

Detecting anticipatory events in handwriting movements[†]

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Abstract. We investigated how visual processes exploit specific anticipatory movements observed in handwriting gestures. Previous research has shown that the kinematic information contained in the downstroke of an *l* is exploited to predict the identity of the forthcoming letter. Here, we determined the moment at which prediction takes place. Two between-letter effects were examined: changes in size (*ll* vs *le*) and changes in rotation direction (*le* vs *ln*). Results show that with only 75% of the *l* downstroke trajectory (or 60% of the downstroke time) subjects are already capable of predicting the identity of the letter following the *l*, that is well before the end of the downstroke. Analysis also reveals that identification takes place after the presentation of the movement acceleration phase. The visual perception of motor anticipation seems to involve the detection of motor events.

1 Introduction

Research presented by Jennifer Freyd (1983a, 1983b) first demonstrated that observers use motor knowledge when decoding static handwritten material. Babcock and Freyd (1988) showed that the spatial distortions produced during movement execution provide information on the direction of the motor sequence and stroke order. This information is exploited during the recognition of artificial characters. Furthermore, knowledge of the underlying production method is particularly relevant for character discrimination (DeKay and Freyd 1991). In the recognition of Chinese logograms, perceptual processes are also sensitive to stroke order, ie to information on the underlying motor sequence (Flores d'Arcais 1994). Moreover, palaeographers often use the information provided by the upstrokes and downstrokes followed by the scribe's pen (the ductus) for deciphering ancient texts (Shailor 1987; Friedman 1992, 1994). When a character is difficult to read, this information enables the palaeographer to infer the movement the scribe executed to trace it. The analysis of movement trajectory constitutes the means by which the character is identified. These studies therefore show the importance of motor information in the perception of static graphic material.

Other studies on the visual perception of dynamic graphic material confirm that visual processes can use motor information. Drawing movements follow a systematic relation between movement velocity and the geometry of its trajectory (Viviani and Terzuolo 1982; Lacquaniti et al 1983). Thus, a circle is drawn at constant velocity whereas the velocity of the graphic movement when drawing an ellipse decreases in the curved regions and increases in the more linear ones. Viviani and Stucchi (1989) showed that spotlights tracing circles were perceived as tracing ellipses when the kinematics of the presented movements corresponded to those of a human drawing ellipses.

[†] A pre-test for this research has been reported in Kandel, Boë, Orliaguet, and Zesiger, 1995 "Visual recovery of motor anticipation in handwriting: Analysis of threshold detection", in *Proceedings of the 7th International Conference on Handwriting and Drawing, 6–10 August* (London, Ontario: International Graphonomics Society) pp 56–58.

In other words, the geometric figure (circle) is interpreted in terms of the movement that produced it (elliptic), eliciting a perceptual illusion.

Kandel et al (1994) and Orliaguet et al (1997) suggested that motor information could be used during visual processes to anticipate forthcoming motor sequences. In everyday life we are permanently predicting other people's movements. For instance, when a person puts his/her hand forward to give us an object, we predict the final position of the movement so we place our hand at the right place for grasping it. In other words, the visual system starts a spatiotemporal 'reading' process of the motor sequence to predict and adapt the organism to the following one. So, the ability to predict movements has a very important adaptative function. Kandel et al (1994) showed that anticipatory information contained in a handwriting gesture can be exploited by perceptual processes to predict the forthcoming motor sequences. For example, by viewing the production of a letter *l*, subjects can predict the identity of the following letter (eg *ll*, *le*, *ln*) well before its spatial information becomes available.

Complementary experiments showed that the visual perception of motor anticipation is observed with pairs of letters (eg *ll*, *le*, *lm*) as well as with letters within words (eg *fille*, *filet*, *filme*) (Kandel et al 1993). This ability is also found with small and large letters and for a large range of movement times (Kandel et al 1995). Prediction scores are higher in conditions where the stimulus provides kinematic information (dynamic presentation) than in conditions where only spatial information is available (static presentation) (Orliaguet et al 1997). The subject does perceive the shape differences, but these differences do not provide enough information to predict the identity of the forthcoming letter. In addition, this prediction ability is not learned during the experiment. It appears from the first trials and subjects are not aware of the quality of their performance.

It is noteworthy that similar results were observed in other kinds of perceptual tasks. In audiovisual speech, visual information can become available well before its acoustic output (Benguérel and Cowan 1974). Cathiard and Lallouache (1992) showed that a French [y] can be correctly identified 160 ms before the voiced output. They observed a correspondence between the identification functions and the acceleration peak of the upper lip as well as the interlabial area. Furthermore, the visual perception of anticipatory grasping movements enables subjects to know whether a glass will be grasped for drinking, throwing, or displacing (Orliaguet et al 1996).

The aim of the present study was to explore when visual processes detect anticipatory information during the presentation of dynamic handwriting movements. More precisely, the goal was to determine the moment at which the subject can predict the following letter. In other words, how much information about the downstroke of an *l* is required to predict whether it will be followed by another *l*, an *e*, or an *n*? Two types of contextual effects were explored: changes in size (*ll* vs *le*) and changes in rotation direction (*le* vs *ln*). The methodological principle was to provide different amounts of kinematic information about the *l*'s downstroke and assess subjects' predictions based on that information.

2 Experiment 1

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 (Thomassen and Schomaker 1986; van Galen et al 1986). That is to say, when reproducing the letter *l*, the movement time of its downstroke is a function of the spatial constraints of the following letter (Orliaguet and Boë 1990; Boë et al 1991). Changes in size (*ll* vs *le*) as well as in size and rotation direction (*le* vs *ln*) entail temporal differences in the downstroke of the *l*. Movement time of the *l* downstroke is shorter when it is followed by another *l* than when it is followed by an *e* and, in turn, is shorter still when it is followed by an *n*. This indicates that the motor system anticipates the following letter while

writing the *l*. The kinematic pattern of the movement executed to produce a letter, as shape distortions, varies according to specific modulations that are essentially due to contextual constraints.

This motor-anticipation phenomenon was demonstrated at a perceptual level by Kandel et al (1994). As mentioned above, perceptual processes seem to use anticipatory motor information to predict the identity of the forthcoming letter. In this experiment our aim was to determine the moment at which the subject can predict the following letter. We therefore studied the evolution of the correct responses as a function of the amount of presented spatiotemporal information. In other words, we investigated the temporal course of the perceptual process during the presentation of the *l* downstroke and the correspondence between perceptual results and movement kinematics. To be more exact, we examined whether the significant increase of identification scores is linked to a specific kinematic event involved in the production of the *l* downstroke.

2.1 Method

To examine the evolution of the visual detection of motor anticipation in handwriting gestures, we used a gating procedure. This technique has proved to be particularly useful for the study of the time course of identification processes in speech (Öhman 1966; Warren and Marslen-Wilson 1987; Cathiard and Lallouache 1992). The stimulus is presented by gradual increases of information from the beginning of the stimulus until its end. The subject's task is to identify it, even if in some trials he/she can only guess. By calculating the number of gates needed for identification, we can investigate the evolution of responses as a function of the presented information.

2.1.1 *Subjects.* Twenty-seven right-handed subjects, between 23 and 30 years old, participated in the experiment on a voluntary basis. Informed consent was obtained and subjects' rights were protected. The subjects had normal or corrected-to-normal vision and were students in several domains.

2.1.2 *Stimulus preparation.* A subject was asked to write the letter *l* ten times in three different contexts (*ll*, *le*, *ln*) on a digitiser (Wacom SD; sampling frequency, 200 Hz; spatial precision, 0.2 mm). As in Boë et al (1991), kinematic analysis revealed that the writing speed of the *l* is determined by the spatial characteristics of the following letter. Three *ls*, one from each digram (*ll*, *le*, *ln*), were thus selected. The three digrams were then cut at the lowest point of the downstroke of the *l*, ie when velocity was minimum. The shape of the three *ls* (*ll*, *le*, *ln*) was slightly modified by calculation to avoid perceptual biases due to geometrical differences (cf Orliaguet et al 1997). This normalisation procedure was necessary for the control of this particular experiment, but other experiments were run with non-normalised stimuli (eg Kandel et al 1993).

The shape of the *l* traces was thus normalised by transforming coordinates $x(t)$ and $y(t)$ of, for example, the *l* of *ll* in $X(T)$ and $Y(T)$ coordinates of an *l* neutral shape that we shall henceforth call template (see Orliaguet et al 1997 for a discussion on shape neutrality). If the *l* starts at t_1 and T_1 (for the *l* of *ll* and for the *l* of the template, respectively) and ends at t_2 and T_2 (for the *l* of *ll* and for the *l* of the template, respectively), the distance $d(t)$ between the beginning of the *l* and the instant t is:

$$d(t) = \int_{t_1}^t \{[x(t)]^2 + [y(t)]^2\}^{1/2} dt.$$

The same procedure was applied to $D(T)$, the distance between the beginning of the template and the instant T . Then the distance $d(t)$ has been normalised to match the total distance $d(t_2)$ with the template's total distance $D(T_2)$:

$$d'(t) = d(t) \frac{D(T_2)}{d(t_2)}.$$

This normalisation changes the quantity $d(t)$ without changing the original kinematics. Finally, the quantities $x'(t)$ and $y'(t)$ will be recovered. They correspond to the distance $d'(t)$ and follow the shape of the template. To obtain $x'(t)$ and $y'(t)$ we use the known functions $X(D)$ and $Y(D)$ and interpolate them with the quantities $d'(t)$ yielding $x'(t) = X[d'(t)]$ and $y'(t) = Y[d'(t)]$. The interpolated coordinates $x'(t)$ and $y'(t)$ thus follow the shape of the template but preserve the original kinematics of the l of ll . The same procedure was used to normalise the l of le and ln .

By this procedure we obtained a single-shaped l with three different kinematic patterns which corresponded to the original productions of ll , le , and ln . Then, each l was cut in several gates, from the beginning of the downstroke until its end, as shown in figure 1. The last gate of each stimulus ended at the lowest point of the downstroke, such that no spatial information on the identity of the letter following the l was available in the stimulus.

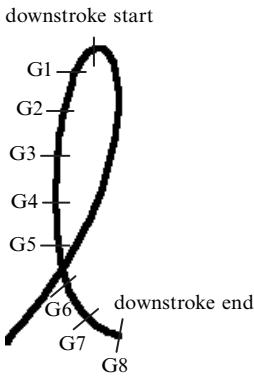


Figure 1. Cutting each l in gates of equivalent trajectory: example of stimulus le .

In this first experiment, the l s were cut into eight gates (G1 to G8), from the beginning of the downstroke until its end. Each gate had exactly the same length. The perimeter of the downstroke was divided into eight identical parts. Each part constituted a gate.

The experiment consisted of two blocks of stimuli: one for the change in size condition ($le - ll$) and another for the change in rotation direction condition ($le - ln$). Each block consisted of 160 trials, making a total of 320 trials.

2.2 Procedure

The experiment was run in a HyperCard 2.2 environment, with a PASCAL extension (XFCN) that enabled the reproduction of the exact dimensions, velocity, and temporal course of the original productions on the screen of the computer. Each l was progressively traced on the screen. The presentation time corresponded to the movement time of the original productions. The stimulus disappeared at the end of the gate and the subject was asked to predict to which couple of letters the presented l corresponded by clicking on one of two buttons of the mouse. For example, for the block presenting le and ll , the subject had to click the LE button only if he/she was 'sure' or 'almost sure' that the l corresponded to le . Otherwise, the other button had to be clicked. The same procedure was used for the other two blocks. This procedure, though apparently complicated, is very efficient for measuring the subject's maximal certainty of response.

The order of presentation of the blocks was counterbalanced whereas stimulus presentation within a block was random. No feedback of results was given to the subjects. The experiment consisted of a total of 320 trials. 10 practice trials preceded the beginning of the experiment.

2.3 Results

For each stimulus, the percentages of correct *le* responses and the distribution of the identification curves were analysed.

2.3.1 Percentages of correct responses. The percentages of correct *le* responses for the two conditions (changes in size *ll-le*, changes in rotation direction *le-ln*) as a function of the eight gates of the downstroke are shown in figure 2.

Analysis indicates that the percentages of correct responses increase significantly as the number of presented gates increases ($F_{7,26} = 23.437$, $p < 0.01$). Overall, results show that subjects predict the identity of the letter following the *l* significantly above chance level (50%) at gate G6: 57% for the change in size condition and 63% for the change in rotation direction condition (t significant at $p < 0.01$ for both conditions). This corresponds to 75% of the downstroke trajectory. Responses for gate G5 do not differ from chance. In addition, performance for the first four gates is significantly below chance [G4: 37% for the change-in-size condition and 44% for the change in rotation direction condition ($t < 0.05$)]. Results for the change in rotation direction condition are equivalent to those of the change in size condition, except for the last two gates ($t < 0.01$).

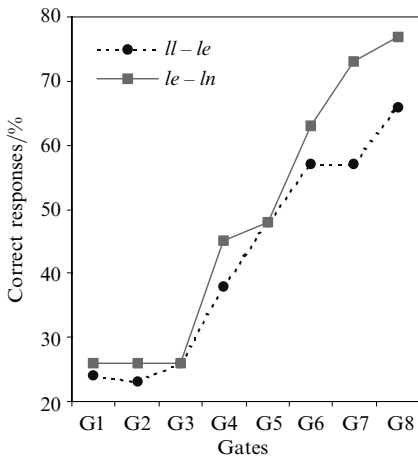


Figure 2. Experiment 1. Percentages of correct *le* responses for the changes in size (*ll-le*) and rotation direction (*le-ln*) as a function of the downstroke gates.

2.3.2 Distribution of identification curves. Performance is rather stable during the first three gates, and then a significant increase takes place at gate G4, ie with the presentation of the first half of the downstroke (cf figure 2). This indicates that correct prediction does not increase progressively, as more spatial information becomes available, but rather implies the detection of pertinent kinematic information provided by the first part of the downstroke. We evaluated the distribution of the percentages of correct responses as a function of gate presentation to support this idea.

The results indicate that correct prediction does not increase progressively, since the distribution of the data is not linear (linear regression test). Furthermore, the results show a correspondence between a significant increase in the percentages of correct responses and the velocity peak of the *l* downstroke (Shapiro and Wilk 1965; Shapiro and Francia 1972).

2.4 Discussion

The aim of this first experiment was to determine the moment at which the information on the production movement provides the critical information (change in size and change in rotation direction) for predicting the identity of the letter following the *l*. The results reveal that with the presentation of 75% of the downstroke trajectory subjects can successfully identify the following letter (percentages of correct responses

are significantly above chance at gate G6). The presentation of the whole downstroke is therefore not necessary for correct prediction. The fact that percentages of correct responses in the change in rotation direction condition are higher than in the change in size condition in gates G7 and G8 could be due to the detection of the temporal increase observed when executing the change in rotation direction of the wrist to produce the *n* (van Galen et al 1986). This supports the idea that the differences observed at the production level are observed at the perceptual level.

Another significant result is that the information provided by the first four gates is insufficient for correct prediction, indicating that the critical cues appear between gates G4 and G6. Subjects' performance for the first three gates is around 25%, which may suggest that they made an effort to answer correctly even in situations where there was not enough information to do so. This shows that the 'maximal certainty' task used in the experiment worked rather well. In addition, responses for gate G5 do not differ from chance.

The analysis of the distribution of the experimental data corroborates the hypothesis on the correspondence between movement production and the detection of anticipatory information. Indeed, the percentages of correct responses regarding changes in size and rotation direction increase significantly during the acceleration phase, that is after the presentation of the velocity peak. The visual detection of motor anticipation in handwriting seems to take place during the first part of the downstroke. It could be argued, however, that subjects' responses were influenced by duration differences between the gates. As a recent experiment on the perception of handwritten anticipatory movements shows, cues on total duration enhance performance in perceptual anticipation by up to 20%. Therefore, another experiment with equivalent gate durations is required to confirm the results obtained in experiment 1.

3 Experiment 2

In this second experiment the detection threshold of the visual perception of motor anticipation was investigated in more detail. Experiment 1 shows that the first part of the *l* downstroke (the acceleration phase) provides the critical information used by perceptual processes. The duration of the gates in the preceding experiment varied from gate to gate. The visual detection of motor anticipation could therefore be due to a processing of movement time differences among stimuli instead of exploiting anticipatory motor information. To avoid this potential bias, the stimuli used in this experiment did not present duration differences between gates. The aim of this experiment, as that of experiment 1, was to determine the nature of the information involved during the detection of anticipatory information.

Gates were thus constituted with identical duration. Stimuli differed only in the duration of the last gate. If duration is the critical information exploited during the perception of motor anticipation, subjects should need the presentation of the whole downstroke to predict the following letter. Conversely, if motor information is used during the detection of the anticipatory event, subjects should be able to respond correctly before the end of the downstroke. Our aim in experiment 2 was to confirm that the visual perception of motor anticipation relies on the detection of kinematic events and not on durational cues.

3.1 Method

In this experiment we also used the gating technique, but the downstroke of the *l*, instead of being cut with a spatial criterion, was cut according to a temporal one. The gates were constituted in such a manner that their duration was identical.

3.1.1 *Subjects.* Nine right-handed subjects, between 20 and 25 years old, volunteered to participate in the experiment. Informed consent was obtained and subjects' rights

were protected. The subjects had normal or corrected-to-normal vision, and were students in several domains, having no particular knowledge of movement control or visual perception.

3.1.2 Stimulus preparation and procedure. The same letter *ls* written in three different contexts (*ll*, *le*, *ln*) were again used in this second experiment. They were cut at the lowest point of the downstroke. The duration of each gate was 50 ms (see figure 3), but the duration of the last gate of each stimulus was variable because it included the remaining part of the downstroke. The downstroke of the *l* of stimulus *ll* was presented in four gates; the downstroke of the *l* of stimulus *le* in six gates and the downstroke of the *l* of stimulus *ln* in eight gates. The experiment consisted of two blocks of stimuli: one for the change in size condition (*le* – *ll*) and a second one for the change in rotation direction condition (*le* – *ln*).

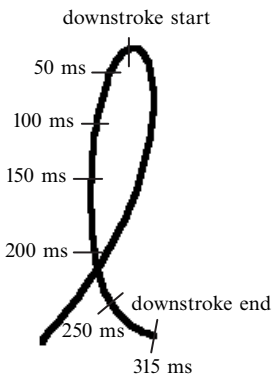


Figure 3. Cutting each *l* in gates of equivalent duration: example of stimulus *le*.

The procedure was exactly the same as in experiment 1. The *l* was progressively traced on the screen and it disappeared at the end of the gate. The subject's task was to predict to which pair of letters the presented *l* corresponded by clicking on one of two buttons of the mouse.

The order of presentation of the blocks was counterbalanced whereas stimulus presentation within a block was random. The experiment consisted of a total of 120 trials. No knowledge of results was given to the subjects.

3.2 Results

As in experiment 1, we analysed the evolution of correct responses and the distribution of the identification curves.

3.2.1 Percentages of correct responses. The percentages of correct responses are shown in figure 4. As in experiment 1, the percentages of correct responses increase significantly as a function of the number of gates presented by the stimulus ($F_{5,30} = 17.166$, $p < 0.01$).

With the information provided by the first four gates (200 ms: 63.5% of the downstroke time) subjects distinguish *le* from *ll* at 60% and *ln* at 77.14%, ie significantly above chance level (t significant at $p < 0.01$ for both conditions). Performance for the first three gates (150 ms: 47.6% of the downstroke time) is significantly below chance ($t < 0.01$): 34% for the change in size condition and 40% for the change in rotation direction condition at 150 ms. Analysis also indicates that the percentages of correct responses for *le* – *ll* are lower than for *le* – *ln* ($F_{1,6} = 29.824$, $p < 0.01$).

Overall, the results show that the information provided by 63% of the downstroke time is enough for predicting the letter following the *l* with at least 50% of response certainty.

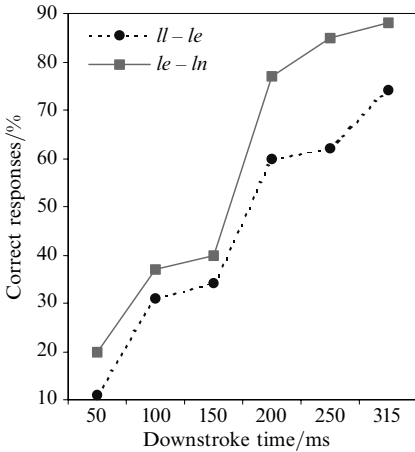


Figure 4. Experiment 2. Percentages of correct *le* responses for the changes in size (*ll-le*) and rotation direction (*le-ln*) as a function of the downstroke time.

3.2.2 Distribution of identification curves. The results indicate that the scores do not increase progressively, and that the increase is observed well before the end of the downstroke. As in experiment 1, the results show that performance increases significantly at a certain point, which corresponds to the occurrence of the velocity peak of the *l* downstroke. This supports the idea that the presentation of the acceleration phase accounts for a significant increase of the percentages of correct responses.

3.3 Discussion

The goal of this second experiment was to perform a temporal analysis of the perceptual processes involved in the visual detection of motor anticipation. Overall, the results show that with the presentation of only 63.5% of the downstroke time (200 ms) subjects can successfully predict the following letter. This implies that the visual detection of anticipatory information does not rely on temporal differences between the stimuli. Furthermore, when 150 ms of the *l* downstroke were presented, performance was significantly below chance level, indicating that the critical cues for correct prediction appeared during the 50 ms period between 150 and 200 ms. The analysis of the curves supports the idea that the cues provided by the first 200 ms, ie by the acceleration phase, are critical during the perceptual anticipation process.

The results confirm those of the first experiment, that perceptual anticipation relies on the cues provided during the acceleration phase, ie the first part of the downstroke, including the velocity peak. Therefore, the whole downstroke is not necessary for correct prediction. The results also show that the percentages of correct responses are higher in the change in rotation direction condition (*le-ln*) than in the change in size condition (*ll-le*). The anticipation observed in the production movement is thus observed at a perceptual level.

4 Experiment 3

Experiments 1 and 2 show that visual processes use kinematic information to predict the identity of the letter following the *l*. Perceptual anticipation takes place well before the end of the downstroke. It could be argued, however, that the 'maximal certainty' response instructions we used could bias results. The subject had to predict to which digram the presented *l* corresponded by clicking on one of two buttons if, and only if, he/she was 'sure' or 'almost sure' of the answer. Otherwise, the other button had to be clicked. The reason for using this strategy, instead of a normal forced-choice manner of response, was to observe the evolution of correct responses during the initial gates and determine the point at which a significant increase took place. The aim of this third experiment is to show that response instructions in experiments 1 and 2 did not bias performance.

4.1 Method

The method was the same as that used in experiment 2, the only difference being in the response instructions.

4.1.1 Subjects. Ten right-handed subjects, between 22 and 26 years old, volunteered to participate in the experiment. Informed consent was obtained and subjects' rights were protected. The subjects had normal or corrected-to-normal vision, and were students from several disciplines, having no particular knowledge of movement control or visual perception.

4.1.2 Stimulus preparation and procedure. The stimuli were the same as in experiment 2. The experiment consisted of two blocks of stimuli: one for the change in size condition ($le - ll$) and a second one for the change in rotation direction condition ($le - ln$). The l was progressively traced on the screen and it disappeared at the end of the gate. The subjects' task was to 'guess' to which couple of letters the presented l corresponded by clicking one of two buttons of the mouse. No further instructions were administered. The order of presentation of the blocks was counterbalanced whereas stimulus presentation within a block was random. The experiment consisted of a total of 120 trials. No feedback of results was given to the subjects.

4.2 Results

As in experiments 1 and 2, we analysed the evolution of correct responses for the change in size and the change in rotation direction conditions.

4.2.1 Percentages of correct responses. The percentages of correct responses are shown in figure 5. As in experiments 1 and 2, the percentages of correct responses increase significantly as a function of the number of gates presented by the stimulus ($F_{5,45} = 18.57$, $p < 0.01$).

Subjects distinguish le from ll at 72% (ie above chance level, t significant at $p < 0.01$) with the information provided by the first four gates (200 ms: 63.5% of the downstroke time). They distinguish le from ln at 67% (ie above chance level, t significant at $p < 0.01$) at gate G3 (150 ms: 47.6% of the downstroke time). Performance for the first three gates in the change in size condition does not differ from chance. Percentages for the change in rotation direction condition do not differ from chance up to 100 ms presentation (gates G1 and G2). Percentages of correct responses for $le - ll$ are systematically lower than for $le - ln$ but differences are not significant.

Overall, the results show that prediction above chance level is possible with the presentation of the first 100 ms of the downstroke time.

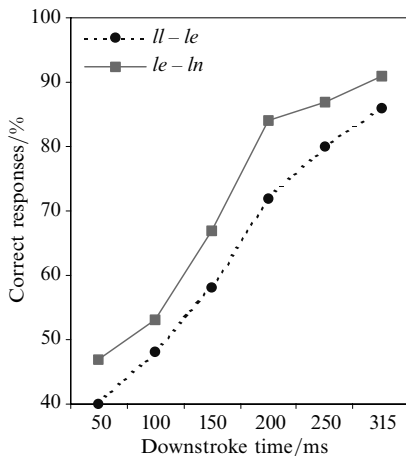


Figure 5. Experiment 3. Percentages of correct le responses for the changes in size ($ll - le$) and rotation direction ($le - ln$) as a function of the downstroke time.

4.3 Discussion

The results show that scores increase significantly after the presentation of 63.5% of the downstroke time (200 ms) for the change in size condition, which is similar to the performance observed in experiments 1 and 2. In the change in rotation direction condition, correct prediction above chance level (67%) takes place in the preceding gate (150 ms: 47.5% of the downstroke time). Data also indicate that the percentages of correct responses are higher in the change in rotation direction condition ($le - ln$) than in the change in size condition ($ll - le$), although in this experiment differences are not statistically significant. It therefore seems that our results were not biased by methodological strategy differences, except for a 50 ms advance observed in the change in rotation direction condition.

5 General discussion

The goal of this study was to determine the detection threshold in the visual perception of motor anticipation in handwriting. The first experiment reveals that the threshold is at 75% of the downstroke trajectory and the second experiment that it is at 63.5% of the downstroke time, which is in approximately the same range of xy coordinates. Experiment 3 confirms these results. The presentation of the whole downstroke is not necessary for correct prediction. Another relevant result is that the prediction relies on the presentation of the acceleration phase of the downstroke. Analysis reveals that the moment at which correct prediction takes place seems to include the velocity peak. Percentages of correct responses are systematically higher in the change in rotation direction condition ($le - ln$) than in the change in size condition ($ll - le$). These differences are probably due to the fact that the anticipatory movement for producing the l of ln is affected by the change in rotation of the wrist needed to trace the n (cf van Galen et al 1986). The production of the l of ll or le does not require this additional wrist gesture. Changes in rotation direction seem to be more salient, therefore easier and faster to detect than changes in size.

It is noteworthy that the critical point in the downstroke—where guessing turns into prediction—is in the vicinity of the crossing with the upstroke. Although this spatial cue could be used by subjects during the perceptual process, as shown in other experiments on handwriting recognition (Freyd 1983a; Babcock and Freyd 1988), it is unlikely that it provides critical information on the identity of the following letter. Orliaguet et al (1997) have shown that subjects do detect spatial cues during this kind of perceptual task but this information seems to be insufficient for correct prediction on a merely spatial basis. In addition, the shape of all the stimuli used in the experiments was normalised, thus avoiding eventual perceptual biases due to differences in spatial information at any point of our l s.

Another important remark concerns the fact that the experiments involved changes in letter size and rotation direction with one cueing letter and two response alternatives. The reader may question whether these results can generalise to the whole alphabet. A previous, unpublished, experiment on handwriting production run in our laboratory showed that ll , le , and ln represent all the $l+$ letter possibilities one can find in our cursive alphabet: the production of the l of ll is equivalent to the production of the l of lb or lt ; the production of the l of le is equivalent to the production of the l of lu or lo ; and the production of the l of ln is equivalent to the production of the l of lm or lr . Although more perceptual experiments would be desirable and in other pairs of letters discriminational information could be more ambiguous, it would be impossible to test all the possible combinations of the alphabet. Furthermore, as in many neuropsychological studies, single-case data can be presented to show the existence of a particular phenomenon without making it less robust than a study performed on a larger sample.

Overall, the experiments confirm that information on the production movement of the first letter enables subjects to predict the identity of the following one well before spatial cues become available. The visual detection of motor events (eg the acceleration phase), and its use in predicting forthcoming information, suggests that perceptual processes do exploit anticipatory motor information.

Although these results support the idea of a perception–production link, they do not actually prove it. Another series of experiments seems to be more convincing. The same kind of task was presented to children aged 7 to 11 years. Results show that prediction is at chance level at the ages of 7 and 9 years, and only at the age of 11 years do scores become equivalent to adult performance (Kandel et al, forthcoming). Perceptual anticipation, in fact, appears at the age at which handwriting control becomes more stable and anticipation is clearly observed at the production level. It therefore seems that the information provided by the gesture cannot be exploited perceptually if it cannot be linked to the individual's motor performance.

Another experiment, in which the same perceptual anticipation task was applied to human handwritten traces as well as artificially generated ones (Kandel et al 2000) supports the idea of a motor–perceptual interaction. The authors manipulated the distribution of the velocity along the trajectory and thus generated stimuli that did not look like human handwriting movements. Results show that correct prediction is only possible when velocity–shape covariations are in agreement with possible handwriting movements, suggesting that visual processing does exploit anticipatory motor information to predict forthcoming sequences, but only the motor information that the subjects are themselves capable of producing.

Finally, this idea has proven to be efficient in the area of automatic recognition of handwritten traces. The computational potential of an approach to movement pattern recognition based on movement pattern generation has been demonstrated in connected cursive handwritten character recognition by Wada et al (1995).

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