtered (as described in the Methods section) to reduce the influence of tremor on the other response variables of interest.

RMSE

As indicated by larger RMSE values, even when the influence of tremor was removed with filtering of the force data, participants with PD were significantly less accurate than controls in matching force levels across all conditions ($F_{1,58} = 16.48, P < 0.001$; Fig. 6). There was a significant effect for cognitive load ($F_{1,4,79,5} = 21.06, P < 0.001$), indicating that as the cognitive load increased, there was greater error in performance of the force tracking task. Furthermore, a significant interaction was identified between group and cognitive load ($F_{1,4,79,5} = 7.90, P = 0.003$). Post hoc analysis revealed that the increase in error with greater cognitive load occurred only for the participants with PD; error was significantly greater during the subtract 3 condition compared with the no cognitive load condition ($P = 0.001$). Greater error in performance was found in the sinusoidal tracking task compared with the pseudorandom tracking task ($F_{1,58} = 64.17, P < 0.001$), and this effect was influenced by the interaction between cognitive and waveform type ($F_{1,7,98,1} = 10.29, P < 0.001$), indicating that the cognitive load had a greater effect on the forces generated during the sinusoidal tracking task than the pseudorandom tracking task. Post hoc analysis revealed that the difference was significant for the comparison between no cognitive load condition and subtract 3 condition ($P = 0.001$). None of the three-way or four-way interactions were significant.

Lag

The time lag between the display forces and the response forces was significantly greater for participants with PD compared with controls ($F_{1,58} = 15.28, P < 0.001$; Fig. 7). The lag increased significantly with cognitive load ($F_{1,7,100,0} = 34.18, P < 0.001$), and was greater during the pseudorandom tracking task compared with sinusoidal tracking task ($F_{1,58} = 28.54, P < 0.001$). The interaction between group and waveform type was significant ($F_{1,58} = 7.84, P = 0.007$), indicating that the relative increase in lag from the sinusoidal tracking task to the pseudorandom tracking task was greater in participants with PD compared with controls. The interaction between group and cognitive load ($F_{1,7,94,3} = 4.76, P = 0.014$) was also significant, showing that the effect of cognitive load on lag was greater in participants with PD compared with controls. Post hoc analysis revealed that this significant effect was between the no cognitive load condition and the subtract 3 condition ($P = 0.001$). No other interactions were significant.

TABLE 3. Descriptive Statistics for Response Variables for the Sinusoidal Tracking Task Without Cognitive Load for Five Individuals with PD

Variable	No Cognitive Load	Subtract 1	Subtract 3
RMSE			
Mean (SD)	0.66 (0.50)	0.72 (0.54)	0.83 (0.75)
Min–Max	0.00–1.39	0.00–1.50	0.00–2.02
TR			
Mean (SD)	0.01 (0.02)	0.01 (0.02)	0.01 (0.01)
Min–Max	0.00–0.04	0.00–0.04	0.00–0.02
Lag			
Mean (SD)	1.06 (1.31)	1.62 (1.20)	2.06 (0.98)
Min–Max	0.00–2.50	0.25–2.50	0.31–2.50

Abbreviations: PD, Parkinson’s disease; RMSE, root mean square error; SD, standard deviation; TR, tremor integral.

Assessment of the Possible Influence of Fatigue on Force Tracking Performance

Data from five individuals with PD who performed the sinusoidal force tracking task for three minutes under the no cognitive load condition were evaluated (Table 3). There was no main effect of time on any of the variables (TR, RMSE, or lag; $P = 0.22-0.31$).

DISCUSSION

Key Findings

Our results indicate that participants with PD performed poorly at tracking forces compared with adults of comparable age, with performance becoming progressively worse as the degree of cognitive load increased. This was true whether visual information was available to allow the participant to predict the amount of force required. A significant main effect of waveform type (sinusoidal vs pseudorandom) demonstrated that error was largely dependent on waveform. Although participants made greater errors on the pseudorandom tracking task because of the unpredictability of the waveform, the magnitude of the error was greater in the sinusoidal tracking task. This was possibly due to the more gradual change in force levels in the pseudorandom tracking task compared with the sinusoidal tracking task. In general, the force produced by both individuals with PD and controls during both the sinusoidal and the pseudorandom force tracking tasks was less than the target force. This resulted in the RMSE values in this experiment being dominated by underscaling of forces (Figs. 3 and 4).

The significant interaction between group (PD or control) and cognitive load demonstrates that the influence of increasing cognitive load on the deterioration in performance was greater for individuals with PD. Deterioration in performance with cognitive load in the pseudorandom tracking task was also demonstrated by the increase in lag with increased cognitive load. This increased lag may represent slowed response in force production. Although the tremor did not seem to be significantly influenced by cognitive load, the large variability in tremor may have resulted in a lack of adequate power to see any differences in this response variable across different levels of cognitive load. Post hoc analyses showed that, for all dependent variables, most differences in performance across cognitive load conditions occurred between the no cognitive load versus subtract 1 conditions, or the no cognitive load versus subtract 3 conditions. No differences were observed in the subtract 1 versus the subtract 3 conditions. In the future, this information could be used to make the test shorter by using only one of the distraction components.

Implications for Functional Performance

Incorporating cognitive load makes a task more challenging, which may unmask subtle deficits in performance. The basal ganglia are responsible for execution of feed-forward movements²⁴ and the control of generation of internally guided force pulses.²⁵ Dysfunction of the basal ganglia results in a shift from feed-forward control to feedback mechanisms that rely heavily on external cues for error

detection and correction. In individuals with a dysfunctional basal ganglia, when attention to an activity is withdrawn, the movement breaks down and deficits become obvious. This phenomenon can be documented using the ASAP test. Our results concur with those of other investigators who have found deterioration of tracking performance because of distraction in individuals with PD.^{21,26}

Our finding that lag was greater for participants with PD compared with controls during the pseudorandom tracking task (ie, unpredictable target force) compared with the sinusoidal tracking task (ie, predictable target force) is consistent with a study by Bloxham et al.²⁷ Using a movement position tracking task, they found that individuals with PD could use preprogrammed responses to the predictable movements to eliminate the lag between their movements and the target movement. Other studies have demonstrated, however, that this predictive ability is still deficient in people with PD as compared with controls especially in the absence of visual guidance.²⁸ We believe that because of the complex nature of the disease, unpredictability and cognitive components should be an integral part of motor performance tests.

Previous Applications of Technology to Assessment in PD

A number of technology applications have been proposed for assessment of motor performance in individuals with PD. Montgomery et al^{29,30} included a device for automated wrist flexion measurement as a part of a larger diagnostic test battery. Cleveland Medical Devices, Inc., developed the “Kinesia” system (<http://www.cleved.com/Kinesia/overview.shtml>), which uses a wearable device to measure kinematic data in individuals with PD. Other proposed assessment tools use target tracking, an established paradigm for measuring differences between individuals with and without PD.³¹⁻³³ For example, Allen et al³⁴ used a joystick and steering wheel designed for video games to measure the ability of individuals to track pseudorandom or sinusoidal waveforms; they identified a significant between-group difference for individuals with and without PD. Many of the studies used manual tracking approaches in individuals with PD to quantify motor function as a means to evaluate the effects of medication, adjust medication dose, and evaluate effects of deep brain stimulation or other surgeries.^{35,36} Others used tracking to evaluate cognitive or emotional profiles of individuals with PD³⁷ and to investigate tremor.³⁸ Investigators also used larger movements of the arm³⁹ or the wrist⁴⁰ to track targets, approaches that may not be effective in documenting subtle changes in motor control that appear early on; these more subtle changes may require the use of tracking tasks involving precision control. Our methodology was based on previous work by Kurillo et al,^{41,42} who found that many individuals with neurologic disorders make greater errors during performance of precision grip tasks compared with other grips and that some of these impairments are apparent before the appearance of other motor symptoms.⁴³ Thus, a variety of technologies have been explored for PD assessment, but none has been effectively applied to preclinical analysis of individuals with PD.

Implications for Development of a Clinical Assessment Tool for Use in PD

Although positron emission tomography and single-photon emission computed tomography are the current gold standard in the area of biomarkers for PD,⁴⁴ there are several advantages to having a clinical marker. Because nigrostriatal damage accounts for less than half the variability observed in motor impairment in individuals with PD,⁴⁵ a clinical marker would be a useful, direct, and noninvasive measure of motor impairments. Current clinical scales such as the UPDRS cannot precisely quantify motor symptoms early in the disease process,¹⁷ and by combining precise technology and a simultaneous task paradigm, we hope to create a quantitative functional assessment for PD that can be used for diagnosis and measurement of disease progression. Although the long-term goal is to evaluate whether such an assessment is sufficiently sensitive to detect subtle deficits, as a first step, the focus of this study was to develop a force tracking task and to examine whether the data obtained from people with PD are different from those who do not have PD.

Limitations

Deterioration in performance during the latter two thirds of the task could be attributed to fatigue with time rather than cognitive load. Although this is a possibility, the amount of force required for this task is small (2–6 N) relative to the maximum voluntary contraction for similar precision grip tasks (50–60 N). In addition, each trial was only three minutes long, and periods of increasing force were interspersed with periods of decreasing force. We attempted to address this through data collected for five participants with PD performing the three-minute sinusoidal tracking task without cognitive load. No significant deterioration in performance was detected during the subtract 1 or subtract 3 condition compared with the no cognitive load condition. The authors acknowledge that this may be due to lack of power because this observation was made only based on five participants; therefore, future studies should include randomization of the cognitive load conditions to ensure that the results observed were indeed due to the simultaneous cognitive task.

The statistical analyses presented here are based on the average of each variable over one minute of tracking. Because data for force and torque were collected at 100 Hz, this is a considerable data reduction. By using shorter time intervals when calculating variables such as RMSE and lag, further distinctions between case and control participants will emerge. At the same time, using short time intervals will increase the total number of variables. Machine learning or data mining techniques will be needed to combine this large number of variables into a single “score” for this assessment.

CONCLUSIONS

This study describes the development of a novel test, ASAP, to quantify impairments in fine motor control in individuals with PD using high-precision force or torque sensors. The assessment was designed to challenge the deficits commonly encountered as a result of PD, including performance of sequential activities that require switching between motor programs.⁴⁶ These results provide preliminary

evidence that the data acquired for individuals with PD using the ASAP test differ from that acquired for individuals without disabilities. We hope to expand on these results to create a precise, quantitative assessment for measurement of changes in early and preclinical PD. We would also like to expand our assessment to be able to document progressive deterioration of fine motor control as the disease progresses or a decline in progression as a result of neuroprotective therapies.

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