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Visual perception of motor anticipation in cursive handwriting: Influence of spatial and movement information on the prediction of forthcoming letters

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Abstract. The execution of a graphemic sequence is constrained by spatial demands that result in fluctuations of letter shape and movement time. When producing two letters (*ll*, *le*, or *ln*) the movement time and the letter shape of the first letter depend on the execution constraints of the second one. The motor system thus anticipates the production of the forthcoming graphemic sequence during the production of the first letter. An experiment is reported the aim of which was to examine whether the visual system could exploit this anticipatory information to predict the identity of the letter following the *l*. Different *l*s belonging to *ll*, *le*, and *ln* were presented on a screen. Subjects had to predict to which couple of letters (*ll*, *le*, or *ln*) the presented *l* belonged to, by using information on the shape of the *l* and/or the movement that produced it. Results showed that the percentages of correct responses were higher in the conditions where the stimulus provided kinematic information than in the condition in which only spatial information was available. The ability to predict the forthcoming letter seems to be mediated by implicit knowledge on motor anticipation rules.

1 Introduction

Studies relating to word or letter identification have been widely influenced by feature-analysis theories (eg Gibson and Levin 1975). According to these theories, recognition of a letter involves previous perception of its spatial components. For example, uppercase block letters are characterised by several distinctive features—orthogonal or oblique lines, symmetry axis, differences between open and closed curves—and character recognition would consist in detecting and analysing these different features. However, studies of the ability with which the visual system recognises cursive handwritten letters in spite of shape variability, due in particular to between-letter context effects (Wing 1979; Thomassen and Schomaker 1986), showed that the visual system could also be sensitive to the handwriting production rules (Freyd 1987; Babcock and Freyd 1988; Wada et al 1995).

Indeed, several studies from different domains suggest that the visual perception of graphic traces could be partly influenced by knowledge relative to the movements involved in handwriting production. Babcock and Freyd (1988) have shown that the shape of artificial handwritten characters is subject to specific spatial distortions related to the movement that produced them. These distortions provide information on stroke order and on stroke direction, and this information may be used by the visual system to recognise the character. According to the authors, this ability to extract 'dynamic information' from the graphic traces does not involve a conscious knowledge of the production processes but seems rather to depend on an implicit knowledge of these processes. Similar results have been observed with meaningful characters. In the recognition of Chinese logograms, for instance, the visual system is particularly sensitive to stroke order (Fores d'Arcais 1994). The order of stroke writing is an essential component of the orthographic knowledge of a character and this cue is used in lexical retrieval. Information on the production movement can also be used when a character is difficult to read. Paleographers often use the information provided by the upstrokes and downstrokes produced by the pen of the scribe (the ductus) for deciphering ancient texts (Shailor 1987; Friedman 1992, 1994). When a character is unreadable, this information enables the paleographer to infer the movement the scribe executed to trace it. Finally it is noteworthy that the information relative to the production process is also used in the automatic recognition of connected cursive handwritten characters. Wada et al (1995) have shown that the automatic recognition of a sequence of letters could be optimised by extracting some points of the trajectory considered as representative of the movement-pattern generation. Taken together, these data showed that 'dynamic information' contained in a static graphic trace could be extracted to identify a character.

The idea that recognition processes are mediated by knowledge of the underlying production rules is also supported by research on the visual perception of dynamic stimuli. Viviani and Stucchi (1989) have shown that the visual perception of the trajectory of a simple geometrical figure is influenced by implicit knowledge about the laws of graphic production. Their study focused on one of them, the 'two-thirds power law' (Lacquaniti et al 1983), which specifies that the velocity of graphic movements involving the hand–arm system is a function of the curvature of the trajectory. The velocity of a movement drawing a circle is therefore constant, whereas the velocity of a movement tracing an ellipse decreases when the radius of curvature decreases. In their experiment, Viviani and Stucchi presented a spotlight that traced an ellipse. The eccentricity of the ellipse was reduced after each trial. The velocity profile of the trajectory remained constant, ie it corresponded to the one observed in the production of the first ellipse. The results indicated that when the eccentricity was so reduced that the spotlight traced a circle, subjects tended to perceive an ellipse instead of a circle. Thus, when the kinematics of the presented movement was in disagreement with the two-thirds power law, geometric illusions were elicited. These results showed that visual perception is not only influenced, but is also constrained, by the knowledge of the laws of graphic production.

In summary, studies on the visual perception of static and dynamic graphic traces suggested the importance of motor knowledge in perceptual processes (Prinz 1990, 1992; Viviani and Stucchi 1992; Freyd 1987, 1993). Several authors have suggested (Cooper 1992; Prinz 1992; Shiffrar and Freyd 1993) that this knowledge could be used to anticipate forthcoming motor sequences when perceiving human movement. For example, in audiovisual speech perception the perceivers can predict the identity of the forthcoming sound well before its acoustic onset by exploiting information on labial anticipatory movements. During the French 'i'-to-'ou' transitions, the perception of the vocalic rounding gesture during the acoustically silent pause allows the identification of the 'ou' up to 160 ms before the sound (Abry et al 1994).

Our research was carried out within this theoretical framework. It aimed at studying the visual perception of motor anticipation in handwriting. We investigated in particular whether the visual system could exploit anticipatory between-letter effects that affect timing of handwriting production.

Cursive handwriting implies the production of continuous sequences of letters varying in shape and size. Several studies have shown that the shape and kinematics of a letter fluctuate as a function of the production of surrounding letters (eg Thomassen and Schomaker 1986). More recently, Boë et al (1991) observed that in the reproduction of the letter *l* the movement time of the downstroke was a function of the spatial constraints of the following letter. Changes in size (*ll* vs *le*) as well as in size and rotation direction (*ll* vs *ln*) entailed temporal differences in the downstroke of the *l*. The duration of the downstroke of the *l* was shorter when it was followed by another *l* than when it was followed by an *e*. In turn, the duration of the downstroke of the *l* followed by an *e* was shorter than when the *l* was followed by an *n*. This indicates that the motor system anticipates the following letter while writing the *l*. Therefore, the kinematic pattern of the production movement of a letter varies according to the specific motor adjustments that are essentially due to spatial contextual constraints.

If the perception of graphic handwritten traces is mediated by knowledge of the underlying production rules, the visual system should detect information on anticipatory movements and exploit it to predict forthcoming motor sequences. The experiment presented in this paper aims at showing that the spatial and/or movement information contained in the *l* could be used to predict the identity of forthcoming letters.

2 Method

2.1 *Subjects*

Forty-three right-handed volunteer subjects, between 20 and 32 years old, participated in the experiment. Among these subjects, there were thirty-five school teachers who participated in the first part of the experiment. The aim of this first part was to prepare the stimuli used in the second part of the experiment. The remaining eight subjects participated in the second part of the experiment, ie the perceptive task. They were students in several domains and they had no particular knowledge concerning movement control or visual perception.

2.2 *Preparation of the stimuli and procedure*

Thirty-five primary school teachers wrote three times the digrams *ll*, *le*, and *ln* on a sheet of paper. They were asked to write the digrams between two horizontal lines, (spaced 6 cm apart), at normal speed, as if they were preparing an exercise for their pupils. The shape of the *l* was analysed according to different geometric measures. Results indicated that the parameters that differentiate the shape of the *l* in the three contexts were essentially the slant of the *l* with respect to the baseline and, to a lesser extent, the amplitude of its loop. We then selected a subject who produced the *l* that corresponded most closely to the mean parameter values.

This subject was asked to write ten times each digram (*ll*, *le*, *ln*) on a digitiser (Wacom SD; sampling frequency, 200 Hz; spatial precision, 0.2 mm). The data were stored and processed on a Vx Macintosh. Software was used to display the graphic trace and the velocity profile as shown in figure 1.

As in Boë et al (1991), kinematic analysis revealed that the writing speed of the *l* was determined by the spatial characteristics of the following letter. The movement time of the downstroke of the *l* was shorter when it was followed by an *l* than when it was followed by an *e*. In turn, the downstroke movement time was shorter when the *l* was followed by an *e* than when it was followed by an *n*. These results confirmed that the preparation of the second letter is partly carried out during the production of the downstroke of the *l*.

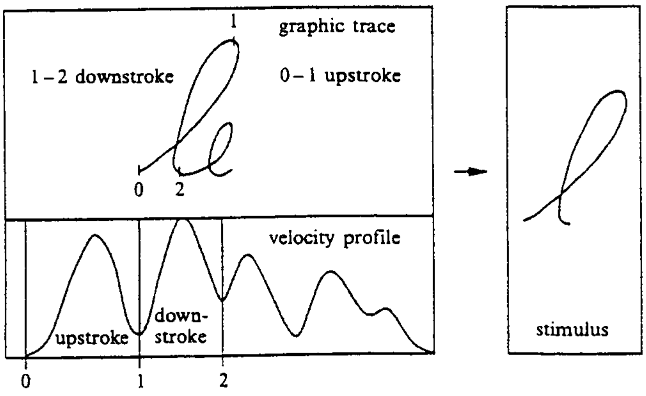

Figure 1. Display of the graphic trace and velocity profile.

We chose the *l* whose movement times were the closest to the mean values of the subject's productions (240 ms for the *l* of *ll*, 315 ms for the *l* of *le*, and 380 ms for the *l* of *ln*). Three *l*s, one from each digram, were thus selected. The three digrams were then cut at the lowest point of the downstroke of the *l*s, ie when velocity was minimum (see figure 1). These stimuli were used in the first two experiments.

The experiment was run in a HyperCard 2.2 environment, with a PASCAL extension (XFCN) that enabled the reproduction of the exact size, velocity, and temporal course of the original productions on the screen of the computer. In the first experimental condition (see figure 2), the *l*s were presented with the *shape + movement* differences of the original productions. Each *l* was progressively traced on the screen. When the lowest point of the downstroke was reached, the *l* disappeared and the subject was asked to predict to which of the three digrams (*ll*, *le*, *ln*) the presented *l* corresponded. In the second experimental condition, the *l*s contained only the *shape* differences observed in the original traces (see figure 2). The *l*s were flashed on the screen without any kinematic information. The presentation time corresponded to the movement time of the original productions, ie 240 ms for the *l* of *ll*, 315 ms for the *l* of *le*, and 380 ms for the *l* of *ln*. Again, the subject's task was to predict the identity of the letter following the *l*.

A third experimental condition was prepared to examine the role of *movement* information. The subject who produced the stimuli for the first two conditions was asked to write each digram ten times on the digitiser. He was instructed to try to write all the *l*s as similar to each other as possible. These productions were then cut at the lowest point of the downstroke of the *l* and presented on the screen without any kinematic information (as in the *shape* condition) to thirteen subjects. These subjects were asked to predict to which of the three digrams (*ll*, *le*, *ln*) the presented *l* corresponded. This preliminary test aimed at selecting three 'neutral' shapes, ie *l* shapes that could not be identified as belonging to any of the three digrams. Three *l*s were thus selected, one for each digram. The kinematic analysis of the *l* showed, as in Boë et al (1991), that the movement time of its downstroke varies according to the spatial constraints of the following letter. Although the shapes of the selected *l*s were very similar, they were slightly modified in order to obtain a strictly identical *l* shape. Therefore, in this *movement*

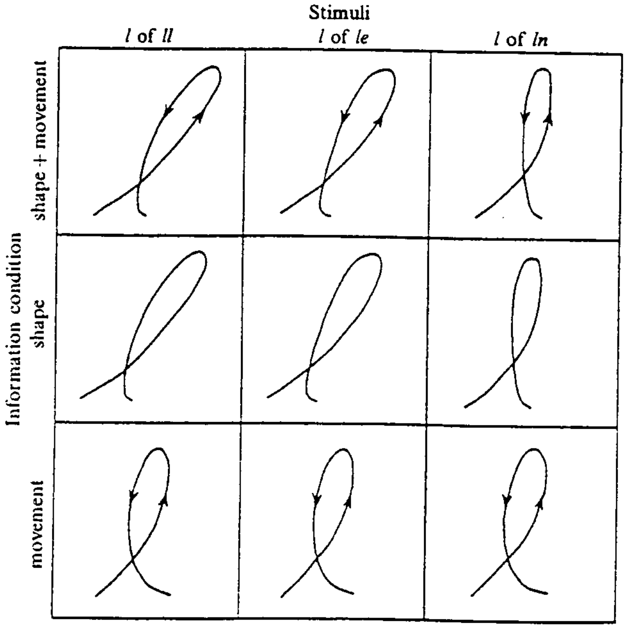

Figure 2. Shape and movement differences in the original traces.

condition, the *l*s had the same shape but three different kinematic patterns (see figure 2). The downstroke durations of the *l* of *ll*, *le*, and *ln* were respectively 250 ms, 310 ms, and 370 ms, ie they were similar to those presented in the *shape + movement* condition.

As in the first condition, each *l* was progressively traced on the screen and disappeared when the lowest point of the downstroke was reached. The subject then had to predict whether the presented *l* belonged to *ll*, *le*, or *ln*.

Each subject performed the three conditions (*shape + movement*, *shape*, *movement*) in a counterbalanced order. There were 36 random trials in each condition (12 for the *l* of each digram). The experiment therefore consisted in 108 trials. No feedback of results was given to the subjects.

3 Results

3.1 *Percentage of correct responses*

The percentages of *ll*, *le*, and *ln* responses as a function of stimuli (*l* of *ll*, *le*, or *ln*) and of experimental condition (*shape + movement*, *shape*, *movement*) are shown in figure 3. The correct responses are indicated by arrows. When the stimulus contained only information on the *shape* of the *l*, the percentage of correct responses, although higher than 33% (52% for the *l* of *ll*, 41% for the *l* of *le*, 34% for the *l* of *ln*), did not statistically differ from chance (*t* not significant at $p < 0.05$ for each of the three *l*s). In addition, the variability of the responses in the *shape* condition was much higher than in the other two conditions. This was due to differences in the subjects' response strategies. For example, when the *l* of *ln* was presented, four subjects responded 85% correct whereas three subjects responded 10% correct. A similar pattern of results was observed for the *l*s of *ll* and *le*. These results indicated that the subjects perceived the shape differences between the *l*s, selected a response (either *ll*, *le*, or *ln*) and tended to respond in the same manner throughout the whole experimental condition even if this response was not the correct one. Only one subject scored 33% of correct response, ie responded at random.

In the *shape + movement* condition, the percentages of correct response (75% for the *l of ll*, 72% for the *l* of *le*, 88% for the *l* of *ln*) were above chance (*t* significant at $p < 0.01$ for all stimuli). The same pattern of results was observed in the *movement* condition (68% for the *l* of *ll*, 65% for the *l* of *le*, 70% for the *l* of *ln*). This showed that subjects could predict the identity of the letter following the *l* just by using the

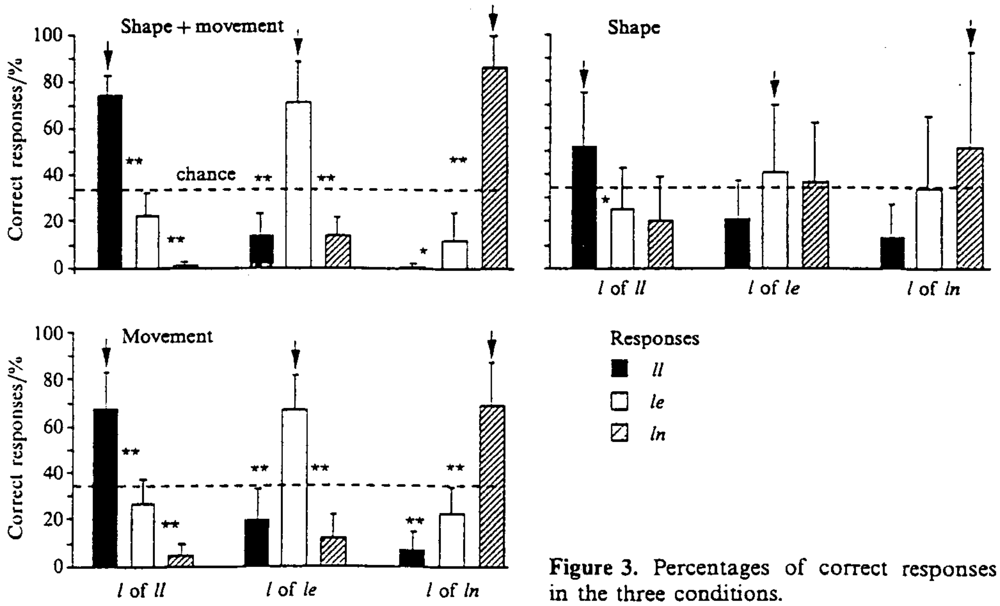

Figure 3. Percentages of correct responses in the three conditions.

information on the production movement. However, it is noteworthy that the percentages of correct responses for the *shape + movement* condition (mean = 78%) were higher than in the *movement* condition (mean = 68%) ($F_{1,23}$, $p = 0.03$). Therefore, the spatial information contained in the *l* entails improved the performances.

3.2 *Percentage of incorrect responses*

The analysis of the pattern of incorrect response confirmed the above results. At the production level, it was shown that the movement time of the downstroke of the *l* followed a *ll* < *le* < *ln* hierarchy. Percentages of incorrect responses indicated that this hierarchy was observed at the perceptual level as well.

In the *shape + movement* condition, when the presented *l* belonged to *ll*, *le* responses were less frequent than *ll* responses ($t_7 = 7.85$, $p < 0.01$) but were more frequent than *ln* responses ($t_7 = 3.98$, $p < 0.01$). The same pattern of results was observed for the *l* of *ln*. Indeed, *le* responses were less frequent than *ln* responses ($t_7 = 2.51$, $p = 0.04$) but more frequent than *ll* responses ($t_7 = 7.53$, $p < 0.01$). This means that the less frequent responses corresponded to the stimulus that was kinematically the least compatible with the correct response. For the *l* of *le* we observed that the movement time was intermediate with respect to the movement time observed for the *l*s of *ll* and *ln*. This observation at the production level was also reflected at the perceptual level. The percentages of *ll* and *ln* responses for the *l* of *le* were not significantly different but they were less frequent than *le* responses ($t_7 = 7.02$, $p < 0.01$ and $t_7 = 7.71$, $p < 0.01$, respectively).

In the *movement* condition, the results were similar to those obtained in the *shape + movement* condition. For the *l* of *ll*, *le* responses were less frequent than *ll* responses ($t_7 = 4.26$, $p < 0.01$) and more frequent than *ln* responses ($t_7 = 5.23$, $p < 0.01$). When the *l* belonged to *ln*, the inverse hierarchy was observed (*ln* > *le* > *ll*, $t_7 = 3.63$, $p < 0.01$ and $t_7 = 4.44$, $p < 0.01$). For the *l* of *le*, *ll* and *ln* responses were not different but they were less frequent than *le* responses ($t_7 = 4.70$, $p < 0.01$ and $t_7 = 7.66$, $p < 0.01$, respectively).

Finally, in the *shape* condition the same tendency was observed but the results were statistically different only for the *l* of *ll*. For this stimulus, *ll* responses were higher than *le* responses ($t_7 = 2.49$, $p = 0.04$). For the other two stimuli the results were similar to those obtained in the latter conditions but none of the statistical comparisons was significant at $p < 0.05$.

4 Discussion

The aim of this study was to show that the visual system could detect the spatial and kinematic differences observed in the production of the letter *l* written in three different contexts (*ll*, *le*, *ln*), and exploit them to predict the identity of the subsequent letter. Results showed that the percentages of correct responses were higher in the conditions where the stimulus provided kinematic information than in the condition in which only spatial information was available.

In the *shape* condition, correct responses did not differ from chance and were less frequent than in the other two conditions. This indicates that the anticipatory information available in the spatial configuration of the *l* is not easily exploited to predict the identity of the following letter. The subject does perceive the shape differences, but these differences do not provide enough information for predicting clearly the identity of the forthcoming letter. It seems therefore that the contextual shape fluctuations of the handwritten letters—at least the fluctuations due to motor anticipation in handwriting—are more difficult to exploit than the spatial distortions that provide information on stroke order and direction of the production movement (cf Babcock and Freyd 1988). This could be due to the fact that handwriting is extremely personal. In other words, the shape fluctuations presented in our experiment could differ consistently from the subject's own shape fluctuations and thus prevent him/her from recovering knowledge on production rules. The distortions specifying stroke order and direction could be easier to exploit because they are less personal and rely on a 'grammar of action' (Goodnow and Levine 1973) that specifies the movement sequencing in most graphic productions (Van Sommers 1984; Thomassen et al 1991). Consequently one may suppose that, as was shown in a study on the visual perception of locomotion movements (Beardworth and Bukner 1981), the subject's performance would be better when he/she is presented his/her own productions than when other people's movements are presented. If this was the case, it would show that the knowledge of production rules was not only due to visual learning but depended in part on knowledge of one's own motor productions. Such a result would signify the motor processes entered in the genesis of percepts. It would provide support for motor theories of perception discussed primarily in speech perception (Liberman and Mattingly 1985) and developed more recently in the neurophysiology of human movement perception (Rizolatti et al 1996).

The results for the *shape + movement* and *movement* conditions indicated that the visual system detected the kinematic differences observed in the downstroke of the *l* of each digram and exploited them to predict the identity of the following letter. Furthermore, the hierarchic pattern of response in both experimental conditions suggested that the use of kinematic information was rather precise. Indeed, the hierarchy observed at the perceptual level reflected the hierarchy observed in the production movements. Kinematic information is therefore essential for the prediction of the following letter. However, the percentages of correct responses for the *shape + movement* condition are higher than those observed for the *movement* condition. This result suggests that spatial information concerning motor anticipation in handwriting improves performances when it is combined with information on the kinematic pattern of the handwriting movement. As suggested by Shiffrar (1994), the perception of human movement would involve a convergent processing of spatial and movement information.

Finally, it is noteworthy that mean percentages of correct responses did not change from trial to trial. Thus, the ability to anticipate the forthcoming letter was not learned throughout the experiment. In addition, subjects reported that they had the impression of responding at random throughout the whole experiment. They were not aware that they predicted correctly the identity of the letter following the *l* in the *shape + movement* and *movement* conditions. This indicates that, when perceiving the production movement of an *l*, subjects use from the beginning of the experiment an implicit knowledge relative to the way the digrams have been written. This corroborates the results obtained in static-graphic trace recognition (Babcock and Freyd 1988) and in dynamic-form perception (Viviani and Stucchi 1992).

Taken together, our results therefore show that the knowledge of anticipating motor rules allows the prediction of the forthcoming components of the motor sequence. However, further investigations are necessary to specify what kinematic parameters (movement time, amplitude of peak velocity, timing of velocity profile) and spatial cues (curvature and slant of the letters, variations of line thickness) influence this perceptive anticipation. Moreover, it would be interesting to attempt to replicate the present results with other letter pairs in order to analyse what spatial and kinematic cues are exploited by the visual system in other between-letter contexts.

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