Using Handwriting to Assess Fine Motor Control in Alzheimer's Disease

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Abstract. We describe a computerized handwriting protocol to assess fine motor development and/or deficits. We report results from this protocol comparing healthy older adults and patients with Alzheimer's disease (AD). The handwriting of AD patients showed reduced fluency for more complex movement patterns, the baseline of their writing often slanted upward, and they tended to produce curved letter shapes with more curvature and straight lines that were straighter.

1. Introduction

Handwriting is a complex, fine motor, skill that nearly everyone is able to perform effectively. An important question is how complex skills like handwriting change during the course of normal aging and in neurodegenerative processes such as Alzheimer's disease (AD). This research compared the production of simple handwriting and pre-handwriting units in age- and education-matched samples of healthy elderly controls (NCs) and AD patients

1.1 Hierarchical Control in Handwriting

As illustrated in Figure 1, one way to characterize handwriting production is as a hierarchically organized control system with three functional levels (Lindemann & Wright, 1998; Thomassen & van Galen, 1992; van Galen, 1991): high level intentions, mid-level motor schema, and low-level basic motor functioning. Control at each of these levels is potentially influenced by self-monitoring processes based primarily on visual feedback but also on proprioceptive feedback. The exact nature of any deficits in the writing depends on which of these processes is impaired and the degree of the impairment. Previous studies of the writing of Alzheimer's patients, have focused primarily on deficiencies at the intentional level: e.g., difficulties with sentence content, word selection, and spelling (Ericsson et al., 1996).

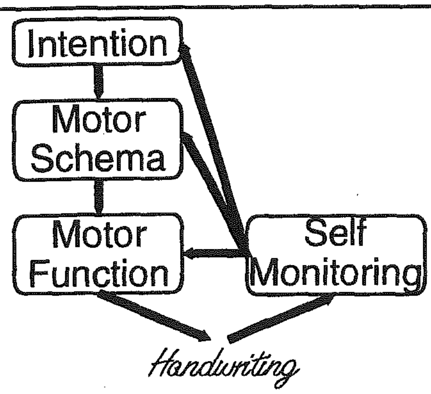

Figure 1. A simple, hierarchical scheme for handwriting control.

At the more motoric levels of functioning, there is currently only limited evidence for impairment in Alzheimer's disease, in general, and for handwriting specifically. In this research we explore whether a fine-grained analysis of a well-learned motor skill, handwriting, will reveal deterioration in the performance of Alzheimer's patients.

2. Task Overview

Diverging from previous approaches, this project used a computerized handwriting protocol, structured as a series of increasingly more demanding, but simple, tasks to assess fine-motor control in AD patients. Teulings et al. (1997) used a similar protocol successfully to characterize fine motor difficulties in Parkinson's patients. The eight tasks in the protocol are shown in Figure 2. They range in complexity from very simple (e.g., 10 horizontal lines back and forth) to somewhat more complex (e.g., 5 connected repetitions of the letter "n").

The protocol minimizes involvement of the intentional level of processing by focusing on simple, repetitive writing tasks, by providing memory aids (i.e., cards depicting each task) that were available throughout the task, and by verbal assistance to the participants.

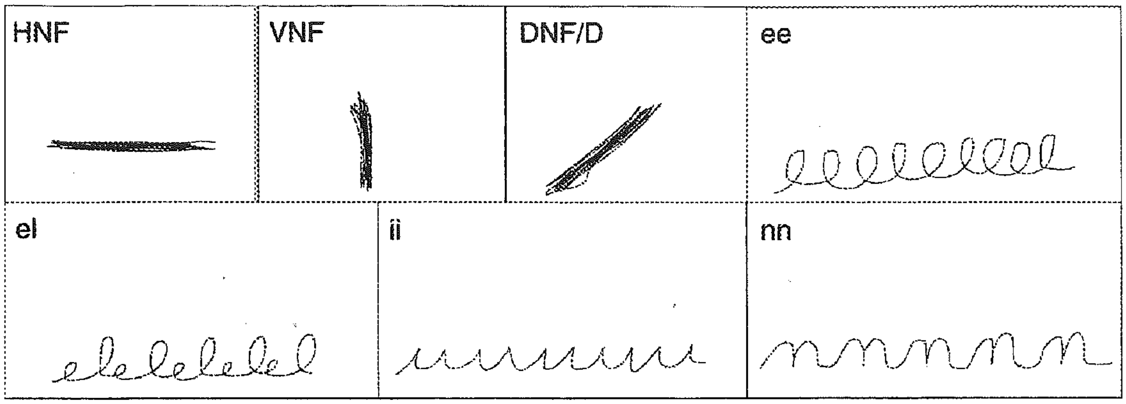

Figure 2. Examples of the eight tasks used in the protocol

The manipulation of the presence/absence of concurrent visual feedback for the tasks involving diagonal lines provided an opportunity to study the influence of the visual self-monitoring process. Marquardt, Gentz, and Mai (1995) have demonstrated that over-reliance on visual feedback can alter or disrupt handwriting performance of some AD patients as well as other patients with neurological deficits.

The design allows us to distinguish between deficits at the basic motor level and the motor schema levels of performance. Deterioration in basic motor functioning should be apparent across tasks for all levels of difficulty. Deterioration at the schema level should be reflected in decreased writing fluency that becomes more apparent for more complex tasks, because these tasks require the execution of a more complex motor schema.

Writing fluency is an important dependent measure in this research, more important than writing shape. We use the term fluency to denote the increased movement speed and smoothness associated with improved coordination arising from practice. Fluency is not the same as legibility. As Wright (1990) demonstrates, it is critical to observe the handwriting process and not simply compare the written product. With care and time, many individuals are capable of producing natural looking handwriting in unpracticed writing contexts without using the fluent writing processes characteristic of skilled productions controlled by a motor program. As shown in the table on the right, writing fluency is reflected in three measures used in this research.

Measure	**Description**	**With Impairment**
Dysfluency Count	# within-stroke velocity minima	Increases
Stroke Duration	Time per stroke	Increases
Peak Velocity	Within-stroke maximum velocity	Decreases

Along with fluency measures, we look for changes in writing shape. We did not, however, expect to see dramatic shape changes. Although AD patients are impaired in the reproduction of more complex figures, we expected our participants, all of whom had mild to moderate symptoms of AD to be able to produce clearly recognizable trajectories for all of the writing tasks. There might, however, be changes in letter shape for the more complex tasks.

2.1 Participants

A total of 40 AD patients (20 male, 20 female) and 108 healthy older adults (38 male, 70 female) provided handwriting protocol data. The two groups were similar in age with the NC group (m = 77, range = 56-91) slightly older than the AD group (m = 74, range = 47-90) . Cognitive functioning was assessed with the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) and the Blessed Information, Memory, and Concentration Test (BIMC; Katzman et al., 1983). The NC group scored within the normal range for both the MMSE (M = 27.7, SD =2.2) and BIMC (M = 29.9, SD = 2.4). The AD patients, in comparison, showed mild to moderate cognitive impairment on both tests: MMSE (M = 19.5, SD =6.2) and BIMC (M =17.5, SD = 6.8).

2.2 Data Recording and Materials

Participants produced handwriting samples by writing with a hand-held stylus on a sheet of unlined paper affixed to the surface of Wacom digitizing tablet. This tablet was attached to a laptop computer, which sampled the x/y coordinates of the stylus tip 100 times per second. Each participant wrote with two penlike styli, with no cord or other attachments. The first stylus had a nylon tip, which left no mark on the paper, and was used for the first three tasks in the protocol, for which participants received no concurrent visual feedback of the trajectory produced. For the remainder of the tasks, the participant wrote with a stylus having an ink tip, which wrote normally allowing him/her to view the written trajectory.

3. Results

3.1 Fluency

Figure 3 summarizes data from the three indicators of fluency along with the mean stroke length data. There were significant main effects of group for all three measures. The differences were all in the expected direction. AD participants had a higher dysfluency count [$F(1,146) = 10.19$, $p < 0.01$], took longer to produce individual strokes [$F(1,146) = 14.63$, $p < 0.001$], and produced lower peak velocities [$F(1,146) = 4.94$, $p < 0.05$]. For all three of these measures, there is an interaction of condition and group. For dysfluency count [$t(146) = 5.56$, $p < 0.001$] and stroke duration data [$t(146) = 4.38$, $p < 0.001$], this interaction is best characterized as a larger deficit in the performance of the AD group for complex tasks involving production of letters than for the less complex line-production tasks. This pattern is consistent with the idea that the deficit is related primarily to the motor schema rather than to the low-level processes of motor control and coordination.

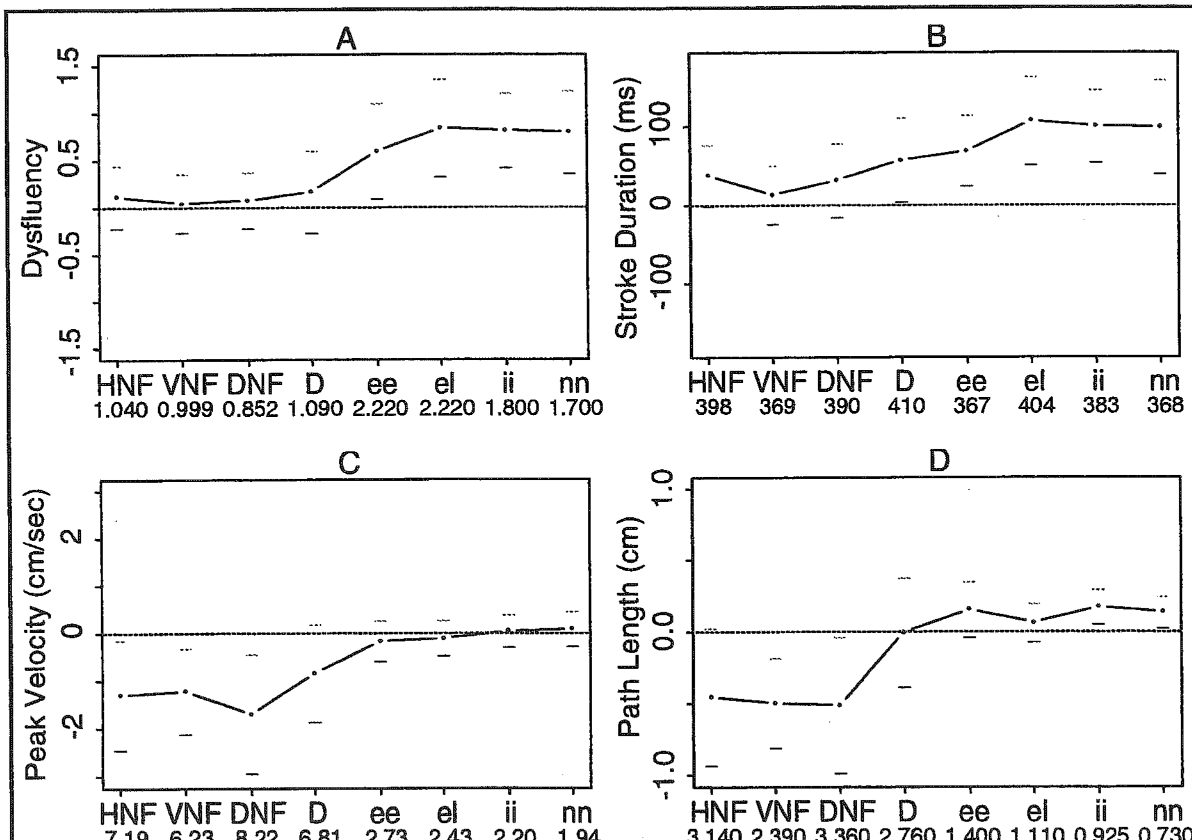

Figure 3. Mean data for each of three fluency measures and path length. Each panel shows the difference across the two groups, with scores for NC group subtracted from scores for AD group. The labels on the abscissa refer to the conditions described in Figure 1. The numbers below each label give the mean score for that condition. The bars on each point are 95% confidence intervals.

The peak velocity data appear to tell a different story, however. In this case, there was also an interaction between performance in the letter and line tasks [$t(146) = 5.60$, $p < 0.001$]. However, the direction of the interaction was opposite to what we expected: i.e., AD participants performed more like the NC group in the more complex letter tasks than in the simpler line tasks. One possible confounding factor in this comparison was the changes across task in mean stroke length, shown in Panel D of Figure 3. It is well documented that in handwriting, peak velocity follows stroke length closely. For these data, path length, which we do not see as a measure of fluency, varied across conditions exactly as did peak velocity. This suggests that the observed differences in peak velocity should not be interpreted as changes in fluency.

3.2 Effects of Visual Feedback

There were large, highly reliable effects of the presence/absence of concurrent visual feedback on fluency, shape, and consistency measures and strong interactions of these effects with conditions, suggesting that this manipulation was effective. However, there were no reliable interactions of this factor with subject groups.

3.3 Shape Measures

There were several unanticipated differences between the groups in the shape of their handwriting. Perhaps most interesting is an interaction between groups and the line versus the letter tasks for stroke curvature. The AD group tended to make straighter strokes than the NC group in the line tasks and more curved strokes in the letter tasks. There are at least two ways that this finding can be interpreted. AD participants may be more stimulus driven than the NCs. An alternative interpretation is that the AD group participants were more focused on demonstrating their competence at these simple tasks by performing carefully and precisely.

Two other differences in shape across groups involved stroke angle and baseline angle. In the letter conditions, the AD group wrote with less slant: i.e., the orientation of their strokes is more nearly vertical. This would be consistent with the AD participants being more stimulus driven; the samples used as stimuli were written with very little slant. The difference in baseline angle – the angle of the line connecting the base of a sequence of letters – cannot be interpreted in this way, however. The writing of the AD group tended to move upwards across the page, sometimes dramatically so; the writing of the NC group was generally flat and horizontal.

3.4 Discriminating the AD from the NC Groups

Although not our primary goal for this research, it is instructive to ask how well we can discriminate the two groups based just on data from the handwriting protocol. In a linear discriminant analysis of the 148 participants, 8.6% were misclassified; most of the errors were AD participants classified as normal. For comparison, if the discrimination was based on MMSE and BIMC, 7.1% were misclassified. It may also be useful that discrimination based on both the data from the protocol and the standardized tests reduced the misclassifications to 1.4%: two AD participants were classified as normal.

4.0 Conclusions

1. These results confirmed the expectation that there is a difference in the way AD and NC participants produce handwriting with AD participants being less fluent than normal controls.
2. There was little evidence for deficits at the basic motor level or in self monitoring.
3. The observed deficits can be interpreted as problems carrying out motor schema.
4. Along with differences in fluency, there were small, systematic differences in the shapes produced by the two groups.
5. Data from the handwriting protocol did almost as well as the combination of two standardized tests (MMSE and BIMC) at discriminating AD from NC participants. Combining data from the standardized tests and the handwriting protocol allowed for even better discrimination of these groups.

References

Ericsson, K., Forssell, L. G., Holmen, K., Viitanen, M., & Winblad, B. (1996). Copying and handwriting ability in the screening of cognitive dysfunction in old age. *Archives of Gerontology and Geriatrics, 22,* 103-121.

Folstein M. F., Folstein, S. E., & McHugh, P. R. (1975). Mini-Mental State: A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12,* 196-198.

Katzman, R., Brown, T., Fuld, P. et al., (1983). Validation of a short orientation-memory-concentration test of cognitive impairment. *American Journal of Psychiatry, 140,* 734-739.

Lindemann, P., & Wright, C. E. 1998. Skill Acquisition and Plans for Actions: Learning to Write with Your Other Hand. In D. Scarborough and S. Sternberg (Eds.), *Methods, Models, and Conceptual Issues* (pp. 523-584). Cambridge, Massachusetts: MIT Press.

Marquardt, C., Gentz, W., Mai, N. (1995). On the role of vision in skilled handwriting. *Basic and Applied Issues in Handwriting and Drawing Research,* M. L. Simner (Ed.). Nijmegen: International Graphonomics Society.

Thomassen, A. J. W. M. & G. P. van Galen (1992). Handwriting as a motor task: Experimentation, modelling and simulation. In J. J. Summers (Ed.), *Approaches to the study of motor control and learning* (pp. 113-144). New York: North-Holland.

Teulings, H.-L., Contreras-Vidal, J. L., Stelmach, G. E., Adler, C. H. (1997). Parkinsonism Reduces Coordination of Fingers, Wrist and Arm in Fine Motor Control. *Experimental Neurology, 146,* 159-170.

van Galen, G. P. (1991). Handwriting: Issues for a psychomotor theory. *Human Movement Science, 10,* 165-191.

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