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Perceptual-Motor Complexity of Printed and Cursive Letters

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ABSTRACT. A number of factors determining the perceptual-motor complexity of letter forms are discussed. An experiment is reported in which primary school children wrote the lower-case letters of a cursive alphabet twice, once after the visual presentation of printed letters and once after the visual presentation of cursive stimulus letters. Response-initiation-time differences between these two types of experimental trials were considered to reflect a cognitive translation process from the graphemic to the motoric level. The analyses revealed that spatial ambiguity, allographic variability, contextual ambiguity, and letter frequency are determinants of the time needed by children for perceiving printed and producing corresponding cursive letters. The motoric complexity of writing cursive letters was investigated by analyzing writing velocity, dysfluency, and curvature measurements of produced grapheme segments. The analyses indicated that letter frequency and the curvature of grapheme segments determine the motoric complexity of cursive graphemes. Educational implications based on these findings are discussed.

LEARNING TO WRITE involves the mastering of printed and/or cursive letters, a complex learning process with both cognitive and motoric aspects. Models of reading and writing, like those of Ellis (1982, 1988) and Margolin (1984), state that in order to write (or read) correctly, a subject must have sufficient lexical knowledge (lexical route) or have a set of phoneme-grapheme translation rules with which phonological codes can be translated into graphemic codes (phonological route). In both ways, a motor program, i.e., an internal representation of a movement pattern, is activated and stored in a short-term motor buffer. The motor program controls the motoric output process and consists of an abstract code (Keele, 1981) representing the number of strokes and their spatial relations (Van Galen & Teulings, 1983). When a decision about which letter to execute is made, the output process is still under the influence of allographic variability (Van Galen & Van der Plaats, 1984; Wing, Nimmo-Smith, & Eldridge, 1983). Allographs are different motoric realizations of one letter or grapheme, e.g., the *r* and *R* are two allographs of the grapheme **r**. Besides having to learn the printed letter forms in order to read, children have to learn the allographic variations of the letters of the written language in order to build up a sufficient number of motor programs with which handwriting can be acquired.

Before learning to produce cursive graphemes, a child has already been familiarized with printed letters and is able to read short words (Barbe, Lucas, & Wasylyk, 1984). When children learn to read, they are often allowed or instructed to copy printed letters to improve letter recognition. In elementary writing education, children also often start by drawing printed letters (Barbe et al.). A considerable amount of research has been concentrated on the advantages and disadvantages of manuscript writing, i.e., the writing of printed letters and the problems that may occur when children have to realize a transition from manuscript to cursive handwriting (Barbe et al.).

In many countries, the first few years of writing education are concerned with writing printed letters. Cursive letter forms are introduced somewhere between the second and fourth grade (Barbe et al., 1984). In the Netherlands, first-grade pupils have no more than 5 months' practice in writing printed letters before they start to learn cursive handwriting. Recently, Dutch reading and writing exercises have been combined into one curriculum in which printed letters are restricted to reading and cursive letters to writing exercises. In the latter case, letter forms, printed as well as cursive, are introduced simultaneously, but only the cursive ones have to be written (see Figure 1). From a theoretical point of view, this educational situation presents a child with a rather complex learning situation. Reading asks, according to our analysis, the command of a many-to-one strategy of information processing: The child must learn that both printed and cursive forms of letters should evoke one single phoneme. In the writing situation, however, the task is of a one-to-many mapping type. Depending upon the task (printed vs. cursive writing), the child has to select his motor programs from quite divergent repertoires. It is the latter stimulus-response ambiguity that was studied in the present investigation. The present study concentrated on the effects of the variation of letter type (printed vs. cursive) upon the initiation of cursive script.

We designed an experiment in which primary school children had to write lower-case cursive letters under speed instructions. The experiment consisted of two different conditions. In one condition, the visually presented letters were printed; in the other condition, cursive letters were presented. We predicted that the two different conditions would mainly affect

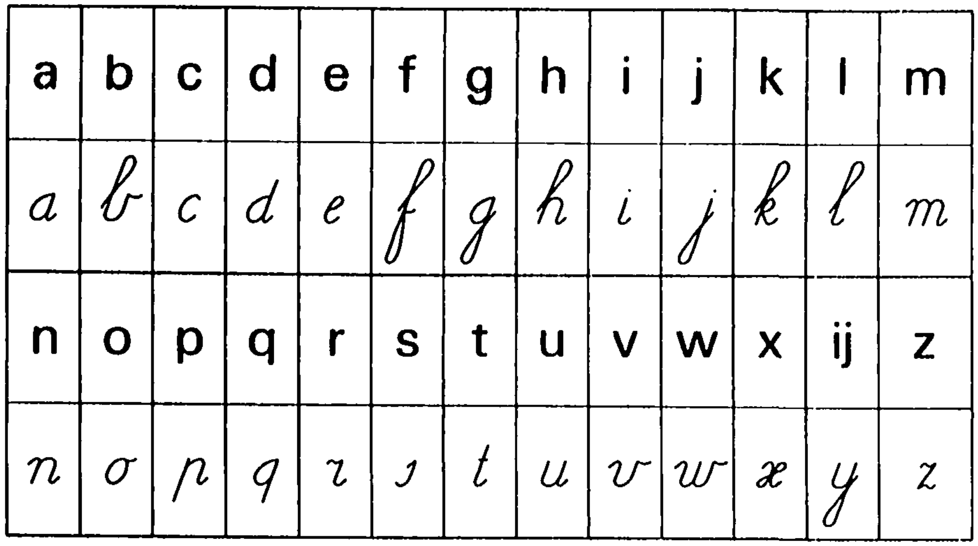

FIGURE 1. An example of a printed (rows 1 and 3) and cursive alphabet (rows 2 and 4) as used in Dutch reading and writing curricula.

response-initiation time and not the kinematics of the cursive writing movements, because once the writing movements have started a motor program has already been installed in the short-term motor buffer (Klapp, 1979; Van Galen & Teulings, 1983). Because of the higher stimulus-response compatibility in the cursive condition, shorter response-initiation times were expected in this condition than in the printed letter condition. Because Dutch school children are not used to writing printed letters, we did not investigate the effects of the reverse of the aforementioned experimental conditions. Subjects did not have to write printed letters after the visual presentation of cursive letter forms.

The Perceptual or Cognitive Complexity of Printed Letters

We hypothesized that the difference in response-initiation times between the printed and cursive letter conditions reflects a cognitive translation process from the graphemic to the motoric level in the output process. An inspection of the duration of this process for separate letters of the alphabet might reveal a number of letter complexity factors of importance to educational practice. Recent investigations with adult subjects have shown that the internal representations of letter forms in motor memory contain spatial information and that each allograph is represented by a different motor program in long-term motor memory (Teulings, Thomassen, & Van Galen, 1986; Van Galen & Teulings, 1983).

In view of these findings, we hypothesized the existence of at least three different aspects determining the difficulty of response initiation of lower-case letters: (1) Spatial ambiguity: This factor concerns the widely investigated educational problem of letter reversals (Chapman & Wedell, 1972; Sharfman-Koenigsberg, 1973). Letters that are spatially ambiguous, i.e., that change into other letters after rotation (e.g., b, d, p, q) present a heavier load upon the motoric initiation process than letters whose identity stays unaffected by such spatial transformations (e.g., a, g, k, s). (2) Allographic variability: Letters having many lower-case allographs (e.g., r, s, t) are more complex than letters having only one lower-case allograph (e.g., e, j, o) because in the first instance the correct allograph has to be chosen from a number of alternatives, whereas in the second instance there are no other allographs from which to choose. (3) Contextual ambiguity: A third aspect of letter complexity that is important to elementary writing education is the contextual ambiguity of letters. Usually letters are not perceived in isolation. They are preceded and followed by other letters. When a letter has no context, as in many instances of elementary writing education, the form of the letter should be so distinctive that it cannot be mistaken for other graphemes. Letters that are dependent on contextual information for their recognition are, for example, the printed letters l, i, o, b, g, and q, which might, respectively, be perceived as the digits 1, 1, 0, 6, 9, and 9, as well as the printed letter x, which might be interpreted as a multiplication sign. Printed letters that might be regarded as contextually unambiguous are a, e, f, h, k, s, and z.

A factor that might also influence response-initiation time in our task is the frequency with which letters are used in written language. Van Galen (1980) has shown that frequently used graphemes are initiated faster than infrequently used graphemes insofar as frequency is defined by the number of times a letter has to be written within the experiment. By measuring the correlation between response-initiation times and letter frequencies in general, we investigated whether the frequency with which letters are used in written language has any relation to the ability of children to recognize letters and to retrieve the correct motor programs from memory.

The Motoric Complexity of Cursive Letters

In a study of repetitive writing behavior of primary school children (Meulenbroek & Van Galen, 1986), we investigated the motoric complexity of various cursive writting patterns (loops, arcades, wave forms, and zigzags). We observed that the speed and quality of wrist movements in the up-strokes of a zig-zag were higher than those of finger movements, which are responsible for the downstrokes of this pattern. The most difficult cursive writing pattern for primary school children appeared to be the wave form. We argued that the wave-form pattern called for uninterrupted monitoring of the continuously changing contributions of wrist and finger activity. Because of these results and considering the general maturational direction of motor development from proximal to distal (Gesell, 1940), we hypothesized that in learning cursive handwriting the motoric complexity of a cursive grapheme is determined by the amount of accurate finger movements that is needed to realize the grapheme. Thomassen and Teulings (1985) advised developers of writing curricula to refrain from using cursive letter forms with unnecessary high curvatures or sudden curvature changes because these aspects are motorically very demanding and time consuming. In our experiment, we investigated the motoric complexity of cursive letters by measuring the writing velocity in which they were written by normal school children and determining the relationship between these measurements and the realized writing dysfluency and maximum curvature data. We hypothesized that motorically complex letters would be written more slowly than less complex letters and that sudden curvature interruptions within grapheme segments would reflect a demand on distal finger activity.

Method

Subjects

Seventy-five children from an ordinary, urban, primary school served as subjects in the experiment. From grades 2–6, we selected 15 children per grade. The mean age of the subjects was 10 years, 0 months, with a range of 7 years, 4 months to 12 years, 9 months.

Procedure and Apparatus

All subjects performed the experiment in an air-conditioned, moderately lit, sound-proofed van. Each subject was seated on a school chair in front of a school desk, both adjusted to the body size of the subject. The visual stimuli consisted of two series of 26 slides. A slide projector projected the stimulus via a special mirror upon the writing surface of the desk. The projection contained no double reflections. On each slide, the contours of two adjacent, horizontally placed bright squares and one bright letter of a cursive or printed alphabet was depicted. Printed and cursive stimulus letters were familiar to the subjects because they were respectively chosen from the reading and writing curricula of the school. The mirror above the school desk was placed in such a manner that the projected body of the smallest letters was 5 mm on the writing surface and the area within the projected contours of the squares had a surface of 30 × 30 mm. The letter was always presented in the center of the left-hand square. The subject had to write the corresponding cursive grapheme in the center of the right-hand square.

All subjects were instructed to write the correct cursive grapheme as quickly as possible whenever a new letter was presented in the left-hand square. An Apple-2 microcomputer controlled the slide projection and the recording of the writing movements. The latter were sampled at a rate of 100 Hz by means of an Apple-2 XY tablet and a slightly thicker than normal ballpoint pen, which were both attached to the microcomputer. After the subject had completed a grapheme, the experimenter stopped the sampling period, which had a maximum duration of 6 seconds, and a high tone was presented as an indication for the subject to shift the non-ruled writing paper (format 4A) upwards to such a degree that the just written letter came to be situated above the two squares. An intertrial rest period of about 20 seconds was used to store the latency and the sampled writing movements on a diskette.

Printed and cursive stimulus letters were presented blockwise to all subjects and in a random order between subjects. Within the printed and cursive letter conditions, the letters of the alphabet were randomized for each subject. Each subject performed 52 trials and wrote, in a cursive manner, each letter of the alphabet twice, once after the presentation of a printed letter and once after the presentation of a cursive stimulus letter.

Data Analysis

Data analyses were performed by means of a VAX-11/750 computer after filtering the recordings with a low-pass filter of 12 Hz. On visual inspection, trials were scored as incorrect whenever the wrong cursive letter was produced or when the letter was incomplete according to the writing curriculum. The response-initiation time for each correct trial was determined, i.e., the time between the beginning of the presentation of a slide until the beginning of the first stroke of the produced grapheme. Each grapheme was then divided into a prefixed number of upgoing, downgoing, and/or horizontal segments by means of an interactive computer analysis system. This standard segmentation of the produced graphemes is depicted in Figure 2.

A distinction was made between the initial and final strokes of a grapheme and the body of the letter itself (see Figure 2). Because it was reasoned that in normal handwriting the movement dynamics of initial and final strokes are influenced by preceding and following letters, these strokes were excluded from the analyses.

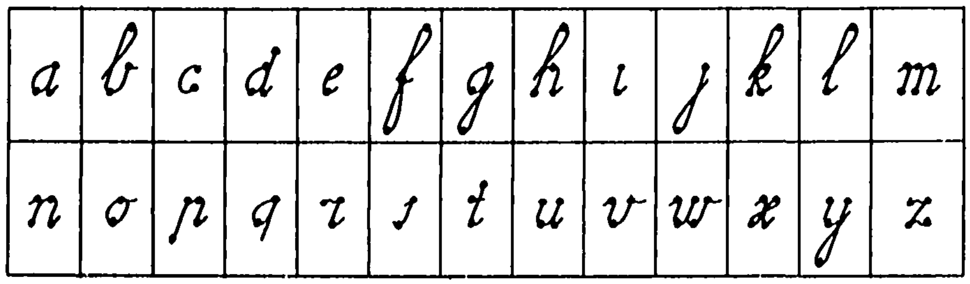

FIGURE 2. Segmentation of cursive graphemes in data analyses. Dots within the letters indicate segment boarders. Initial and final segments of the letters were excluded from the data analyses.

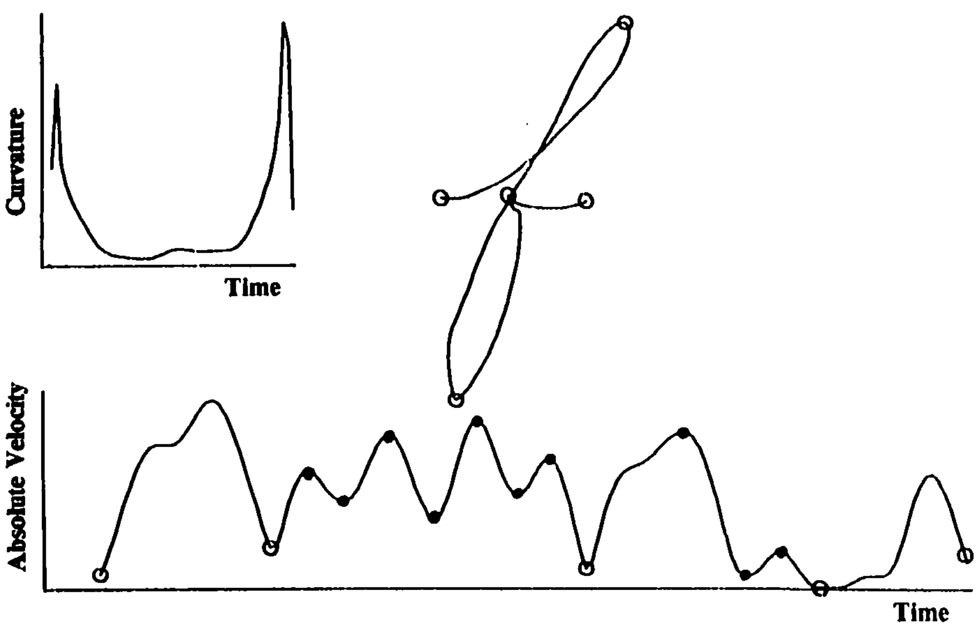

FIGURE 3. Overview of the analysis of one trial. The letter f (cut in four segments; open circles) and the corresponding velocity pattern of the writing movements (lower graph). Response-initiation time, movement time, distance, mean velocity, and dysfluency (number of velocity changes—closed circles—per cm) were calculated on the basis of the velocity pattern. Maximum curvature of the central downstroke of the grapheme f was calculated on the basis of the upper left graph.

Of each of the central grapheme segments depicted in Figure 2, the following measures were calculated: movement time, distance, mean velocity, maximum curvature, and dysfluency. An example of the analysis of one trial is depicted in Figure 3. The number of velocity changes per unit length (with exclusion of the velocity dips at the borders of the cut segments) was regarded to reflect the dysfluency with which grapheme segments were produced. It was reasoned that when more than one velocity change occurs during the production of a grapheme segment, motoric impulses interrupt the ballistic and fluent manner in which a handwriting stroke is normally produced (Meulenbroek & Van Galen, 1986, 1988).

Results and Discussion

Effects of Printed Versus Cursive Letter Presentation

Response-Initiation-Time Effects of Letter Presentation Mode. The mean response-initiation time in the printed letter condition was significantly higher than in the cursive letter condition (1.22 seconds and 0.93 second, respectively), $F(1, 74) = 86.48$, $p < .001$. This result corresponded with our hypothesis that in the printed letter condition children need more time to choose the correct motor program than in the cursive letter condition. No significant differences were found between these two conditions with respect to the mean movement time and number of velocity changes per produced grapheme. This means that the type of stimulus letter did not influence the time needed to perform the cursive letter nor the fluency with which it was written. Small but significant differences were found between the printed and cursive letter conditions in writing distance (2.035 cm and 2.121 cm, respectively), $F(1, 74) = 14.95$, $p < .001$, and writing velocity (1.623 cm/second and 1.723 cm/second, respectively), $F(1, 74) = 9.58$, $p < .01$. It has been shown that children perform longer cursive writing trajectories with somewhat higher writing velocities (Meulenbroek & Van Galen, 1986). The question remains why the subjects realized slightly longer writing trajectories in the cursive than in the printed letter condition. An explanation may be that the cursive stimulus letters contained longer trajectories than the printed stimulus letters. Although the height of the bodies of printed and cursive stimulus letters was equal, the actual trajectories of cursive stimulus letters were longer than of printed stimulus letters, especially in the case of extenders (i.e., letters containing ascenders--b, d, f, k, l, h—and descenders—f, g, j, p, q, y). Corpus-sized letters (i.e., a, c, e, i, m, n, o, r, s, u, v, w, x, z) were written with 1.9% longer writing trajectories in the cursive than in the printed letter condition, whereas extenders were written with 5.8% longer writing trajectories in the cursive condition.

Response-Initiation-Time Differences for Separate Letters. The upper graph of Figure 4 depicts the mean response-initiation time for each letter of the alphabet in the printed (open circles; dotted line) and cursive letter (closed

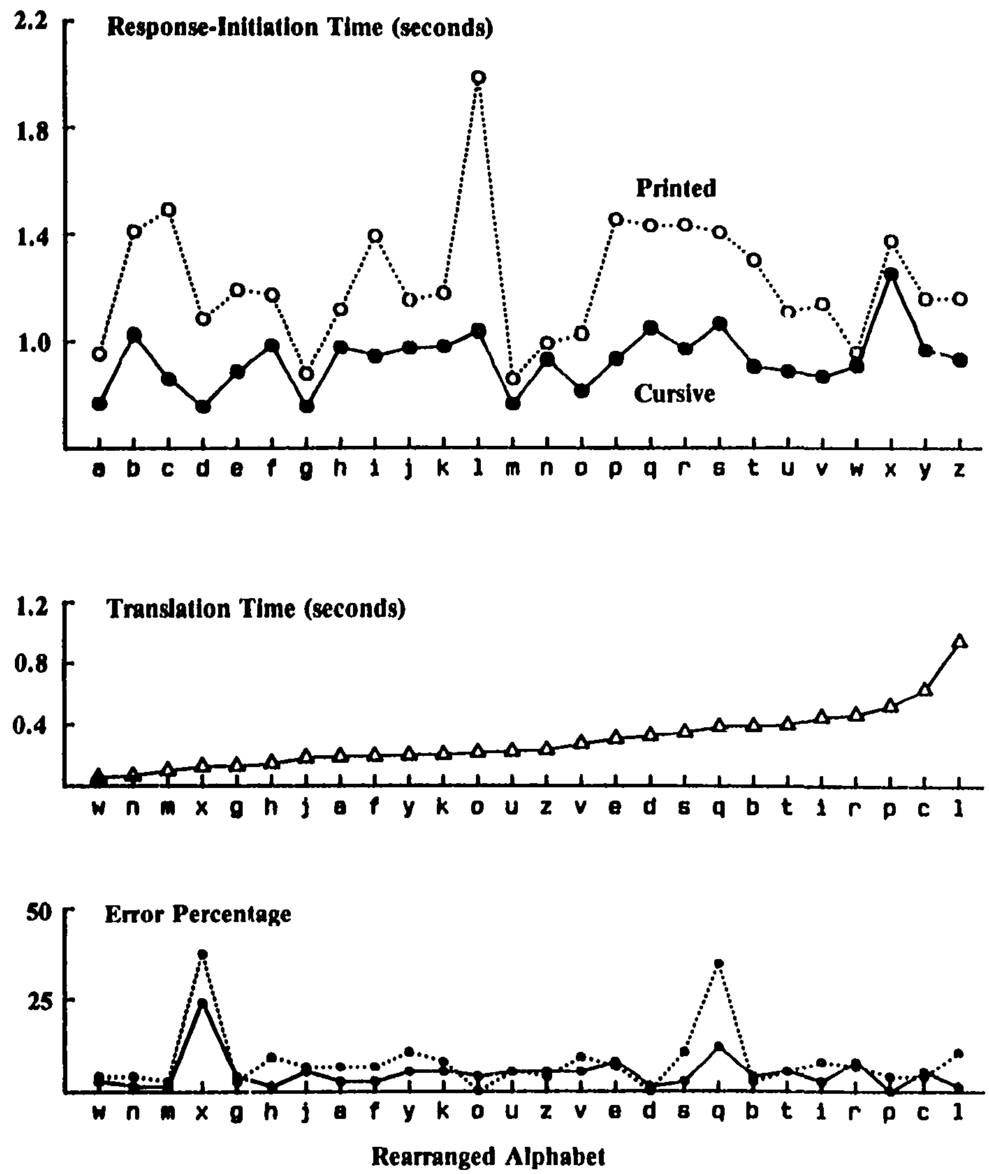

FIGURE 4. Upper graph: mean response-initiation time per grapheme in the printed (dotted line) and cursive (solid line) conditions. Middle graph: translation time per grapheme (i.e., response-initiation time in printed minus response-initiation time in cursive letter conditions). A rearranged order of the alphabet on the *x* axis has been chosen according to increasing translation times. Lower graph: Error percentage in printed (dotted line) and cursive (solid line) letter conditions as a function of the rearranged alphabet.

circles; solid line) conditions. For all letters, the mean response-initiation time in the printed letter condition was longer than in the cursive letter condition.

The mean translation time (i.e., the response-initiation-time difference between the printed and cursive conditions) for each letter is depicted in the middle graph of Figure 4. In this graph, a rearranged order of the alphabet has been chosen according to an increasing translation-time criterion. According to our assumptions, these results reflect the time subjects need to perform a cognitive translation process from the graphemic to the allographic level. It appears from the analyses that the spatially ambiguous letters b, d, p, q need more time to be converted from the printed to the cursive form than the spatially unambiguous letters a, g, k, s. The mean translation-time difference was 0.193 second ($t = 4.51$, $p < .01$). Further, it appears that the letters b, d, p, q, which are spatially ambiguous along the vertical axis, need longer translation times than the letters m, n, u, w, which are ambiguous along the horizontal axis. The difference in translation times between these latter two groups of letters was 0.253 second ($t = 4.58$, $p < .01$). This suggests that reversals of spatially ambiguous letters are mainly caused by mirror reversions along the vertical dimension and not along the horizontal dimension. This result corresponds with the findings that, in children as well as adults, up-down discrimination is superior to left-right discrimination (Flanders, 1976). The middle graph also shows that letters with a relatively large number of allographs (r, s, t) need longer cognitive translation times than letters with only one allograph (e, j, o). The mean difference amounted to 0.146 second ($t = 2.75$, $p < .01$). Finally, this graph shows that contextually ambiguous letters (b, g, i, l, o, q, x) require longer cognitive translation time than contextually unambiguous letters (a, e, f, k, h, s, z). This difference amounted to 0.127 second ($t = 3.32$, $p < .01$).

For each of the 75 subjects, the correlation between response-initiation time per letter and letter frequency was calculated in the printed and cursive conditions. In the printed letter condition, 28 positive and 47 negative correlations were found (sign test: $p < .05$), with a mean correlation of $Rxy = -.061$. In the cursive condition, 17 positive and 58 negative correlations were found (sign test: $p < .01$), with a mean of $Rxy = -.116$. The lower graph of Figure 4 shows that the infrequent letters x and q were incorrectly performed in many cases. The total error percentage was 8.1% in the printed letter condition and 4.9% in the cursive letter condition. Apart from these two letters, it appeared that a positive correlation of 0.21 was present between translation times and total number of incorrectly performed trials. These results show that, in general, letter frequencies influenced response-initiation time significantly in such a manner that more frequently used letters were retrieved more quickly from memory than less frequently used letters.

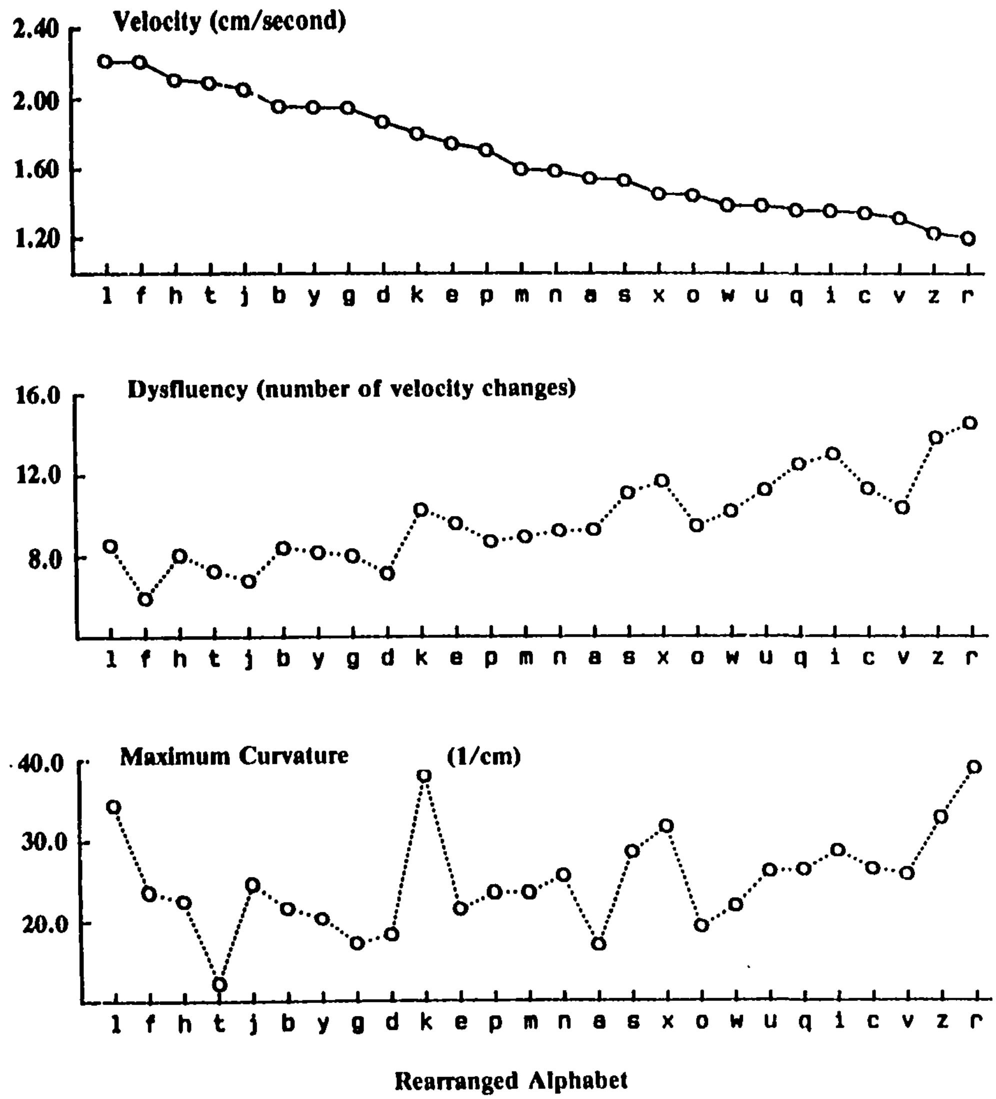

FIGURE 5. Mean writing velocity (upper graph), writing dysfluency (middle graph), and maximum curvature (lower graph) as a function of the letters of the alphabet. The rearranged alphabet on the *x* axes reflects an order of decreasing writing velocities.

Analysis of Writing Trajectories

Motoric Complexity of Cursive Graphemes. Figure 5 depicts the realized writing velocities (upper graph), writing dysfluency data (middle graph), and the maximum curvature data (lower graph). The letters depicted on the

x axes of the graphs of Figure 5 were rearranged according to a decreasing writing speed criterion. Negative correlations were found between the velocity and dysfluency measurements ($Rxy = -0.789$, $p < .01$) and between the velocity and maximum curvature measurements ($Rxy = -.415$, $p < .01$). A positive correlation was found between the dysfluency and the maximum curvature measurements ($Rxy = .387$, $p < .01$). According to our assumptions, the rearrangement of the alphabet on the x axes of the graphs in Figure 5 reflects an order of increasing motoric complexity of cursive graphemes. The most complex letters were r and z. These letters are the only two letters of the alphabet of the writing curriculum containing horizontally oriented wave-form segments. This result corresponds with earlier findings concerning motoric complexity of wave-like patterns (Meulenbroek & Van Galen, 1986). With the exception of the letter q, all extenders were written with higher writing velocities than corpus-sized letters. It appears that extenders are easier to write than corpus-sized grapheme segments, probably because the longer trajectories of ascenders and descenders elicit faster and more fluently performed writing movements. Data that justify this interpretation can be observed in the lower two graphs of Figure 5. The letters k, s, and x are relatively dysfluent and written with high maximum curvatures. The letter k is a relatively difficult letter to write because of the combination of an ascender and a very demanding body with sudden changes in rotational direction. The letters s and x also contain changes of rotational complexity within one stroke and are, therefore, also relatively complex.

Developmental Aspects

We reported about the developmental aspects of the data of the present experiment in Meulenbroek and Van Galen (1988). It appeared that there was a significant main effect of grade level on response-initiation times, $F(4, 70) = 7.46$, $p < .001$, with a linear decreasing trend, $F(1, 70) = 2.31$, $p < .001$. No interaction was found between grade level and stimulus presentation mode on response-initiation time. Significant decreasing quadratic age trends were found in movement time, velocity, maximum curvature, and dysfluency data, again with no significant interactions with stimulus presentation mode. With increasing age, the maximum curvature of grapheme segments decreased, whereas the minimum curvature increased. This means that young children performed cursive graphemes with relatively straight trajectories and sudden changes, whereas older children realized medium curved trajectories instead of straight segments and avoided strong curvature changes. These results were extensively discussed in Meulenbroek and Van Galen (1988).

Conclusions and Educational Implications

In this experiment, primary school children wrote single cursive graphemes under speed instructions after presentations of printed and cursive letters. An analysis of response-initiation-time differences between the printed and cursive letter conditions revealed a number of factors that, according to our assumptions, influenced the duration of a cognitive translation process from the graphemic to the allographic level. These factors were spatial ambiguity of allographs, number of lower-case allographs of a grapheme, contextual ambiguity of allographs, and letter frequency. Although no attempt was made to determine the weight with which each factor contributed to the overall complexity of a letter, our data showed that spatially ambiguous letters, letters having many lower-case allographs, context-dependent letters, and seldomly used letters required relatively long preparation intervals. The aforementioned complexity factors might be called within-letter-mode factors. It might be argued that another complexity factor, the between-letter-mode factor similarity, could have influenced the translation time. One might expect a small translation time when the printed and cursive forms of a letter are similar. However, the reverse appears to be the case. The data show that translation time is relatively large with letters whose printed and cursive forms are similar (c, i, q) and relatively small with letters whose printed and cursive forms are dissimilar (a, f, g). The mean difference in translation time between these two groups of letters was 0.239 second ($t = 4.20$, $p < .01$). This result shows that the distinctiveness of a letter form, within as well as between letter modes, is an important aspect determining the ease with which the letter is recognized and retrieved from memory.

It might also be argued that the ecological validity of the present experiment would have been higher if not only a visual presentation mode were used. Teachers normally introduce the visual form of a letter together with its acoustical form. The fact that letters were not verbally presented in this experiment might have been the reason for the relatively long response-initiation times. However, it must be recognized that in writing education a reasonable amount of time is spent by pupils in practicing the writing of letters without verbal assistance of the teacher. In these situations, pupils cannot rely on acoustical information, and visual aspects of the task become more important. Secondly, our experimental procedure has ecological validity for computer-assisted writing education, which presently is based more on visual than on acoustical instructions (Plamondon, Suen, & Simner, 1989).

The motoric complexity of cursive graphemes was investigated by comparing the writing velocities, dysfluency measurements, and the maximum curvature data of the produced letters of a cursive alphabet. It appeared that the cursive graphemes r and z, two graphemes containing small, horizontally oriented, wave-like segments, were performed with the slowest writing velocity. Graphemes containing ascenders and descenders (i.e., extenders) were written relatively quickly because these graphemes contain relatively long segments that can be produced with higher writing velocities as compared with more strongly curved corpus-sized graphemes that require slower writing movements. It should be mentioned that the exact form of the trajectories of cursive letters is culture as well as curriculum dependent.

The results of this experiment offer us an opportunity to advise developers of reading and writing curricula to take into consideration the cognitive complexity factors of letter forms when they determine the order in which single letters appear in the curriculum. When we let this sequence be determined by complexity, i.e., first the simple letters and then the more complex letters or when printed and cursive letters are introduced simultaneously, the order that is depicted in the middle graph of Figure 4 might be recommended. This recommendation is especially relevant for those countries in which the first 3 or 4 years of writing education consist of writing printed letters. When a curriculum is being developed solely for learning cursive handwriting, the order that is depicted in Figure 5 might be a sequence that guarantees that motorically less complex cursive letters precede the motorically more complex ones. Furthermore, the results of this experiment might be used for minor but motorically important changes in cursive letter forms themselves to ensure that they elicit compatible, fast, and fluent writing movements. The negative correlation between realized curvature and writing velocity of the produced cursive writing segments suggests that cursive letter forms should not contain unnecessary high curvatures and sudden curvature changes within the up- and downgoing letter segments. The results showed that cursive letters should not contain straight trajectories because cursive grapheme segments were produced by older children with slightly curved movements instead of straight lines. A few examples for cursive letter improvement are shown in Figure 6.

Finally, the present results suggest a number of recommendations for the teacher teaching children the complex psychomotor skill of handwriting. At the introduction of a new letter form in primary handwriting education, the teacher should emphasize the identity of the letter instead of comparing the letter with letters that were practiced earlier. This might prevent a number of letter confusions. The relationship between the sound and the form of the letter and the graphic features of the letter can be discussed instead. For the same reason, it is advisable to avoid the presentation of a sequence of spatially ambiguous letters. After having taught the letter b, the teacher should not continue with the letter d but first pay attention to a totally dif-

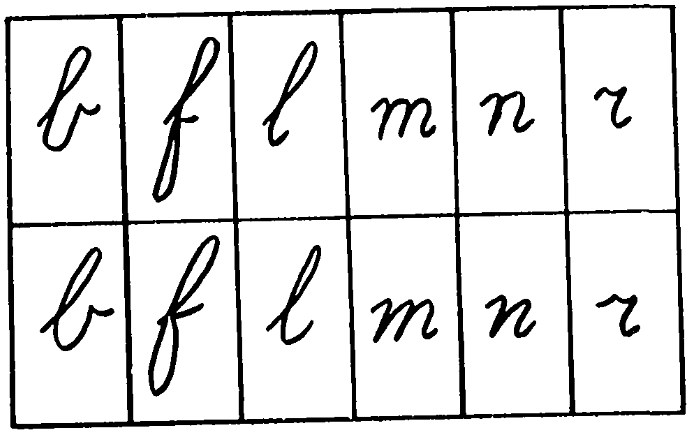

FIGURE 6. Examples of the improvement of cursive letter forms on the basis of the reduction of unnecessary and strong curvature in letter segments. The upper row represents original models of cursive letter forms as used in a Dutch writing curriculum. The lower row represents improvements of these forms as far as straight trajectories are replaced by slightly curved trajecto..es and strong curvature changes within the up- and downgoing segments have been avoided.

ferent letter form, e.g., the letter f. When a number of context-dependent letters have already been learned, the context-dependent letters (l, i, o, b, g) might be presented with context, e.g., in small words.

Teachers should also be aware of the important relationship between the curvature of letter strokes and the ease with which these strokes can be written. High curvatures are produced in low speed and low curvatures are produced in high speed. If we assume that the motoric characteristics of the handwriting of a teacher is imitated by pupils to a reasonable degree, then it is justified to recommend that the teacher demonstrate the dynamic aspects of handwriting in an efficient manner. Our analyses suggest that each stroke should, as much as possible, be executed by means of a single motoric impulse. On the basis of a decision about where the stroke ends, an increase of velocity must be initiated at the beginning of the stroke and, subsequently, a decrease of velocity should be initiated when the penpoint is in the middle of the stroke. The stroke is completed when the speed of the penpoint is at a minimum or almost zero. Showing pupils this kind of handwriting production might prevent mere copying or tracing letter models in continuously low speeds (Meulenbroek, 1989).

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