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Spatial features of angular drawing movements in Parkinson's disease patients

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Abstract

The present study shows that drawings from Parkinson's disease (PD) patients display specific spatial features when compared to those produced by age-matched controls. Their drawings are globally smaller, or more precisely, the larger the requested size, the greater the size reduction. PD subjects have also more difficulties in producing obtuse than acute angles: angles of obtuse patterns are shrinking and their segment lengths are shortened. This could be due to the fact that an obtuse angle brings the effector joints close to the limits of their functional ranges of motion, which may be reduced in PD patients. Results related to segment direction show that PD patients are globally more imprecise than controls in the production of movement directions, but perform nevertheless relatively well for horizontals and verticals drawn in preferred directions. These results are referred to two contradictory models relating movement direction to the type of movement coordination involved. © 1998 Elsevier Science B.V. All rights reserved.

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1. Introduction

Parkinson's disease (PD) involves many movement disorders due to basal ganglia abnormalities involving both temporal and spatial parameters. A general slowness of movement is frequently mentioned, and this also appears in drawing or writing behavior (Stelmach, 1991; Phillips and Stelmach, 1991). PD patients exhibit longer movement preparation times than controls do (Phillips et al., 1989; Goodrich et al., 1989). They are also reported to present deficits in using advance information to improve movement performance (Flowers, 1978; Jones et al., 1992), and to rely more on external visual feedback during movement execution (Cunnington et al., 1995; Flowers, 1976; Klockgether and Dichgans, 1994; Stern et al., 1983), this increased reliance upon vision being possibly due to the deficit in the production of appropriate forces (Martin et al., 1994). In a drawing task, PD patients were shown to use a much lower axial pressure than controls, without modulating the pressure level as a function of task progression from the first to the last drawn segment, thus demonstrating difficulties in modulating forces in the course of movement (Vinter et al., 1996). As far as spatial features are concerned, movements performed by PD patients present shorter amplitudes when compared to control subjects, possibly because of a strong impairment of the regulation of force amplitude (Stelmach and Castiello, 1992; Teulings and Stelmach, 1992). A recent study demonstrated that many years before the disease is diagnosed, the handwriting of premorbid PD patients already presents some specific spatial features, such as less round strokes and more abrupt changes of direction (Helsper et al., 1996).

One task variable which provides much insight into the deficits of fine motor abilities in PD patients is related to the production of sequences of movements. Impairments in performance emerge as soon as the patients are required to link together several movement units. When performing a reaching movement for instance, PD subjects display a greater delay between the limb transport phase and the hand opening phase than is usually recorded in controls (Zackon, 1989; Castiello et al., 1994). Drawing behavior also reveals a difficulty in the execution of multi-segment (or stroke) movements. Longer pauses at the vertices of geometric figures are observed in PD patients (Berardelli et al., 1986a; Vinter et al., 1996). Similar results have been reported for the execution of other sequential skills (Goldenberg et al., 1986; Benecke et al., 1986, Agostino et al., 1996). Impairments in the coordination of multi-joint movements are also reported (Flash et al., 1992). As pointed out by Teulings and Stelmach (1992), a crucial deficit in PD motor functioning may be seen in the production of movements that imply a coactivation of several effector joints. Teulings et al. (1997) recently revealed that PD patients display a reduced capability to coordinate wrist and finger movements when trying to produce handwriting-like patterns, as attested by a high degree of dysfluency of movements produced in certain directions.

The present study aims at investigating whether such a deficit in movement coordination may also cause alterations of the spatial characteristics of movements, particularly with regard to the accuracy with which movement directions are reproduced. We know that the other deficit in Parkinsonian motor functioning, the production and regulation of force, is probably responsible, at the spatial level, for the reduction of movement amplitude. It is thus likely that an analysis restricted to spatial features of movements only demonstrates specific alterations in PD patients. Three spatial variables are therefore investigated: segment length, segment direction and angle. We wonder to what extent is the reduction in movement amplitude dependent on the model's size. PD subjects were reported to be able to modify stroke size in an handwriting task by increasing the average stroke size from 0.42 to 0.58 cm (Teulings and Stelmach, 1992), but to display less modulation in their handwriting between small and large strokes (Helsper et al., 1996), as if they tended to restrict their range of movement amplitude around some central value. It is thus likely that the patients experience the same kind of difficulties in a drawing task even if sizes slightly larger than those usually present in handwriting are requested.

A second spatial variable investigated in the present study concerns segment direction. Several authors agree upon the fact that a lack of coordination in movement appears as soon as PD patients are asked to perform movements which necessitate the control of a large number of muscles and joints.With regard to handwriting, two different systems of mapping between effectors and movement directions or axes have been suggested in the literature. In line with Hollerbach's model (Hollerbach, 1981), some authors have proposed that finger movements are responsible for the production of verticals, hand movements for that of horizontals, whereas oblique directions are obtained through a contribution of both effectors (see Schomaker et al., 1989, for instance). In this perspective, oblique directions should be the most difficult to produce and should be severely impaired in PD patients, a prediction which finds support in evidence presented by Teulings et al. (1997). Meulenbroek and Thomassen (1991) provide a different anatomical description of the production of movement directions where it appears that oblique directions (oriented along two main axes, 45–225°, 135–315° when 0° corresponds to the rightward oriented horizontal, with direction increasing in a counterclockwise rotation) are the simplest directions to perform. They involve only one effector, either the finger (top-left/bottom-right direction) or the hand (top-right/bottom-left direction). Interposed oblique directions between these two main axes and the horizontal–vertical axes would elicit the control of both hand and finger movements. Vertical and horizontal directions would require the participation of both effectors also, moving either congruently (verticals) or incongruently (horizontals). However, according to the authors, these last directions benefit largely from visual control.

In perception, the well-known "oblique effect" established for the perception of orientation (Appelle, 1972) suggests also that the encoding of directions is more precise for the horizontal–vertical axes than for the oblique ones, probably thanks to the use of an internal gravitational frame of reference (Cecala and Garner, 1986). However, the situation may be more complicated for the PD group. Several studies report that these patients show specific visuospatial disorders, independently of the production of any motor activity (Boller et al., 1984; Mortimer et al., 1982; Maeshima et al., 1997). In particular, they display more imprecision and variability than controls in their judgment of the visual vertical and horizontal directions (Danta and Hilton, 1975).

In our study, horizontal and vertical directions as well as a variety of oblique directions are present in the models presented to the participants. Moreover, the task is a copying task, the model being available during movement execution. Since PD patients encounter special difficulties in the production of directions which involve a co-activation of several effector joints, in line with Hollerbach's model, we would expect the greatest imprecision for the production of oblique directions. Drawing precise predictions from Meulenbroek and Thomassen's model is more complex, because of the possibly interfering role of the patients' stronger reliance upon vision in movement execution. Taking into account their motor impairment, PD patients should be more imprecise for the horizontal–vertical directions and for the interposed oblique directions than for those aligned with the main oblique axes. Their visual disorder in the perception of the verticality and horizontality may, however, reduce the difference between obliques and horizontals or verticals. Finally, because of their increased use of visual control, they could benefit from the direct comparison with the available model and may reproduce the vertical or horizontal directions more accurately than expected.

The third spatial variable targeted in our study is related to the drawing of angles. The drawing of angular figures has been investigated in young adults and has revealed interesting effects with regard to the difference between the drawing of acute and obtuse angles (Meulenbroek and Thomassen, 1993; Desbiez et al., 1996, in press). Under speed constraints, subjects draw acute angles without pauses at the angle and tend to lengthen the size of the segment leading up to the angle, whereas pauses at angles are systematically observed for obtuse patterns, the sizes of which are also smaller than those of acute figures. It has been suggested that the graphic production of acute angles is facilitated because of the back-and-forth nature of the movements, making it possible to exploit muscular elasticity. In contrast, obtuse patterns involve drawing in a more or less constant direction, bringing the effector joint close to the limits of its functional range of motion. [1]

Our task does not require the subjects to draw under speed constraints. In a similar task, PD patients adopted rather low velocities and produced systematic pauses at the angles, which prevents from the use of muscular elasticity (Vinter et al., 1996). Therefore, the drawing of acute patterns should not require a more accurate timing demand in view of the use of their elasticity potential, as it would be the case if they were drawn like "non-stop" patterns. Consequently, we might expect PD patients to be more impaired in the drawing of obtuse rather than acute patterns,

[1] The limits of motion of an effector joint should be considered as designating functional ranges of motion, not mechanically defined boundaries. Having to hold the writing styles between the thumb and index fingers limits the effective range of motion of the joints in the thumb and fingers, and between these segments and the metacarpal bones. Moreover, the functional range of motion of finger and hand joints is much smaller than could be expected on the basis of their mechanical range of motion, i.e. the proximal joints start to be involved in movement of increasing amplitude already when the amplitudes are small (Meulenbroek et al., 1993). Consequently, the obtuse angle elicits joints' excursions that are likely to approach the joints' functional ranges of motion more quickly than the acute angle, merely because the amplitude covered in obtuse angle production is larger than in acute angle production.

because these patients should avoid bringing the effector joint close to its limits of motion. Shorter segment sizes and angle shrinking should be observed.

These predictions were examined in a study where PD patients and controls were asked to copy as accurately as possible a series of acute and obtuse patterns of different sizes.

2. Method

2.1. Participants

Three groups of subjects participated in the study. The first group included six right-handed adults (4 males and 2 females) with idiopathic Parkinson's disease (age range: 52–76 years, mean age: 66.50 years). They were in mild stages of the disease (stage I for 3 of them, stage II for the others). The duration of the disease ranged between 5 and 10 years (mean duration: 7.8 years). None of them presented a micrographia in handwriting. They were under medication at the time of the test and were tested in the hospital when no tremor appeared in their upper limb. As some of the impairments observed in the motor behavior of PD patients also characterize normal aging, we thought it useful to compare the performance of the patients with two different control groups, a younger and older elderly one, selected to cover the age range of the PD group. Two groups of elderly age-matched adults therefore served as controls, these groups differing according to their age. One group (called elderly 1) included seven right-handed young elderly subjects (5 females and 2 males), and their ages ranged from 52 to 63 years (mean age: 60.20 years). The second group (called elderly 2) was made up of seven right-handed middle-aged elderly subjects (4 females and 3 males), and their ages ranged from 66 to 77 years (mean age: 72.50 years). These control subjects were volunteers, and they did not exhibit any signs of neurological or psychological disturbances. They were tested at the University of Dijon.

2.2. Apparatus

The subjects drew on a digitizer tablet (Calcomp Drawingboard), controlled by an IBM 486 PC, by means of a special-purpose pen (Teulings and Maarse, 1984) that allowed the recording of the axial pressure exerted on the stylus while drawing. Movements were sampled at a rate of 100 Hz with a spatial accuracy of 0.2 mm. The position of the tablet was adjusted for the subject, but it was always horizontally aligned with the table on which it was supported. The response sheet (format A4) was also horizontally aligned, and an experimenter moved it horizontally and vertically in such a way that the subject did not modify his or her arm position in the course of the experiment. The angle formed by the drawing forearm and the horizontal base of the paper sheet was approximately 50–60°, corresponding to a geometrical configuration to which Meulenbroek and Thomassen's model (Meulenbroek and Thomassen, 1991) should apply.

2.3. Models

Sixteen different acute models (45°) categorized into 4 groups, and 8 obtuse models (135°) divided into 2 categories were used in the experiment. Patterns consisted of two straight-line segments of identical lengths. They are illustrated in Fig. 1.

Eight acute and obtuse patterns consisted of either a horizontal or a vertical segment and an oblique segment (labeled category HO and VO, respectively). Four different models were obtained in each category by rotating the pattern. Two other categories of acute patterns were added, consisting of two oblique segments: OO1 patterns had a horizontal or vertical axis of symmetry, and OO2 patterns had an oblique axis of symmetry. The models were presented in three sizes: the segment length was of 0.5, 1 or 1.5 cm. Subjects were asked to draw seventy-two models in all, presented in a random order. Before the analysis, the patterns were generally regrouped into three categories: acute HVO (combining the HO and VO patterns), obtuse HVO and acute OO (combining the OO1 and OO2 patterns). More detailed analyses will be reported only when needed.

2.4. Procedure and data analysis

The participants had to copy the models presented in identical squares of 3×3 cm^2 located immediately below the models. Starting points as well as movement direc-

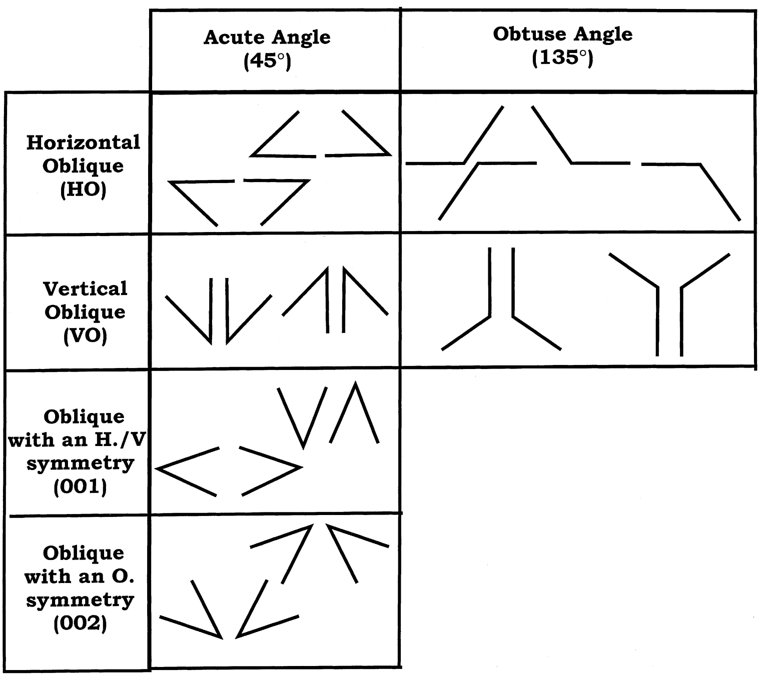

Fig. 1. Illustration of the models used in the experiment.

tions were free, but participants were asked to reproduce the patterns accurately without pen-lifts, to pay attention to the size and shape of the model and to adopt a normal speed. Twelve models per sheet of paper were randomly presented in 3 rows of 4 patterns each. For each trial, subjects were required to hold the pen at an initial position indicated by a black dot, located at the bottom-right hand corner of the square in which the drawing had to be done. They were instructed to draw as soon as a beep signal was emitted.

Data were analyzed off-line by means of an interactive program (Teulings and Maarse, 1984). Pen-tip displacement data were low-pass filtered with a Finite Impulse Response filter with a transition band between 3 and 12 Hz. The filtered data were displayed alongside tangential velocity profiles. Individual drawing movements corresponding to the segments of the model were isolated by selecting time points at the velocity minima that were closest to the beginning and the end of the model-defined segments. For each submovement, the dependent variables were segment length (cm) and the direction of the first drawn segment (deg). The direction of a segment was defined between 0° and 360° and was computed by calculating the angle of the straight line between the locations of two successive segmentation points (*XY* samples), the angle being defined as the arctan of $\mathrm{d}Y/\mathrm{d}X$ with the 0° corresponding to the horizontal, rightward vector. The angle (in deg.) formed by the two consecutive segments was also determined by computing the difference in direction between the two segments. Vertical segments corresponded to the 90°(top)/270°(bottom) directions. The HVO patterns, eithe acute or obtuse, included two oblique directions: 45°/225° and 135°/315°, the four OO patterns: 22.5°/202.5°, 67.5°/247.5°, 112.5°/292.5° and 157.5°/337.5°.

3. Results

3.1. Segment length

PD patients produced significantly smaller drawings than control subjects, regardless of the age of the controls and whatever the type of pattern. An analysis of the constant errors revealed significant group effects for the acute HVO patterns, $F(2,17) = 7.40$, $p < 0.01$, for the acute OO patterns, $F(2,17) = 5.73$, $p < 0.01$, and for the obtuse HVO patterns, $F(2,17) = 17.98$, $p < 0.001$. However, PD patients drew the acute patterns longer than the obtuse ones, while no similar differences were observed in either elderly group, as attested by a significant Group×Type of pattern interaction, $F(4,34) = 5.59$, $p < 0.001$.

The results reported in Fig. 2 reveal that length accuracy depends on the requested pattern size. The upper figure expresses the constant error as a function of group, pattern and model size, and the lower figure displays the total variability scores (RMSE).

As indicated by the constant errors, it appears again that PD subjects constantly drew smaller segment lengths than controls. However, a clear interaction between

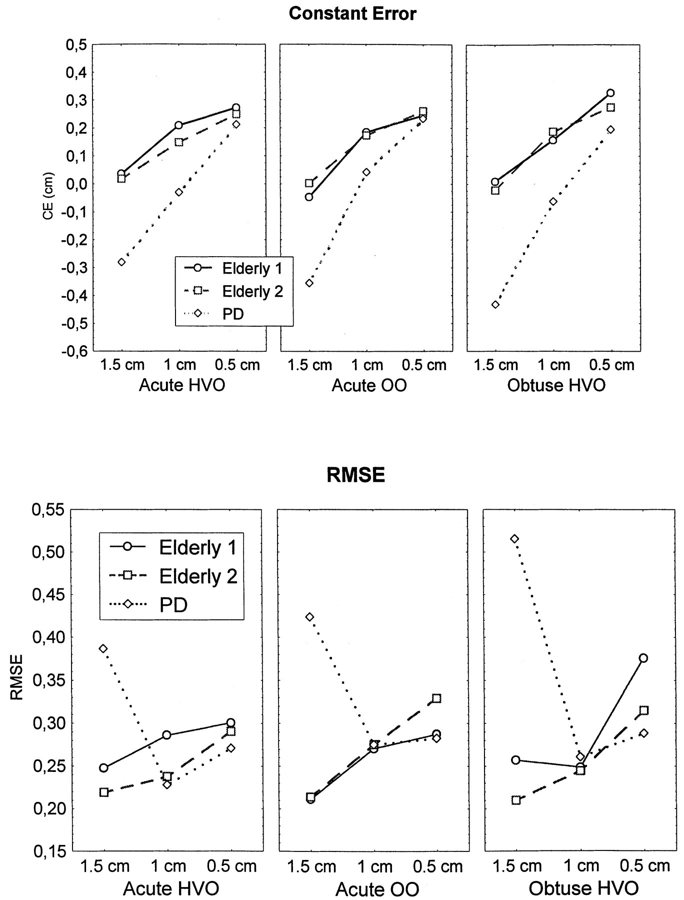

Fig. 2. Segment length as a function of Group, Pattern and Model segment size (the upper figure displays the Constant Error in cm; the lower figure displays the Root Mean Square Error in cm; see the method section -models- for the abbreviations used to describe the patterns).

Group and Size emerged, whatever the pattern (acute HVO: $F(4,34)=6.26$, $p<0.01$; acute OO: $F(4,34)=10.33$, $p<0.001$; obtuse HVO: $F(4,34)=7.75$, $p<0.01$). PD patients, like elderly subjects, drew patterns longer than the models for the small size (0.5 cm), but they did not increase the lengths as required by the increment in model size. The bigger the model, the more they underestimated its size. PD patients displayed a range of amplitudes reduced when compared to controls. The dependence of length accuracy on model size is also reflected in the variability scores, which were much higher for the biggest size than for the other ones in PD patients. The Group by Size interactions were significant for each category of patterns (acute HVO: $F(4,34)=3.61$, $p<0.01$; acute OO: $F(4,34)=4.65$, $p<0.01$; obtuse HVO: $F(4,34)=8.75$, $p<0.001$). The two groups of elderly controls never differed significantly from one another, whatever the pattern and the type of dependent variables considered, $p < 0.70$, while PD subjects performed significantly different from each control group.

A more detailed analysis of the type of patterns did not provide further significant differences for the HVO structure. The same profile of results was observed for the acute and obtuse patterns, whether they contained of a horizontal or a vertical segment. However, when the constant errors recorded for either the oblique patterns having a vertical or a horizontal axis of symmetry (OO1) or those with an oblique axis of symmetry (OO2) were compared, a significant Group by Type of pattern interaction appeared, $F(2,17) = 4.40$, $p < 0.05$. The segment lengths were longer for the OO2 than OO1 patterns in controls, whatever their age, but did not differ in PD subjects.

3.2. Segment direction

As mentioned in the method section, only the first drawn segments were included in the analysis of segment direction. Before running the analysis, we checked whether there were some systematic differences between patients and controls with regard to movement sequencing for each pattern. It appears that they behaved almost identically, adopting the same sequencing (starting location point, movement progression) for all patterns and respecting the different rules and regularities described in the literature (Goodnow and Levine, 1973; Van Sommers, 1984). It is worth mentioning that two directions were never produced by the subjects, whatever their group: those oriented toward the top-left region at 135° and at 157°5. Such a behavior has been largely reported in the literature (Van Sommers, 1984; Meulenbroek et al., 1996), these directions being considered as non-preferred directions. Fig. 3 presents the constant deviations (upper figure) and the RMSE scores (lower figure) as a function of Group for the different segment directions required by the models.

Though no global group effect appeared with respect to the CE scores, the RMSE scores revealed that, on average, PD patients were significantly more imprecise and variable than controls, $F(2,17) = 6.68$, $p < 0.01$, whether horizontals and verticals, $F(2,17) = 4.24$ $p < 0.05$, or obliques, $F(2,17) = 7.94$, $p < 0.01$, are concerned. The two groups of elderly controls did not differ from one another, $p = 0.75$.

With regard to horizontals and verticals, as revealed by the RMSE scores, PD patients, like controls, were more accurate for the drawing of the horizontal or vertical in a preferred direction (i.e. respectively 0° and 270°) than for the production of these segments in non-preferred directions, as shown by an ANOVA in which these directions were compared, $F(1,17) = 79.48$, $p < 0.001$. In controls, the increase of imprecision for non-preferred directions was higher for the horizontal than for the vertical, $F(1,13) = 5.38$, $p < 0.05$, which is in agreement with Meulenbroek and Thomassen's model (Meulenbroek and Thomassen, 1991), suggesting that drawing a horizontal is motorically more complex than drawing a vertical. However, no such difference appears in PD patients, $F < 1$, who, consequently, were particularly imprecise for the 90° direction, $F(2,16) = 7.45$, $p < 0.01$.

If the oblique directions are broken down into regions, it appears that the performance of PD patients was more imprecise than that of controls for all regions,

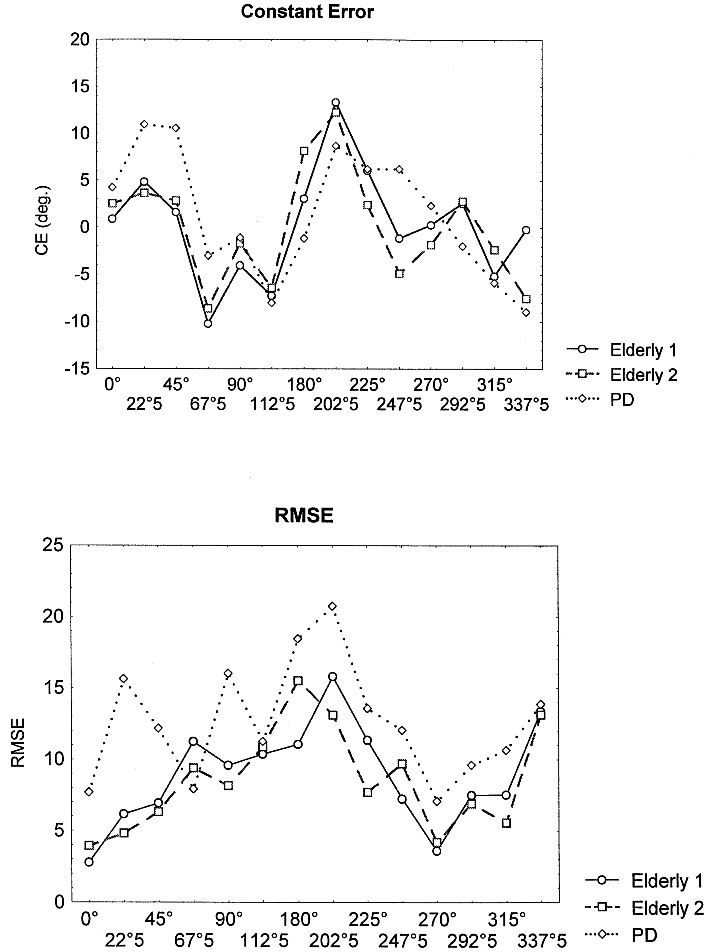

Fig. 3. Segment direction as a function of Group and Model segment direction (upper figure: Constant Error in deg.; lower figure: Root Mean Square Error in deg.; 0° corresponds to the rightward oriented horizontal, 90° to the topward oriented vertical).

toward the top-right, $F(2,17)=6.01$, $p<0.01$, the bottom-left, $F(2,17)=3.24$, $p<0.06$, and the bottom-right, $F(2,17)=4.26$, $p<0.05$. However, it is again worth conducting a finer analysis. As far as the top-right region is concerned (22.5°, 45°, 67.5°), a significant Group by Direction interaction, $F(4,34)=5.42$, $p<0.01$, shows that PD patients were particularly imprecise in the reproduction of the 22.5° and 45° directions, but tended to be more precise than controls for the production of the 67.5° oblique. The constant errors provide similar results, and indicate that the deviations recorded for the 22.5° and 45° directions are oriented toward 67.5°. If the oblique directions are regrouped in either "interposed directions" (22.5°, 67.5°, 112.5°, 202.5°, 247.5°, 292.5° and 337.5°) or "main directions" (45°, 225° and 315°)

and contrasted to the horizontal–vertical orientations, the results reveal that the patients were similarly imprecise in all categories of directions ($F < 1$), while controls were more imprecise for the oblique interposed directions than for the other categories, $F(2,26) = 5.43$, $p < 0.01$. Thus, controls presented globally the best performance for the 0–45° region and for the 270–315° region, while this was restricted to the 0° and 270° directions in PD patients, and possibly the 67.5° oblique.

3.3. Angle production

Fig. 4 presents the constant errors (upper figure) and the associated RMSE scores (lower figure) as a function of group and type of pattern.

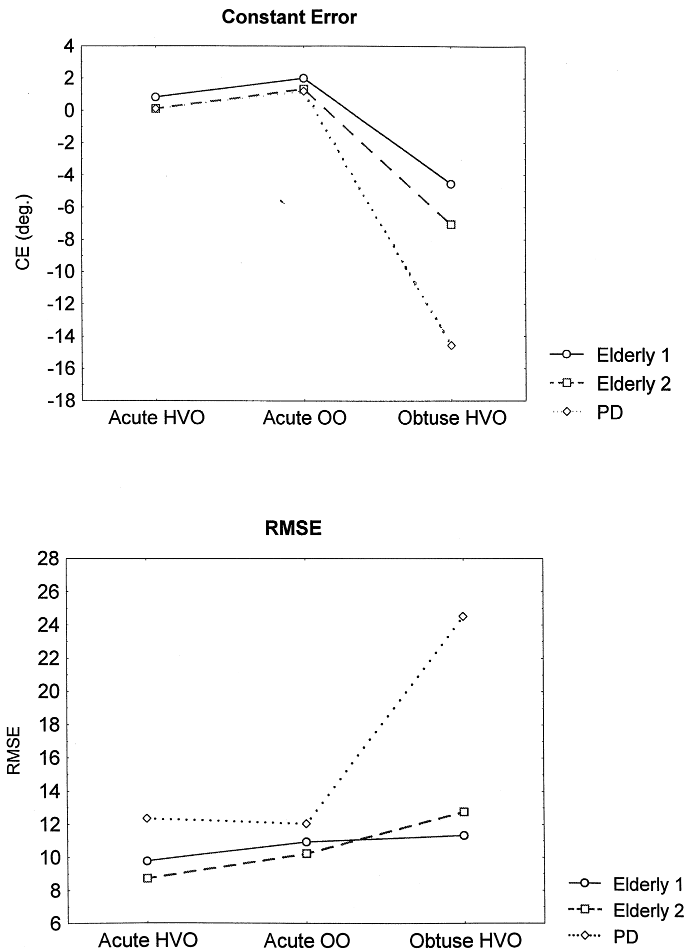

Fig. 4. Angle as a function of Group and Pattern (upper figure: Constant Error in deg.; lower figure: Root Mean Square Error in deg).

As indicated by the constant errors, both controls and PD patients were more accurate when they had to draw acute rather than obtuse angles, $F(2,34) = 24.59$, $p < 0.001$. However, the underestimation of obtuse angles was significantly stronger in PD patients than in controls, $F(1,17) = 5.28$, $p < 0.05$. A significant Group by Pattern by Size interaction revealed that the figure size did not modify the errors in the angle reproduction of acute patterns, while for obtuse patterns, PD subjects performed similarly to controls for the biggest patterns (on average in absolute values, respectively 131°, 129° and 127° for the elderly 1, elderly 2 and PD group), but shrunk the angle of medium (respectively 130°, 130° and 116°) and small patterns (respectively 129°, 124° and 117°) when compared to controls, $F(8,68) = 2.54$, $p < 0.02$.

The RMSE scores provided similar results, showing that PD patients were globally more imprecise than controls in angle production, $F(1,17) = 5.46$, $p < 0.02$, and particularly for obtuse patterns, $F(2,34) = 11.30$, $p < 0.01$. There were no differences between obtuse patterns consisting of a horizontal or a vertical segment ($p < 0.70$): in both cases, PD patients were less accurate, and produced less open angles. With regard to acute patterns, the angles of OO1 patterns were drawn larger than those of OO2 patterns, whatever the group, $F(1,17) = 47.56$, $p < 0.001$.

4. Discussion

As could be expected from numerous reports, PD patients' drawings are globally smaller. The reduction in movement amplitude is not restricted to the specific graphic skill of handwriting. However, the deficit in the calibration of movement amplitude appears to be dependent on the requested model size. PD patients do not differ from controls for the production of small segment sizes (0.5 cm), which they even overestimate on average (up to about 0.7 cm), like controls do. The size of segments of 1 cm is still slightly overestimated by controls, while PD patients appear quite accurate for the reproduction of this size. A clear reduction in movement amplitude in patients characterizes segments of 1.5 cm (to about 1.2 cm). They consequently display a restricted range of amplitude, centered around 1 cm, when compared to controls, a phenomenon similar to the restricted variations in amplitude they show in handwriting (Helsper et al., 1996). The results also show that the production of movement amplitude is a function of the type of pattern drawn. As expected, obtuse patterns were reproduced with significantly shorter sizes than acute ones by PD patients.

A deficit in force production seems responsible for the reduction in movement amplitude, several EMG bursts being recorded in PD patients for the execution of a movement where controls would display a perfect bell-shaped velocity profile (Berardelli et al., 1986b; Eichhorn et al., 1994). As long as a given effector is mobilized in a task, the longer the amplitude required, the more muscular commands, and the more PD patients may encounter difficulties in movement execution. The production of movement amplitude is also dependent on the effector joint involved in the movement. Meulenbroek, et al. (1993) have shown that the maximal displacement of the fingers, the wrist and the forearm-arm is of 1, 5 and 15 cm respectively, with respective optimal values of 0.3, 0.5 and 5 cm. Only finger and wrist movements should consequently be involved in our task, with a main contribution of the wrist joint, considering the range of produced amplitudes (0.7–1.2 cm on average for patients, 0.7–1.5 cm for controls). If, because of their impairment in movement coordination, the patients tried to execute the drawings for as long as possible using the same effector in our task, possibly the wrist, it is conceivable that they showed a greater amplitude reduction for longer rather than smaller patterns, as for obtuse rather than acute patterns, the latter bringing the effector joint more quickly than the former close to the limits of its functional range of motion. The shrinking of obtuse angles by PD patients seems also coherent with this hypothesis, because the more obtuse the angle, the closer to its limits of motion it brings the effector. These deficits appear specific to Parkinson's Disease and is not shared by the normal aging of motor behavior, at least with respect to the period of age investigated in our study.

However, this interpretation appears to be at odds with the fact that PD subjects performed similarly to controls for the biggest obtuse patterns and shrunk the angle of the medium and small patterns only. To account for this unexpected result, it seems necessary to hypothesize that PD patients stopped for longer after having drawn the first segment of the biggest obtuse patterns than they did for the smaller patterns, and perhaps repositioned their hand during the pause. Pauses at the angles did indeed increase as a function of segment length (from 265 to 350 ms on average) but a similar size effect on pauses was also obtained in controls. Data on finger and wrist movements would be necessary to discuss further this undoubtly rather ad-hoc hypothesis.

A pattern effect on segment length was also observed in control subjects: oblique patterns with an oblique axis of symmetry (OO2) were drawn longer than those with a horizontal or vertical axis of symmetry (OO1). Considering that the angle of OO2 patterns was also shrunk, it could be suggested that control subjects drew these patterns using movements closer to back-and-forth movements, centered around one of the main oblique axes (45–225°/135–315°), than they did for OO1 patterns. This type of movements permits an exploitation of muscular elasticity, which leads subjects to lengthen segment size (Meulenbroek and Thomassen, 1993; Desbiez et al., 1996). Despite that subjects were not required to draw fast, the geometry of OO2 patterns may have enhanced more dynamical movements in controls, not in PD patients because of their general impairment in force production.

As expected, PD patients were globally more imprecise than controls in the reproduction of segment directions. However, they performed relatively accurately when they were asked to produce horizontals and verticals in a preferred direction (respectively from left-to-right and from top-to-bottom), and also an oblique segment oriented at 67°5. These results, as well as those obtained in controls, appear highly ambiguous with respect to both the Hollerbach model and the Meulenbroek and Thomassen model. In accordance with the first model, accuracy was observed for two directions (horizontal and vertical) which some authors consider not to require a simultaneous co-activation of two effectors (see Teulings et al., 1997, for instance). This result constitutes a strong point in favor of this model, since in PD patients, these two directions are clearly more accurately reproduced than all others. However, this model does not predict a difference between horizontals or verticals drawn in a preferred or non-preferred direction, and cannot account for the worse performance of controls for the horizontal and vertical drawn in a non-preferred direction in comparison to some oblique directions (22°5–45°/292°5–315°). The global "oblique effect" predicted by this model failed to be obtained in controls, and was totally absent in PD patients. Note that in the data reported by Teulings et al. (1997) where the best performance of PD patients was recorded for the drawing of horizontals and verticals, there was also a difference between preferred or non-preferred directions for the horizontals, though no similar difference was observed regarding the production of verticals. In accordance with the second model, the worst performance in PD patients and controls was globally obtained for the horizontal and vertical drawn in a non-preferred direction. Controls were also quite accurate for the directions corresponding to the main oblique axes (45° and 315°), considered as the easiest to perform at a motor level by Meulenbroek and Thomassen (1991). However, the model predicts a clear advantage of these main oblique directions in comparison to the horizontal–vertical ones and this was not observed in controls, nor in PD patients. Moreover, though the model suggests that the accuracy of the horizontal and vertical may benefit from visual control, it is hard to see why this should be rectricted to the preferred directions.

Thus no clear distinction appears in our results between an oblique axis and a horizontal–vertical axis in controls, while from the results in PD patients, it may be argued that the horizontal and vertical orientations are the least demanding ones in terms of movement coordination insofar as they are drawn in a preferred direction. As a matter of fact, the degree of practice or familiarity of the movement seems to have a great impact in the accuracy of movement directions, since the performance of both PD patients and controls is at best for preferred directions, including both horizontals or verticals and obliques. These results appear closer to those obtained by Plamondon and Clement (1991), who failed to distinguish between two orthogonal axes in movement generation on the basis of a kinematic analysis of stroke drawing movements, but nevertheless observed faster velocities for preferred directions. Whatever this issue, Parkinson's disease clearly affects movement direction accuracy, the patients experiencing more difficulties in movement coordination than controls. The visual disorder shown by these patients in the perception of the horizontal and vertical cannot account for the results, since their best performance is precisely recorded for the horizontal and vertical, as it is in controls. Imprecision in movement direction displayed by the patients is thus mainly due to their motor impairment. However, the role played by visual guidance of the movement in PD patients remains obscure and should be investigated. Their better performance for the drawing of the horizontal and vertical in a preferred direction may indeed depend on the availability of visual feedback during movement execution.

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References

Agostino, A., Berardelli, A., Formica, A., Stocchi, F., Accornero, N., Manfredi, M., 1996. Analysis of repetition and non-repetitive sequential arm movements in patients with Parkinson's disease. Movement Disorders 9, 311–314.

Appelle, S., 1972. Perception and discrimination as a function of stimulus orientation: The oblique effect in man and animals. Psychological Bulletin 78, 266–278.

Benecke, R., Rothwell, J.C., Dick, J.P.R., Day, D.L., Marsden, C.D., 1986. Performance of simultaneous movements in patients with Parkinson's disease. Brain 109, 739–757.

Berardelli, A., Accornero, N., Argenta, M., Meco, G., Manfredi, M., 1986a. Fast complex arm movements in Parkinson's disease. Journal of Neurology, Neurosurgery and Psychiatry 49, 1146–1149.

Berardelli, A., Accornero, N., Argenta, M., Meco, G., Manfredi, M., 1986b. Scaling of the size of the first EMG agonist burst during rapid wrist movements in patients with Parkinson's disease. Journal of Neurology, Neurosurgery and Psychiatry 49, 1273–1279.

Boller, F., Passafiume, D., Keefe, N.C., Rogers, K., Morrow, L., Kim, Y., 1984. Visuospatial impairment in Parkinson's disease. Archives of Neurology 41, 485–490.

Castiello, U., Bennett, K.M., Scarpa, M., 1994. The reach to grasp movement of Parkinson's disease subjects. In: Bennett, K.M., Castiello, U. (Eds.), Insights into the Reach to Grasp Movements. North-Holland, Amsterdam.

Cecala, A.J., Garner, W.R., 1986. Internal frame of reference as a determinant of the oblique effect. Journal of Experimental Psychology: Human Perception and Performance 12, 314–323.

Cunnington, R., Iansek, R., Bradshaw, J.L., Phillips, J.G., 1995. Movement-related potentials in Parkinson's disease. Presence and predictability of temporal and spatial cues. Brain 118, 935–950.

Danta, G., Hilton, R.C., 1975. Judgment of the visual vertical and horizontal in patients with Parkinsonism. Neurology 25, 43–47.

Desbiez, D., Vinter, A., Meulenbroek, R.G.J., 1996. Biomechanical and perceptual determinants of drawing angles. Acta Psychologica 94, 253–271.

Desbiez, D., Vinter, A., Meulenbroek, R.G.J., (in press) Activations différenciées de processus centraux et périphériques dans une tâche de dessin: analyse des pauses et des amplitudes du mouvement. L'Année Psychologique.

Eichhorn, T., Arnold, G., Mai, N., Gasser, T., Oertel, W.H., 1994. Disturbance in the execution of automated handwriting movements. A sensitive marker for early Parkinsonism. Movement Disorders 9, 121.

Flash, T., Henis, E., Inzelberg, R., Korczyn, A.D., 1992. Timing and sequencing of human arm trajectories: Normal and abnormal motor behavior. Human Movement Science 11, 83–100.

Flowers, K.A., 1976. Visual closed-loop and open-loop characteristics of voluntary movements in patients with Parkinsonism and intention tremor. Brain 99, 269–310.

Flowers, K.A., 1978. Lack of prediction in the motor behaviour of Parkinsonism. Brain 101, 35–52.

Goldenberg, G., Wimmer, A., Auff, E., Schnaberth, G., 1986. Impairment of motor planning in patients with Parkinson's disease: Evidence from ideo-motor apraxia testing. Journal of Neurology, Neurosurgery and Psychiatry 49, 1266–1272.

Goodnow, J.J., Levine, R., 1973. The grammar of action: sequence and syntax in children's copying of simple shapes. Cognitive Psychology 4, 82–98.

Goodrich, S., Henderson, L., Kennard, C., 1989. On the existence of an attention-demanding process peculiar to simple reaction time: Converging evidence from Parkinson's disease. Cognitive Neuropsychology 6, 309–331.

Helsper, E., Teulings, H-L., Karamat, E., Stelmach, G.E., 1996. Preclinical Parkinson features in optically scanned handwriting. In: Simner, M.I., Leedham, C.G., Thomassen, A.J.W.M. (Eds.), Handwriting and Drawing Research: Basic and Applied Issues. IOS Press, Amsterdam.

Hollerbach, J.M., 1981. An oscillation theory of handwriting. Biological Cybernetics 39, 139–156.

Jones, D.L., Philipps, J.G., Bradshaw, J.L., Iansek, R., Bradshaw, J.A., 1992. Programming of single movements in Parkinson's disease: Comparison with Huntington's disease. Journal of Clinical Experimental Neuropsychology 14, 762–772.

Klockgether, T., Dichgans, J., 1994. Visual control of arm movement in Parkinson's disease. Movement Disorders 9, 48–56.

Martin, K.E., Phillips, J.G., Iansek, R., Bradshaw, J.L., 1994. Inaccuracy and instability of sequential movemnts in Parkinson's disease. Experimental Brain Research 102, 131–140.

Maeshima, S., Itakura, T., Nakagawa, M., Nakai, K., Komai, N., 1997. Visuospatial impairment and activities of daily living in patients with Parkinson's Disease. American Journal of Physical Medicine and Rehabilitation 6, 383–388.

Meulenbroek, R.G.J., Thomassen, A.J.W.M., 1991. Stroke-direction preferences in drawing and handwriting. Human Movement Science 10, 247–270.

Meulenbroek, R.G.J., Thomassen, A.J.W.M., 1993. Exploitation of elasticity as a biomechanical property in the production of graphic stroke sequences. Acta Psychologica 82, 313–327.

Meulenbroek, R.G.J., Rosenbaum, D.A., Thomassen, A.J.W.M., Schomaker, L.R.B., 1993. Limb-segment selection in drawing movements. The Quaterly Journal of Experimental Psychology 46A, 273–299.

Meulenbroek, R.G.J., Thomassen, A.J.W.M., Schillings, J.J., Rosenbaum, D.A., 1996. Synergies and sequences in copying L-shaped patterns. In: Simmer, M.L., Leedham, C.G., Thomassen, A.J.W.M. (Eds.), Handwriting and Drawing Research: Basic and Applied Issues. IOS Press, Amsterdam.

Mortimer, J.A., Pirozzolo, F.J., Hansch, E.C., Webster, D.D., 1982. Relationship of motor symptoms to intellectual deficits in Parkinson disease. Neurology 32, 133–137.

Phillips, J.G., Stelmach, G.E., 1991. The contribution of movement disorders research to theories of motor control and learning. In: Summers, J. (Ed.), Approaches to the Study of Motor Control and Learning. North-Holland, Amsterdam.

Phillips, J.G., Müller, F., Stelmach, G.E., 1989. Movement disorders and the neural basis of motor control. In: Wallace, S. (Ed.), Perspectives on the Coordination of Movement. North-Holland, Amsterdam.

Plamondon, R., Clement, B., 1991. Dependence of peripheral and central parameters describing handwriting generation on movement direction. Human Movement Science 10, 193–221.

Schomaker, L.R.B., Thomassen, A.J.W.M., Teulings, H.L., 1989. A computational model of cursive handwriting. In: Plamondon, R., Suen, C.Y., Simner, M. (Eds.), Computer Recognition and Human Production of Handwriting. World Scientific, Singapore.

Stelmach, G.E., 1991. Basal ganglia impairment and force control. In: Requin, J., Stelmach, G.E. (Eds.), Tutorials in Motor Neuroscience. North-Holland, Amsterdam.

Stelmach, G.E., Castiello, U., 1992. Functional force control in Parkinson's disease patients. In: Stelmach, G.E., Requin, J. (Eds.), Tutorials in Motor Behavior II. North-Holland, Amsterdam.

Stern, Y., Maysen, R., Rosen, J., Ilson, J., 1983. Perceptual motor dysfunction in Parkinson's disease: A deficit in sequential and predictive voluntary movement. Journal of Neurology, Neurosurgery and Psychiatry 46, 145–151.

Teulings, H.-L., Maarse, F.J., 1984. Digital recording and processing of handwriting movements. Human Movement Science 10, 165–191.

Teulings, H-L., Stelmach, G.E., 1992. Simulation of impairment of force amplitude and force timing in Parkinsonian handwriting. In: Stelmach, G.E., Requin, J. (Eds.), Tutorials in Motor Behavior II. North-Holland, Amsterdam.

Teulings, H.L., Contreras-Vidal, J.L., Stelmach, G.E., Adler, C.H., 1997. Parkinsonism reduced coordination of fingers, wrist and arm in fine motor control. Experimental Neurology 146, 159–170.

Van Sommers, P., 1984. Drawing and Cognition. Cambridge University Press, Cambridge.

Vinter, A., Desbiez, D., Gras, P., Pozzo, Th., 1996. The drawing of angular figures in Parkinson's Disease patients: preliminary report. In: Simner, M.I., Leedham, C.G., Thomassen, A.J.W.M. (Eds.), Handwriting and Drawing Research: Basic and Applied Issues. IOS Press, Amsterdam.

Zackon, T.W., 1989. Reaching movements and pursuit tracking performance in patients with Parkinson's disease. Unpublished Doctoral Thesis, McGill University.