Effects of Extensive Practice on Bradykinesia in Parkinson’s Disease: Improvement, Retention and Transfer

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We investigated the effects of extensive practice of rapid aiming on bradykinesia and, more specifically, generation of peak velocity, in discrete rapid aiming and in transfer to reach-to-grasp. Twenty-one participants (seven young adults, seven older adults, and seven adults with mild to moderate Parkinson’s disease (PD) while on medication) engaged in eight practice periods per week for three weeks (> 700 trials), with changes in performance measured weekly. Retention was measured weekly for three weeks postpractice. Movement time decreased with one week of practice, primarily due to a decrease in time-to-peak velocity. With practice and after retention, the PD group generated peak velocity as consistently as both neurologically healthy groups, but remained more variable in time-to-peak velocity. Transfer was observed in the neurologically healthy groups, but not in the PD group. We concluded that short-term practice (one week in our paradigm) is sufficient for decreasing movement time, but more extensive practice is needed to improve consistency of rapid aiming performance for people with mild to moderate PD.

Keywords: kinesiology, motor control, neuroscience, older adults, physical therapy

Bradykinesia, or slowness of movement, is a cardinal symptom of Parkinson’s disease (PD). People with PD generate slower movements, whether discrete or sequential (Agostino et al., 1994; Benecke, Rothwell, Dick, Day, & Marsden, 1987; Benecke, Rothwell, & Dick, 1987; Harrington & Haaland, 1991). Bradykinesia is observed when there is a high index of difficulty (Fitts, 1954), i.e., high accuracy, which requires error corrective processes, or a low index of difficulty in which ballistic processes are emphasized (Rand, Stelmach, & Bloedel, 2000; Sanes, 1985; Smiley-Oyen, Worthingham, & Cross, 2002).

When moving rapidly to a target, people with PD exhibit lower peak velocity and peak acceleration, and they reach peak velocity more slowly than age-matched controls (Guo et al., 2004; Pfann, Buchman, Comella, & Corcos, 2001; Rand et al., 2000; Robichaud, Pfann, Comella, Brandabur, & Corcos, 2004; Smiley-Oyen et al., 2002). These kinematics are consistent with electromyography in which the
first force impulse was lower in people with PD, there were multiple small pulses in reaching peak velocity, and the timing between the agonist and antagonist was more variable (Hallett & Khoshbin, 1980; Kelly & Bastian, 2005; Pfann et al., 2001; Pfann et al., 2004; Robichaud, Pfann, Vaillancourt, Comella, & Corcos, 2005). Generally, these findings support the position that a primary source of bradykinesia is under-activation of the supplementary motor area in the basal ganglia-thalamic-cortical circuit, thus decreasing motor unit recruitment and slowing the generation of force (Berardelli, Rothwell, Thompson, & Hallett, 2001).

Studies indicate, however, that bradykinesia can be reduced with practice. People with PD decreased movement time and increased peak velocity with one to three days of practice, although still moving more slowly than age-matched controls (Flament, Vaillancourt, Kempf, Shannon, & Corcos, 2003; Platz, Brown, & Marsden, 1998; Pratt, Chasteen, & Abrams, 1994; Smiley-Oyen et al., 2002). Nutt and colleagues (Nutt, Lea, Van Houten, Schuff, & Sexton, 2000) found improvement early (first three trials) when practicing a reciprocal tapping task, but limited improvement with longer practice (a total of 21–25 one-minute trials over three days), whereas controls continued to improve. Agostino and colleagues (2004) also found improved movement times in a sequential aiming task with one day of practice, but found extensive practice (up to two weeks) to be of “scarce benefit” for those with PD. These findings are in contrast with the results in which two weeks of practice were necessary for those with moderate PD to show clear improvement in more complex movement sequences (Smiley-Oyen, Lowry, & Emerson, 2006).

For these changes to have clinical implications, not only must there be some change with practice, but the degree to which improvements in motor performance can be retained is important. Poorer retention was observed at a 1-hr retention interval after 100 trials of practice (Platz et al., 1998) and at a 1-day retention interval after 90 trials of practice (Smiley-Oyen et al., 2002). In contrast, practicing over two days for a total of 120 trials, Behrman and colleagues found only minor deterioration in sequential rapid aiming 48 hr after the end of practice (Behrman, Cauraugh, & Light, 2000). With two weeks of sequential rapid aiming practice, Agostino et al. (2004) found 3-day retention of faster movement times in the PD group, and with three weeks of practice, people with PD showed 3-week retention of two sequential tasks (Smiley-Oyen et al., 2006). It appears that people with PD require more practice for retention, but they can retain.

Another important question in terms of therapeutic intervention is whether improvement transfers to a related task. Transfer has been examined in people with PD by their ability to transfer rules or the gain of a movement (a more cognitive form of transfer) from one situation to another; this type of transfer was intact in people with PD (Dominey, Ventre-Dominey, Broussolle, & Jeannerod, 1997; Smiley-Oyen, Worrington, & Cross, 2003; Werheid, Zysset, Muller, Reuter, & von Cramon, 2003), and in older compared with young adults (Lazarus & Haynes, 1997). Adapting a learned sensorimotor mapping (such as a change in a force perturbation or visual distortion) was impaired in PD (Krebs, Hogan, Hening, Adamovich, & Poizner, 2001; Messier et al., 2007; Verschueren, Swinnen, Dom, & De Weerdt, 1997). Interestingly, neurologically healthy older adults exhibited transfer when required to adapt a visuomotor skill, but it was not as robust as that found in young adults (Seidler, 2006; Seidler, 2007). The type of transfer used in the current study was neither an application of rules to a different task nor a new
sensorimotor mapping, but rather an ability to transfer movement characteristics (i.e., speed) to another aiming task, from aiming at a 2-dimensional target to reaching and grasping a 3-dimensional target.

The purpose of the current study was to examine the effect of extensive practice (more than 700 trials over three weeks) on speed, and specifically on developing peak velocity in a discrete rapid aiming task in which accuracy constraints were minimal. Retention was measured up to three weeks. Transfer of speed and peak velocity from a rapid aiming movement (to a 2-dimensional target) to a rapid reach-to-grasp action (to a 3-dimensional target) was also measured. Performance was compared in people with PD, age-matched neurologically healthy older adults (OAs), and neurologically healthy young adults (YAs).

Methods

Participants

Twenty-one people participated in this experiment, seven with diagnosed idiopathic PD (4 men, 3 women; mean age 66.1 years ± 6.4), seven age- and gender-matched neurologically healthy control participants (4 men, 3 women; mean age 66.4 years ± 4.5), and seven neurologically healthy YAs (4 men, 3 women; mean age 22.5 ± 1.2). Exclusionary criteria for PD participants included the presence of cognitive impairment, severe dyskinesias, marked tremor or rigidity, history of alcoholism, moderate to severe depression, marked postural instability, or any neurological pathology other than PD. Physician evaluations were obtained for all PD patients. Table 1 describes individual participants. Patients were tested and practice took place while “on” medication to reduce motor control deficits that may obscure improvement with practice and learning. Recruitment and testing were performed in accordance with institutional procedures, and participants gave their informed consent before testing.

A battery of tests was administered to determine overall emotional, cognitive, and motor status. Depression was measured using the Beck Depression Inventory II (Beck & Steer, 1987), and cognitive functioning was measured using the Shipley Institute of Living Scale (Zachary, 1986), the Mini-Mental State Examination, and the verbal version of the Symbol Digit Modalities Test (Smith, 1982). The Purdue Pegboard (Lafayette Instruments) and reciprocal tapping task (10 s of tapping) were used to assess speed of finger dexterity and arm movements, respectively. There were no group differences in education, IQ, Mini-mental, or depression. Persons with PD completed significantly fewer items on verbal Symbol Digit compared with young adults, and both motor tests indicated that the PD group was bradykinetic compared with the other two groups even in their ON medication state (see Table 2.)

To determine the degree to which motor control fluctuated from session to session for the PD group, variability of performance for each PD participant was assessed across sessions for performance on the Purdue Pegboard and reciprocal tap. Out of a possible 16 data points for each participant (2 tasks × 8 sessions), only one data point for each of three PD participants was outside two standard deviations from their mean (the Baseline reciprocal tap performance was faster for one participant and slower for another participant, and at P3 one person’s reciprocal tap performance was faster). These results indicate that motor control for a given PD participant was relatively stable across the practice and retention testing sessions.
<table>
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<tr>
<th>ID</th>
<th>Age</th>
<th>Duration</th>
<th>H&amp;Y</th>
<th>Medication</th>
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<th>Tremor</th>
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Task

People with PD completed the rapid aiming movement with their most affected hand. Age-matched adults used the hand corresponding to their Parkinson’s counterpart. Young adults completed this experiment using their nondominant hand; this was done so YAs would be sufficiently challenged by the task thereby encouraging effective practice. The task consisted of holding a hand-held stylus on home position and moving (typically in a low arc) to the target as fast as possible; they were seated and positioned so trunk motion was not involved. An auditory warning tone followed by a ‘go’ tone (at random intervals varying between 800 and 1200 ms) signaled the start of the movement. The participants were instructed to complete the task as fast as they could while maintaining no greater than a 10% error rate.

Apparatus

The aiming movement involved moving from home position to a 10cm diameter target that was 35cm from the starting point to target center (index of difficulty equal to 3.2). The transfer task was reaching and grasping a cylinder that was 7cm
in diameter placed 35cm from the starting point. An IRED was placed on the posterior lateral wrist just proximal to the radial styloid process to collect x, y, and z coordinates of arm movement. In addition an IRED was placed 2.5cm above the tip of the stylus held by the participants to be used to identify the end of a rapid aiming trial. The IREDS were part of the OptoTrak Camera System (model 3020, Northern Digital, Ontario, 1 mm resolution). Data were collected at 200 Hz.

Procedures

This task was part of a larger study in which all participants practiced four different tasks. (The other tasks were a postural sequence, buttoning, and an interception task; they also practiced rapid aiming to a small target.) They participated and adhered to the practice and testing schedule as described below.

Orientation. The purpose of this session was to familiarize participants with the tasks and procedures. They completed trials for all motor tasks and some of the paper and pencil tests were administered, as were the motor control tests (Purdue Pegboard and reciprocal tap).

Baseline (B). The remainder of the paper and pencil tests was administered, and the motor tasks readministered. After Baseline assessment, practice was initiated.

In-Home Practice. Because most practice took place when experimenters were not present, practice procedures are described in detail to show the participants received sufficient instruction. The discrete aiming task was practiced in addition to the other tasks (interception, buttoning, and whole body postures, and discrete aiming to a small target). Each practice period was 20–30 min in duration, with each participant completing 30 discrete aiming trials to the large target and 30 to a small target. We used a semiblocked practice schedule (5 trials per set, with six sets per practice period) to provide contextual interference and thereby promote long-term retention (Healy & Sinclair, 1996; Shea & Morgan, 1979). Start and stop buttons connected to a millisecond timer provided movement time feedback for the participants. They were to minimize their time, but hit the target with only one miss every ten trials. After a set of five trials they entered in their practice log their time for the last trial and the number of errors for that set. After in-home training there was a weekly visit to observe practice and offer instruction, correction, and encouragement. Their performance logs were checked when they came to the laboratory for the test sessions. They completed eight in-home practice periods per week (240 trials per week, 720 practice trials over three weeks), with no more than three practice periods per day, preferably one to two per day. The final practice period occurred within 24 hr of the performance session in the research laboratory. Based on their log and verbal report, all participants completed practice as requested.

Performance Weeks 1, 2, 3 (P1, P2, P3). Testing in the laboratory was conducted once per week, maintaining the same day of the week and time of day for each person’s testing sessions. Participants were tested on the posture sequence and buttoning before discrete aiming. Twelve accurate aiming trials were completed. If a spatial error occurred that trial was replaced. If more than one trial resulted in a miss, the participant was instructed to slow down and to try not to miss the
target again. If they had not missed a single trial by trial ten they were informed to speed up slightly. Because these trials were viewed as a part of the practice portion of the design, augmented feedback was given in the form of response time.

**Retention 1, 2, 3, 4 (R1, R2, R3, R4).** After three weeks of practice, participants stopped practicing and retention was assessed in the laboratory at day two postpractice (R1), and then once a week for three weeks postpractice (R2, R3, R4). Testing was identical to previous sessions only no augmented feedback was given.

**Transfer.** The transfer task (reach-to-grasp) was administered at B, R1, and R4. No augmented feedback was provided for any transfer trials. Procedures and number of trials were the same as discrete aim, except they were to grasp the cylinder with a power grasp, and lift it straight up. Error trials (bumping the cylinder or mis-grasping it) were repeated, with the goal to maintain no more than a 10% error rate.

**Data Reduction and Analysis**

The data were filtered with a 2nd order Butterworth filter using a 21 Hz low pass cutoff frequency (Smith, 1989). For short duration movements a higher cutoff frequency is desirable since abrupt movements tend to consist of higher frequency components that are important for more accurate analysis. Thus, this cutoff frequency was selected to optimally remove noise without eliminating important signal information (Winter, 1990). The onset of movement was defined as the first point in which there were five consecutive samples in which tangential velocity increased. The magnitude of tangential velocity (referred to from this point on as velocity) was determined by calculating the instantaneous linear velocity of the wrist IRED at each sample point (distance delta/sample time). The end of the aiming movement was at impact on the target, identified by an acceleration spike based on the stylus IRED. The end of the reach-to-grasp movement was the point at which vertical motion of the wrist IRED was observed.

All trials were examined off-line by replaying the trajectory of the IREDs for each trial in a 3-dimensional visual environment using custom-designed software to check for correct identification of the start and end of the movement, including correct identification of the lift of the cylinder. If the algorithm incorrectly identified the beginning or end of the movement, then the incorrect event was corrected by the experimenter based on visual replay of the trial and examination of the accompanying position, velocity, and acceleration profiles.

The primary dependent variables were movement time (MT), peak velocity (PV), time-to-peak velocity (TTPV), and the coefficient of variation (cv) of MT, PV and TTPV. Coefficient of variation was used rather than standard deviation to account for mean differences in variables, thus controlling for inherently greater variability in higher means. Data were reduced by calculating a mean across 12 trials within each laboratory testing session for each participant. Error trials were not analyzed. Percent error rates for rapid aiming and reach-to-grasp for the groups were between 0 and 2%, except for YA at P3 (7%) and PD at P1 (4%). These low error rates indicate that the accuracy requirement was minimal.

Because of the small sample size, we conducted nonparametric analyses. To capture changes specific to practice we compared B to P3 within group using
Wilcoxon Signed Ranked Tests (WSRT). To assess overall change as a result of practice and after three weeks of retention, we compared B to R4 within group using WSRT. As a follow-up we also compared P3 to R1 to capture 2-day retention and R1 to R4 to capture changes across three weeks of retention. Effect sizes were calculated to assess meaningful changes across time (.8 or greater considered large, .5 moderate and .2 small (Thomas, Salazar, & Landers, 1991)). Because effect sizes can be positively biased for small sample size (Hedges, 1981), we were more conservative, interpreting a large effect only if it was 1, and small effect at .5 or below. To examine differences between groups, we assessed performance at B, P1, and R4 using the Kruskal-Wallis H Test (K-WHT), with the Mann-Whitney U Test as a post hoc test to compare two group means. Transfer was examined using the Friedman Test to compare B, R1, and R4. Significance level was set at .05.

Results

Data for rapid aiming across all testing sessions are presented in Figures 1, 2 and 3 for MT, PV, and TTPV, respectively. Data across the three sessions in which transfer was tested are presented in Figure 4.

Rapid Aiming

Movement Time. All groups decreased MT with practice, with the biggest change between B and P1; reduced times were retained (see Figure 1A). The WSRT revealed that the decrease from B to P3 was significant for all three groups: YA and OA group, $z = -2.37$, $p = .018$, with a moderate effect size $(r = .73)$; PD, $z = -2.03$, $p = .043$, $r = .63$. Additional follow-up comparisons between B to P1 and P1 to P2 indicated that all three groups exhibited a significant decrease after the first week of practice, but only the YA exhibited a further significant decrease. All three groups exhibited retention of improvement (performance at B compared with R4, $z = -2.37$, $p = .018$ for each group, $r = .73$). There were no significant changes from P3 to R1 indicating all groups exhibited 2-day retention, and the only significant change across retention sessions was that the PD group exhibited a further decrease, $z = -2.197$, $p = .028$, $r = .68$, indicating that all groups exhibited 3-week retention. Group differences within-session revealed differences within B, P3, and R4, $X^2 (2, n = 21) = 14.72$, 15.22, and 14.18, $p < .001$, respectively, with post hocs showing YA faster than OA and OA than PD in all sessions except for a trend between OA and PD at B ($p = .053$).

There were no significant practice effects for cvMT, but there was a trend for a decrease from B to R4 for PD and OA ($p = .063$) (see Figure 1B). There were no significant differences between groups for cvMT except for a trend at B ($p = .081$), with PD greater than YA.

These results indicate that, as expected, all groups decreased MT with practice and retained improvements, but YA remained faster than OA, and OA than PD. The primary decrease for both older groups was after one week of practice. Coefficient of variability trended downward for both older groups from B to R4, such that variability between all groups was similar by R4.

Peak Velocity. Only YA exhibited an increase in PV with practice (B to P3), $z = -2.37$, $p = .018$, $r = .63$ and retention (B to R4), $z = -2.37$, $p = .018$, $r = .63$ (see Figure 2A). There were no differences between P3 and R1 and R1 to R4 for the
YA, further indicating they exhibited retention. There were group differences at B, P3, and R4, $X^2(2, n=21) = 13.89, 14.18, \text{and } 12.97, p = .001, p = .001, p = .002$, respectively. Post hocs revealed that YA was different from OA and PD at each session ($p < .003$). PD and OA were not different at B, P3 or R4. Follow-up tests indicated that OA PV was higher than PD PV only at R1 ($p = .004$), with a trend to be higher at P1 and P2 ($p = .073$).

The PD group exhibited a trend for a decrease in cvPV during practice ($p = .063$), and a significant decrease from B to R4, $z = -2.20, p = .028, r = .59$ (see Figure 2B). Both neurologically healthy groups also decreased cvPV; the decrease from B to P3 was not significant, but there was a trend from B to R4 ($p = .063$) for both groups. There were group differences for cvPV at B and P3, $X^2(2, n=21) = 7.81$ and $9.45, p = .02$ and $p < .009$, respectively, with post hocs revealing greater variability for PD than YA at B ($p = .02$), and YA lower than the other two groups at P3 ($p = .026$). There were no group differences in cvPV at R4.
Overall, YA was the only group that improved PV with practice, exhibiting a higher PV at each session, and exhibiting a higher PV compared with the other two groups throughout testing. Although OA exhibited a higher mean value for PV compared with PD, there was only one session out of eight in which the OA exhibited a significantly higher PV than PD. The neurologically healthy groups trended downward in cvPV, but only the PD group exhibited a significant decrease. Similar to cvMT, there were no group differences in variability at R4.

**Time-To-Peak Velocity.** The two older groups decreased TTPV with practice (B to P3), PD: $z = -2.20, p = .028, r = .59$; OA: $z = -2.37, p = .018, r = .63$, and YA exhibited a downward trend ($p = .063$) (see Figure 3A). Only the OA exhibited a decrease from B to R4, $z = -2.37, p = .018, r = .63$, with YA exhibiting a downward trend ($p = .063$). There was a nonsignificant decrease for the PD group from B to R4. There were group differences in TTPV, with OA exhibiting a significant decrease from B to R4 ($z = -2.37, p = .018, r = .63$), and YA exhibiting a downward trend ($p = .063$).
differences at B, P3, and R4, $X^2 (2, n = 21) = 11.96, 12.22, \text{ and } 10.58, p = .003, p = .002, \text{ and } .005$, respectively. Post hocs revealed that YA was different from the other two groups at B ($p < .004$), and all groups were different from each other at P3 ($p < .03$). At R4 only the YA was different from PD ($p = .005$). There was a trend for the OA to be slower than YA ($p = .073$) and faster than PD at R4 ($p = .073$).

No group exhibited a decrease in cvTTPV with practice, but both PD and OA exhibited a decrease from B to R4, $z = 2.20, p = .028, r = .59$ (see Figure 3B). There were group differences at B, P3, and R4, $X^2 (2, n = 21) = 10.25, 7.28, \text{ and } 9.45, p = .006, p = .026, p = .009$, respectively, with post hocs revealing that the YA were lower than both older groups at B and P3. At R4 OA and YA exhibited similar variability, while the PD group exhibited greater variability ($p = .002$).

These results indicate that both older groups decreased TTPV with practice, but only the OA retained the decrease through retention. Group differences were

![Figure 3](image-url) — Time to Peak Velocity (A) and Variability of Time to Peak Velocity (B) across Sessions. Symbols are: closed squares (Parkinson’s disease, PD), open squares (older adults, OA), open triangles (young adults, YA), with standard errors as error bars. Abbreviations are: baseline (B), performance (P), and retention (R).
maintained. Both older groups also decreased cvTTPV from B to R4, but the PD group still exhibited higher variability compared with the other two groups at R4.

**Summary.** Generally, practice improved performance for all groups, and retention was observed for all groups. More specifically, MT decreased with practice and this decrease was retained across the 3-week retention interval, although differences between groups were maintained. The YA accomplished this primarily by increasing PV with practice, while the OA and PD improved their performance primarily by decreasing TTPV. Practice decreased variability for all groups to the point of no group differences in MT or PV variability. This, however, was not true for variability in TTPV; the PD group decreased their variability with practice, but continued to exhibit higher variability than the other two groups.

**Transfer: Reach-to-Grasp**

We examined transfer by testing reach-to-grasp performance at B, R1 and R4. Improvement without practice of the task was interpreted as evidence for transfer. The Friedman Test indicated that PD exhibited no change in performance across sessions for any variable (see Figure 4). The OA group exhibited a trend for an increase in PV (\( p = .05 \)) and a significant decrease in TTPV, \( X^2 (2, n = 7) = 10.57, p = .005 \). YA exhibited a trend for a decrease in MT (\( p = .05 \)), an increase in PV, \( X^2 (2, n = 7) = 8.00, p = .018 \), and a decrease in TTPV, \( X^2 (2, n = 7) = 8.00, p = .018 \). These results indicate that the PD group exhibited no transfer, while the OA exhibited transfer only for TTPV and YA for PV and TTPV.

**Discussion**

Movement time in patients with Parkinson’s disease decreased after one week of practice, but further change was minimal. This was also true of the neurologically healthy older adults. These findings support the position that deliberate practice is an important influence on maintaining performance in older adults (Ericsson, 2000). However, extensive practice of this speeded task did not improve speed. These results are consistent with Agostino et al. (2004) in which they found two weeks of sequential aiming practice to be of little additional benefit beyond the initial three days of practice. In contrast, two weeks of practice was needed for clear improvement when motor coordination, rather than just speed, was emphasized (Smiley-Oyen et al., 2006). In the current study more variability of performance in the PD group continued to decrease after one week of practice. Thus, even though improvement in speed of movement may not benefit from extended practice, people with PD can benefit from prolonged practice in other ways, such as improved coordination in more complex actions and more consistent performance.

Our results extend Agostino and colleagues’ (2004) three-day retention interval, showing that these speed reductions can be retained for up to three weeks. What is not known is if the longer practice in the current study, although not further decreasing time, facilitated the three-week retention. Other results indicate that retention is poorer with short-term practice (Platz et al., 1998; Smiley-Oyen et al., 2002), but equal to controls if extensive practice is provided (Agostino et al., 2004; Smiley-Oyen et al., 2006).
Figure 4 — Reach-to-Grasp Transfer across Sessions. A) Movement time. B) Coefficient of variation of movement time. C) Peak Velocity. D) Coefficient of variation of peak velocity. E) Time to peak velocity. D) Coefficient of variation of time to peak velocity. Symbols are: closed squares (Parkinson’s disease, PD), open squares (older adults, OA), open triangles (young adults, YA), with standard errors as error bars. Abbreviations are: baseline (B), 2-day retention (R), 3-week retention (R4). There are no significant effects for coefficient of variable (panels B, D, F).
The decrease in time in the PD group was due primarily to a decrease in time-to-peak velocity. However, even with these improvements with practice, group differences between all three groups were maintained for MT and TTPV, with YA fastest, PD slowest, and OA in the middle. This indicates that both age and disease had an effect on these durations, even with the PD group on medication. Underlying factors found in both OAs and more extensively in people with PD that may contribute to these longer times are slower generation of force, reduced velocity of contracting muscle fibers, cocontraction between agonist and antagonist, and multiple smaller bursts in reaching peak velocity (Ketcham & Stelmach, 2001).

In contrast, in the current study age was the factor that primarily affected ability to increase PV with practice, i.e., young adults robustly increased PV with practice while the two older groups exhibited only minimal and nonsignificant increases. Ketcham and colleagues (2002) found that OAs produced lower peak velocity than YAs, with an increase in this difference as amplitude of the movement increased. One explanation provided by Walker and colleagues (1997) was that older adults choose to use a lower peak velocity. They found that when the accuracy constraints were eliminated, OAs produced PVs that were similar to those produced by YAs during higher accuracy constraints movements, thus showing they could reach these higher PVs but were choosing not to do so. In the current experiment, we had low accuracy demands, and everyone engaged in extensive practice in which they were repeatedly encouraged to move as quickly as possible, which was reinforced by challenging them to beat their previous times in the practice periods. Given those conditions, the OA group still did not produce PV as high as the YA's original PV. Therefore, we conclude that neither OAs nor people with PD can generate PV as high as YAs even with low accuracy demands, encouragement, and extensive practice. Rather, we suggest that factors such as loss of fast twitch muscle fibers and cocontraction of agonist and antagonist muscles are contributing to an inability to generate high peak velocity in both older groups (see for a review on aging see Ketcham & Stelmach, 2001).

The similar PV between PD and OA in the current study is in contrast to previous studies in which people with PD exhibited a significantly lower PV from OA (Rand et al., 2000; Smiley-Oyen et al., 2002). Being on medication is likely to decrease differences in PV between the two groups, but even in the above studies people with PD were on medication, so that does not explain the difference in our findings. The people in the samples also ranged in severity from mild to moderate in all three studies, but it is possible our sample was less affected. However, another contributing factor could be a difference in task constraints. This was a 35cm amplitude movement, which is a greater amplitude compared with other tasks. Thus, increasing the distance may have not only decreased differences between the older groups but increased the difference from the YA.

Group differences in variability of performance were apparent at baseline, but by three-week retention both older groups’ variability was essentially the same as YA for cvMT and cvPV. It was only cvTTPV that remained significantly higher at R4 for the PD, whereas the YA and OA groups’ variability was similar. These results are consistent with previous work in which short-term practice did not normalize muscle activation patterns for people with PD, even though short-term practice did increase movement speed (Flament et al., 2003). Our OA results are in
Consistency in Rapid Aiming in PD with Extensive Practice

Contrast to previous work in which greater timing variability of the agonist persisted in OA compared with YA after 100 trials of practice (Poston, Enoka, & Enoka, 2008), thus suggesting that more extensive practice is needed to reduce variability for OAs. Together, our results indicate that consistency in generating movement times and peak velocity can be attained if the neurological system is healthy or if given sufficient practice. That the PD group could not do so for TTPV even with extended practice points to an inherent characteristic that critically requires intact skeletal motor circuitry through the basal ganglia.

It is of interest to note that the PD and OA groups exhibited greater PV variability than the YA group at the end of practice (P3), but not at the end of retention (R4), indicating that the continued decrease was not the result of practice. Rather, we attribute this additional decrease to the influence of augmented feedback on the older groups. We provided response time after every trial during the performance testing, but provided no response time during retention testing. It is known that frequent augmented feedback can increase trial-to-trial variability (Lee & Carnahan, 1990). Based on this, our data indicate that the two older groups were more influenced by the augmented feedback than the YAs. Thus, removal of augmented feedback during retention testing may have helped the older adults reduce variability in reaching peak velocity. This tendency was also observed in cvTTPV for OA. That this effect was not apparent in the PD group for cvTTPV further supports the inherent nature of this variability in PD.

Retention was observed in all groups, which was expected given the extensive practice. However, transfer was apparent in only a few cases. The YA exhibited transfer for PV and TTPV, while OA exhibited transfer only for TTPV. This is consistent with other studies in which transfer in OAs has been observed for motor skills, but is less robust compared with young adults when adaptation is needed (Seidler, 2006; Seidler, 2007), although Lazarus and Haynes (1997) found that older adults transferred an internal model as well as young adults. In contrast, the PD group did not exhibit any transfer of this rapid movement. People with PD also exhibited impaired transfer when learning a new sensorimotor map (Krebs et al., 2001; Verschueren et al., 1997; Messier et al., 2007), while other studies have shown successful transfer when applying an internal model (Dominey et al., 1997; Smiley-Oyen et al., 2006; Werheid et al., 2003). This lack consistency in the results of ability to transfer may be due to type of transfer being tested, stage of PD, and the presence of medication (see Cools, 2006 for a review of cognitive function related to L-dopa). Thus, more work is needed to better understand the role of the basal ganglia in transfer.

Interestingly, no group exhibited transfer in the variability measures. This may be due to inherent differences between the two tasks; rapid aiming emphasized agonist force generation and de-emphasized the antagonist contribution because hitting the target allowed for much of the deceleration of the movement. (This was true even in the small target condition that was practiced as part of the overall practice protocol.) In contrast, the reach-to-grasp task required participants to rely on the antagonist muscles to slow the movement (as opposed to impact on a target) to pick up the cylinder without bumping it or knocking it over. Thus, while there may be similarities in producing forces to generate PV and TTPV between the two tasks, transfer of consistency may be less likely because of the differential requirement of the antagonist.
It is noted that individuals in our PD group were in the mild to moderate stages of PD and we tested them (and had them practice) while in their ON state of medication. We tested them in the ON state because the primary reason for conducting this study was to observe changes with practice; if they were off medication, learning could have been masked by limitations in their motor control. Therefore, our results may only be generalized to those who are mild to moderately bradykinetic when on medication. While this limits our understanding of the full impact of clinically low dopamine levels, it does translate well to everyday functioning and practical implications for therapeutic intervention through movement.

In conclusion, extensive practice of simple rapid movements may be of minimal practical benefit for those with PD for the purpose of moving more quickly; improvement in speed was not robust beyond one week of practice and transfer was absent. If the goal, however, is to reduce variability associated with speeded movements, then more extensive practice may help as variability of performance in the PD group trended downward across practice and was significantly lower from baseline by the fourth week of retention. But, even with extensive practice, the PD group continued to maintain higher time-to-peak velocity variability than the other two groups. These data indicate that the skeletal motor circuit through the basal ganglia is critical for consistency in time-to-reach peak velocity even in the early stages of PD and may be related to the inconsistencies in rate of force development that are inherent in this disorder.

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