Effects of Alzheimer's Disease on Basic Drawing Processes

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Abstract. Based on analyses of the drawing process for simple, two-stroke patterns, we compared 22 subjects with Alzheimer's Disease and 21, age-matched, normal controls. The two groups differed in a variety of choices about stroke decomposition, stroke order, and stroke direction. The AD subjects often made choices that led to a less efficient or less stable drawing process.

1. Introduction

The research reported here combines two traditions: the use of simple drawing tasks to identify and characterize individuals with Alzheimer's Disease (AD) and research attempting to describe low-level strategies used by normal (control) subjects (NC) to produce simple drawings. Through this combination we hoped to acquire a more detailed understanding of the deficits typically observed on simple graphics tasks for individuals suffering from AD and of the structure of drawing processes more generally.

The most striking features of AD are impairments in episodic learning and memory. At least early in the disease, the procedural memory and learning processes that underlie motor behavior appear to be relatively spared (Almkvist, et al., 1993; Deweer, et al., 1994). So, for example, AD subjects can learn and retain a variety of motor tasks such as rotary-pursuit tracking, bean-bag tossing, and mirror tracing (e.g., Dick, et al., 1996; Eslinger & Damasio, 1986; Knopman, 1991). Within this context it is both interesting and perhaps somewhat puzzling that there are clear and well-established deficits in the ability of AD subjects to reproduce relatively simple patterns (e.g., Ericsson, et al., 1991; Grossi, et al., 1978; Grossman, 1996). For example, Figure 1 shows the attempt of a subject with mild dementia to reproduce a pair of overlapping rectangles in a situation that minimized memory demands. These drawing deficits are sufficiently robust that tests requiring the reproduction of simple patterns are incorporated in standard test batteries used to assess AD (Morris, et al., 1988).

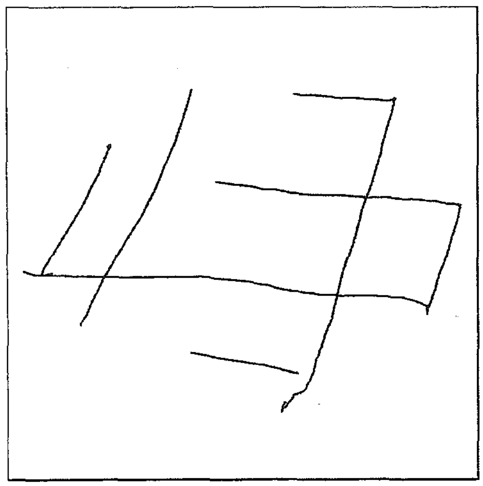

Figure 1. Example of an attempt by an AD subject to draw two overlapping rectangles.

The studies cited above focused on the product of the drawing process (as opposed to the process itself) and have typically used subjective scoring systems to assess the quality of those drawings. The study reported here compared the process used by NC and AD subjects to draw simple figures that can be produced using two strokes. (See Figure 2 for examples.) In this effort, we are building on a second, less clinical, research tradition (e.g., Goodnow & Levine, 1973; Thomassen, Meulenbroek, & Tibosch, 1991; van Sommers, 1984). A goal of this second line of research is to describe the regularities (or according to some authors, rules) which underlie subjects' stroke order, stroke direction, and stroke continuation choices. Developmental research (Akshoomoff & Stiles, 1995 a&b; Goodnow & Levine, 1973) has demonstrated that at least some of these strategies are learned rather than innate. Although it is dangerous to draw analogies between developmental progression and the progress of decline due to dementia, the existence of this developmental progression gives us some reason to speculate that these regularities might be disrupted in AD.

Thus, the goal of this research was to explore a third possible explanation (in addition to perceptual and executive deficits) for the difficulties that AD subjects exhibit in simple drawing tasks. If the tasks in this study reveal differences between AD and NC subjects, this would suggest that, for AD subjects, stroke-production choices no longer automatically adhere to the regularities shown by normals. To the extent that the choices of AD subjects differ from those of NC subjects, it is possible that the AD subjects are using less efficient drawing strategies. An alternative is that these choices differ because AD subjects, to achieve end-state stability (Meulenbroek & Thomassen, 1993), must give priority to goals, such as establishing a reference frame, that conflict with efficiency. Another possibility is that AD subjects have lost the ability to retrieve these choices automatically. Without this guidance, each alternative for stroke order, direction, etc., would become a choice point. Having to re-make these choices would add substantially to the task's cognitive load. Thus, by studying performance for these simple drawing tasks we sought to isolate factors that contribute to the deficits in more complex drawing tasks such as that in Figure 1.

2. Method

2.1 Subjects. Twenty-nine subjects, diagnosed with AD and recruited from the UCI Alzheimer's Disease Research Center and two residential care facilities for dementia patients, participated in the experiment. Of these subjects, seven were largely unable to do the task. Because our goal was to describe the behavior of those who could do the task, not to characterize the populations, we omitted the data from these subjects from all analyses. The AD subjects were classified as mildly to moderately demented; the mean Mini-Mental State Exam (MMSE) score (on a scale from 0 to 30) for the 22 remaining subjects was 20.9 (*SD* =5.5; range = 10 to 29). The seven subjects who were excluded scored in the severely impaired range on the MMSE with scores between 5 and 12. For comparison, the study also included 23 NC subjects who either were spouses of the AD subjects or recruited from local senior centers. Of these two were dropped: one because he was later suspected of having AD and one because her writing exhibited tremors due to an illness unrelated to AD. The mean MMSE score for this group was 28.3 (*SD* = 1.3; range = 26 to 30). All subjects were right handed.

2.2 Data Recording. Subjects drew on paper placed on a Wacom digitizer sampling at 100 Hz. The subject used an inking stylus with no wires attached.

2.3 Stimuli. Figure 2 shows the 17 two-stroke patterns copied by subjects in this experiment. The patterns are numbered for reference in the upper left-hand corner. The numbers adjacent to the patterns label stroke endpoints; they have been assigned starting at the top in a clockwise fashion and are not intended to imply how the pattern might be produced. Neither set of numbers was included on the stimulus cards shown to the subjects. They are included here to aid in identifying strokes in the text and stroke directions.

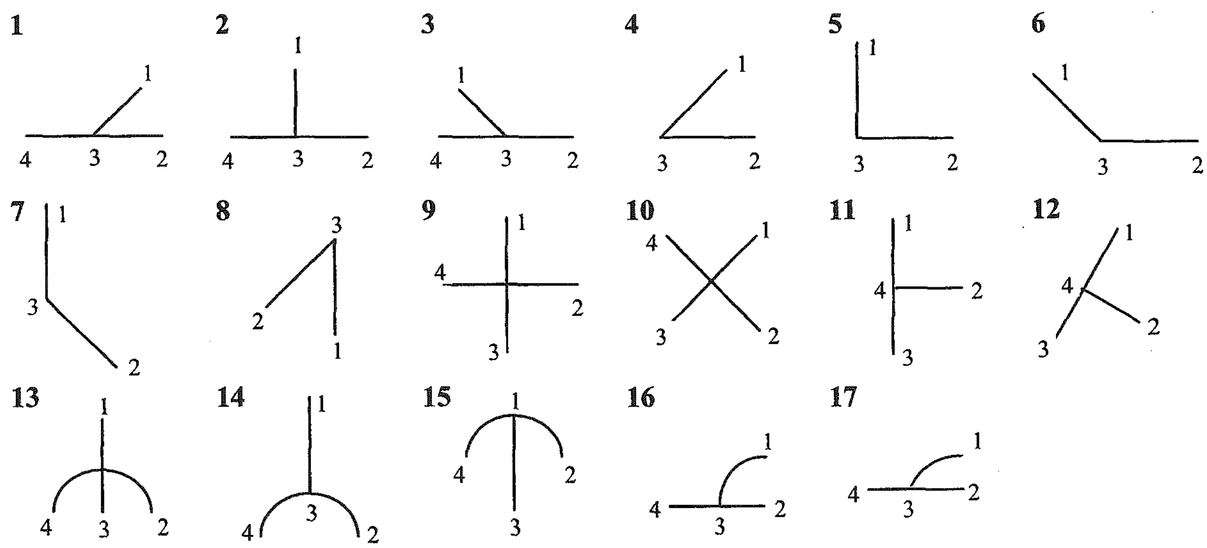

Figure 2. The 17 stimulus patterns used in this study.

2.4 Procedures. Subjects were shown and asked to copy the 17 patterns one at a time. To minimize the memory demands of the experiment, the pattern remained visible until the subject completed the task. The patterns were presented in the sequence shown in Figure 2, with each pattern produced twice in immediate succession. The experimenter monitored the production and, occasionally, would have the subject repeat a pattern if there was problem in the data collection or if the subject appeared confused about what to do.

2.5 Analysis Preliminaries. Using minima in tangential velocity to determine potential stroke endpoints, we first segmented the trajectories into strokes, labeled as shown in Figure 2. An automatic procedure then determined descriptive statistics for each stroke: e.g., duration, a count of dysfluent events (local minima in tangential velocity), length, angle, and curvature.

3. Results

3.1 Overall Performance Summaries. We used three measures to provide an overall summary of the process by which subjects drew the patterns: drawing duration, mean dysfluencies per stroke, and strategy stability. Drawing duration is the time from when the subject began the movement of the first stroke until the time the movement for the last stroke ended. This definition excluded any time at the beginning or the end, when the stylus was on the digitizer, but no drawing movement was actually being made. This measure, however, did include the duration of any periods of inactivity that occurred during or between the strokes. As there was no explicit start signal or instructions to begin quickly, latency was not measured. The dysfluency measure was based on a count of local minima in the tangential velocity profile averaged across the strokes indicated in Figure 2. Subjects' movements in this task were relatively slow and deliberate compared, for example, to those typically observed in the handwriting for these groups. Because of this, the dysfluency counts are large.

As expected, based on previous research (Wright, Lindemann, & Dick, 1998), there was a substantial difference between the two groups on both measures. Table 1 summarizes these differences. Because three AD subjects were not able to complete Patterns 13-17, there are two summaries for Patterns 1-12: one including all the subjects and one including just the subset who completed all of the tasks. For all of these comparisons, there is a substantial effect of subject group [For patterns 1-12: $F(1,41)$ is 11.65, $p < .002$, for durations, and 5.67, $p < .03$, for dysfluencies. For patterns 13-17: $F(1,38)$ is 14.91, $p < .004$, for durations, and 6.54, $p < .02$ for dysfluencies.] There were statistically significant differences between patterns. The most prominent of these is that the patterns involving curved lines – Patterns 13 to 17 – took longer and were produced less fluently than the others. However, we will not describe these differences in detail here, because there were no statistically reliable interactions of these differences with subject group.

Table 1. Two summary measures broken out by subject group and two pattern type subsets.

		Patterns		
		1 to 12 All Ss	1 to 12 Subset	13-17 Subset
Duration (s)	NC	3.57	3.57	4.81
	AD	7.96	6.74	10.09
Dysfluency (Count)	NC	10.1	10.1	14.6
	AD	17.2	14.5	23.5

Strategy stability refers to the way a pattern was produced across the two repetitions. Any change in stroke decomposition, stroke order, or stroke direction indicates a lack of stability. One might expect AD subjects to show decreased stability, if the determination of the strategy for a pattern depends heavily on memory. The data certainly point in this direction. Out of 352 possible comparisons for the NC condition, in 8.8% of cases, the subject changed strategy; of 349 such comparisons for the AD subjects, 20.3% exhibited such a change.

3.2 Decomposition of Logical Strokes into Physical Strokes. The choices a subject makes concerning stroke decomposition, stroke order, and stroke direction are clearly intertwined. In describing these choices, however, it is useful to separate them as much as possible. Following this strategy, we focused first on stroke decomposition: i.e., the choices that a subject makes to divide a pattern into pieces.

The labels in Figure 2 mark the points of decomposition used by most subjects. Thus, for Patterns 1-3 and 9-17, most subjects will produce, in some order and direction, two strokes: a stroke connecting Labels 1 and 3 and another connecting Labels 2 and 4. For each of these patterns, however, it is not only possible, but also sometimes reasonable, to break the logical 2/4 stroke into two pieces. So, in Pattern 14, if the 1/3 stroke were made first, it would probably be easier to make a reasonably shaped half circle, which intersects precisely with the, now drawn, 1/3 stroke, if the 2/4 stroke is made in two pieces. For Patterns 9-10, the 1/3 stroke could be similarly decomposed. Akshoomoff and Stiles (1995a & b) have shown that children typically progress from producing Pattern 9 as four strokes, starting at the intersection, to producing it as two crossing strokes.

For Patterns 1-3 and 9-17, the subjects in both groups used the standard decomposition more than any alternatives. NC subjects produced an alternative decomposition only twice (0.4%). The AD subjects, by contrast, used an alternative decomposition 42 times (8.0%), primarily on Patterns 13, 14, or 15. Given that these are small frequencies based on repeated measures, formal statistics are not appropriate. However, these data suggest that only the AD subjects used the alternative decomposition with any regularity and then only in three conditions involving half circles. As might be expected, in 28 of the 30 instances in which the alternative decomposition was used for Patterns 13-15, the 1/3 stroke was produced before the 2/4 stroke.

There is a similar issue of decomposition for Patterns 4-8. For each of these patterns, the subject had the choice of producing the two strokes distinctly or as one continuous process without a lift or an extended pause between the pieces. The second strategy is, undoubtedly, more efficient (Meulenbroek & Thomassen, 1993). However, for Patterns 4 and 8 it runs contrary to the dominant tendency of producing strokes from left to right and from top to bottom.

Table 2 summarizes the data relevant to this question. For each pattern, the NC subjects were more likely to use an efficient, continuous strategy than the AD subjects were. This tendency was statistically reliable ($\chi^2(1) > 7.95, p < 0.005$) only for Patterns 4, 5, and 6, however. Perhaps, the AD patients were less likely to detect the possibility of using a continuous strategy. Alternatively, they may have been less able to carry out this more complex strategy.

Table 2. Frequencies of continuous and non-continuous strategies broken down by subgroup and pattern for Patterns 4-8.

		Continuous Strategy?			
		Yes	No		
Pattern	**Group**		Gap	Apex	Other
4	NC	21	4	19	2
	AD	7	3	31	3
5	NC	34	9	2	1
	AD	19	20	6	1
6	NC	30	5	4	7
	AD	11	14	16	0
7	NC	30	15	0	0
	AD	25	14	5	2
8	NC	28	8	9	0
	AD	19	10	13	3

The column labeled *Gap* in Table 2 lists the frequency of productions in which the order and directions of the two strokes are consistent with a continuous strategy, but a lift or a long pause occurred between them. The other strategy used often for these figures is labeled *Apex* in Table 2. In this strategy, the subject draws two strokes each starting at the apex of the figure, Label 3, where the two strokes join. If AD subjects were initiating the continuous strategy and then failing to complete it, these attempts would show up as counts in the *Gap* column. However, except possibly for Pattern 7, the relative frequency of the *Gap* and *Apex* strategies, conditioned on the use of a non-continuous strategy, is similar for the two subject groups. This suggests that the reduced occurrence of the continuous strategy for the AD subjects does not simply reflect failed attempts to produce the figures using this strategy.

3.3 Stroke Order and Stroke Direction. If two productions of a pattern have the same stroke decomposition, it is reasonable to ask whether the AD and NC subjects decide on stroke order and direction similarly. Generally, they do agree, especially about stroke direction choices; the only reliable exceptions that we noted involved stroke order. The discussion in the previous paragraph illustrates the similarity of these choices for Patterns 4-8. Two small exceptions to this generalization occur for Patterns 6 and 7. On seven occasions, the NC subjects produced Pattern 6 using a stroke from Label 3 to Label 2, followed by a stroke from Label 1 to Label 3; AD subjects never used this sequence. A similar counter-example, in the opposite direction is provided by Pattern 7. Perhaps because of the strong flow of this pattern downward and to the right, NC subjects always produced this pattern using the continuous strategy or the *Gap* variation of that stroke sequence. AD subjects, however, used the *Apex* or some other strategy on about 15% of their efforts.

Among the remaining patterns, the two groups differed only for Pattern 10. This is an interesting pattern because there are conflicting tendencies that could influence both the stroke order and the direction of the 1->3 stroke. Not surprisingly, a 4->2 stroke (from the upper left to lower right) was used in every instance. Reflecting the conflicting tendencies, in both groups the subjects split evenly in their choice of direction for the 1/3 stroke. The groups differed, however, in the preferred ordering of the two strokes: 76% of the NC subjects produced the 1/3 first, but only 40% of the AD subjects used this ordering ($\chi^2(1) > 9.56, p < 0.005$).

3.4 Precision of Joins. For Patterns 1, 2, 3, 11, 12, 14, 15, 16, and 17, it is reasonable to ask how close together the two strokes are at the join. Generally, both groups of subjects managed to keep the size of these gaps small. However, those of the AD subjects were noticeably larger ($M = 1.4$ mm) than those of the NC subjects ($M = 0.9$ mm) averaged across this set of figures [$t(41) = 2.23, p < .04$].

4. Summary

It is well established that AD subjects exhibit impairments when copying complex figures (e.g., the Rey-Osterrieth figure) and moderately simple patterns (e.g., the overlapping rectangles in Figure 1). This study replicated those findings, examining the process of drawing simple, two stroke patterns. For all of the patterns studied, the productions of AD subjects required approximately twice as long as that of age-matched NC subjects. The productions of AD subjects also had substantially more dysfluent events.

In addition, the data we report here contain, to our knowledge, the first suggestion that AD and NC subjects differ in the low-level choices that they make concerning stroke decomposition, stroke order, and stroke direction. These differences showed up most clearly for patterns that involved conflicting tendencies or for which subjects could gain efficiency by drawing two strokes continuously.

AD subjects may have used different strategies in an attempt to compensate for fine motor-control deficits. However, our research on handwriting (Wright, et al., 1998) suggests that AD subjects can produce the strokes in these figures as fluently as NC subjects, if they are in a simple context or figure. Thus, we believe these strategy differences reflect deficits in the ability of AD subjects to plan or carry out the drawing of simple figures. We intend to explore the possibility that AD subjects use different drawing strategies in an attempt to maintain the precision of their drawings. These deficits, if they can be confirmed and characterized, may help to explain in part the problems that AD subjects encounter when they try to produce more complex figures.

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