

✧ *The Development of Directional Preference in Writing Movements*

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The paper looks into the origin and the development with age of the preference to make either clockwise or counterclockwise curves and contours in writing and drawing. Twenty-six subjects of four age groups performed four writing and drawing tasks. Two of these were writing single symbols and accurately copying patterns; the other two were free scribbling and drawing repeated circles at a high rate. The developing directional preferences that were observed between four years of age and adulthood suggest that two semi-independent motor systems are involved in writing: one, more primitive, for rapid non-figurative tasks evolving from flexion-first to extension-first; the other, which occurs later but more rapidly under a higher degree of cognitive control, for precision and symbolic functions, favouring counterclockwise curves, irrespective of the writing hand.

Introduction

One may regard the production of any piece of handwriting as the production of a sequence of curved line segments. The direction in which a segment is curved will to a large extent be determined by the general shapes of the letters and the script used in formal writing instruction. Although in some cases, such as in closed circles, the segments could in principle be drawn either clockwise or counterclockwise, it is likely that learning to write induces a certain preference for one direction over the other. At the same time, however, it is obvious that the scripts in use must to some degree reflect the most natural movements, not only in terms of slant and size, but also in their direction of rotation.

We have recently obtained data which indicate that there is a systematic difference between clockwise and counterclockwise writing movements. By some of the subjects in these experiments, the counterclockwise versions of continuous loops as well as of repeated circles (Figure 1) were produced more rapidly than their

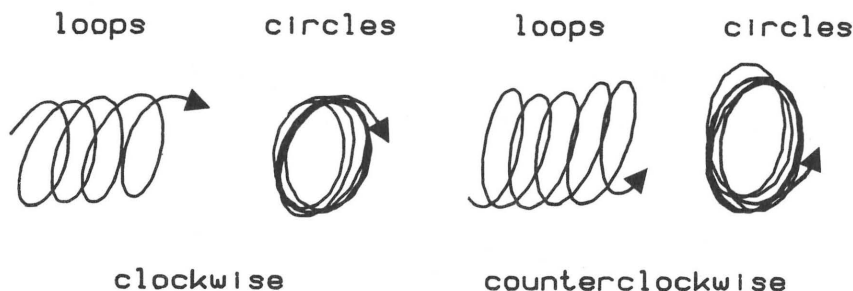


Figure 1. Clockwise and counterclockwise versions of sets of loops and repeated circles, the dynamic properties of which may display directional preferences.

clockwise counterparts; in other subjects this relationship was reversed. We shall refer to that direction of rotation which is apparently the easier one to produce as the preferred direction. This concept may also be used in drawing tasks. If, for instance, a subject copies simple geometric patterns, he may systematically draw the patterns following a specific sequence, e.g., building them up in a clockwise fashion. The cause of such an apparent preference must — just as in the case of writing — be located within the subject's history, in his motoric disposition, or in both.

The research to be reported in the present paper is concerned with a further establishment of the preferred direction in writing and drawing and with finding out whether they have a common basis. Our specific aim is, furthermore, to investigate to what extent directional preference is caused by merely neuromuscular properties of the motor system in its successive stages of development, and to what extent it is determined by higher, cognitive processes which are, in turn, subject to influences such as those of writing instruction.

In the literature on writing and drawing behaviour in children a number of observations have been reported which seem to indicate that a counterclockwise build-up occurs most frequently in children over the age of six. In younger children there is a somewhat less obvious preference, or even a preference for a clockwise sequence of segments. Ames and Ilg (1951) distinguish four developmental stages characterized by the way in which the child is most likely to draw a circle, starting either at the top or at the bottom and continuing in a clockwise or counterclockwise direction. Their findings may be summarized as in Table I.

Table I. Four developmental stages characterized by the manner of drawing circles. Data from Ames and Ilg (1951).

<i>Stage</i>	<i>Age (years)</i>	<i>Starting point</i>	<i>Direction of rotation</i>
1	3	top	counterclockwise
2	3.6	bottom	clockwise
3	4 - 5.6	top	clockwise
4	over 6	top	counterclockwise

More recently Goodnow and Levine (1973) have proposed a set of selection rules describing the sequence following which a geometric pattern is drawn. Of the patterns employed by these authors, the ones that are relevant for the present study are the three patterns having an apex: rhombus, triangle, and inverted V (Figure 2). Two rules describe how these patterns are copied: (1) the starting rule states that the apex will be selected as the starting point; (2) the progression rule states conditionally that if rule (1) is satisfied, the first line to be drawn will be in a left-downward direction. According to these authors, there is a particular relationship between age, on the one hand, and the degree to which the two rules predict copying behaviour on the other. This relationship is summarized in Table II. The age groups 4.5, 6.2, 6.11, and adults follow rule 2 with the very high probabilities of approxi-

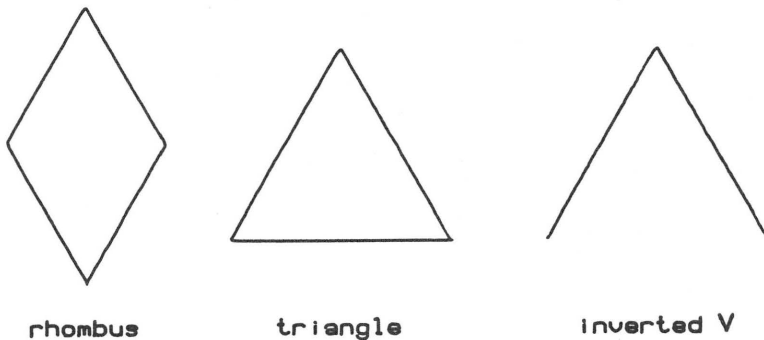


Figure 2. Three of the patterns employed by Goodnow and Levine (1973) which were adopted as copying examples in Part B of the present study.

Table II. Probability of graphic behaviour by five different age groups according to two rules. Data estimated from Goodnow and Levine (1973).

<i>Group</i>	<i>Age (years)</i>	<i>P (rule 1) (start)</i>	<i>P (rule 2) (progress)</i>
1	4.5	0.69	0.88
2	5.2	0.53	0.43
3	6.2	0.59	0.92
4	6.11	0.77	0.94
5	adults	0.75	1.00

mately 90 per cent or higher. Now, if drawing a line from the apex towards bottom-left is similar to drawing the first segment of the counterclockwise production of a circle, these data imply that these age groups display an ever increasing counterclockwise preferred direction. The five-year-olds, however, deviate strongly from these numbers. They stick to rule 2 only just below chance level (43 per cent), which shows that these children probably do not possess a preferred direction; they certainly lack the preference of the other age groups.

A clinical approach to preferred direction in writing has been followed by Blau (1977). He presented his subjects with a standard task consisting of drawing six circles, three with the right hand and three with the left. The proportion of subjects doing this consistently in a counterclockwise direction again appears to be related to their age, as may be concluded from Table III.

From the age of five there appears to be a monotonic increase of the number of subjects drawing counterclockwise circles only. It is of interest to note that these data were obtained by observing right *and* left-hand writing, so that at least here a simple motoric preference rule such as "flexion precedes extension" does not suffice, for the sequence of these mechanics is inverted when a circular pattern is performed in the same direction but with the other hand.

The motor system may in a greatly simplified fashion be viewed as consisting of two antagonist pairs, of which the muscles are denoted as (1:2) and (3:4) respectively. Circular writing movements, irrespective of their direction, are always performed by these four

Table III. Probability of drawing all of six circles in a counterclockwise direction. Data estimated from Blau (1977).

<i>Stage</i>	<i>Age (years)</i>	<i>All counter- clockwise</i>
	5	0.18
2	6	0.29
3	7-8	0.53
4	9-10	0.63
5	11-12	0.71
6	13-16	0.76

muscles. If the order of contraction is 1-4-2-3, 1-4-2-3 . . . in one direction, it will be 1-3-2-4 . . . in the other (Figure 3). The direction of rotation is thus dependent on the sequence of the various muscle contractions. It may be that the neuromuscular processes involved in the sequential innervation of the muscle system play an important role in the origin of directional preferences. This seems likely in view of the fact that the human writing apparatus (arm, wrist, and hand) has an asymmetrical anatomy. A critical prediction would be that directional preferences are hand-dependent, because the left hand is the mirror image of the right. But as we noted above, at least in certain cases preferred direction is independent of the hand used for writing.

Graphic behaviour (i.e., writing and drawing tasks of various kinds) may be considered to be located on a continuum ranging from (1) an accurately copied complex pattern or even the calmly written, orthographically correct product of creative thought on one extreme to (2) making non-figurative, arbitrary scribbles at a very high speed on the other. It is very likely that along this continuum there is a decrease in the relative weight of higher cogni-

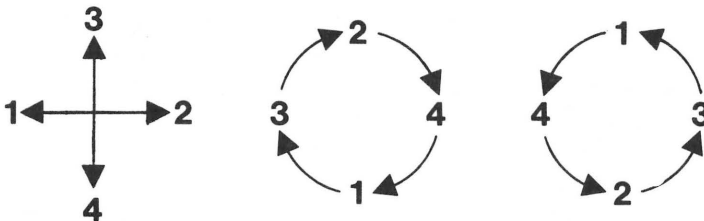


Figure 3. Simplified representation of the two antagonistic muscle pairs involved in the execution of a circular writing movement in two opposed directions.

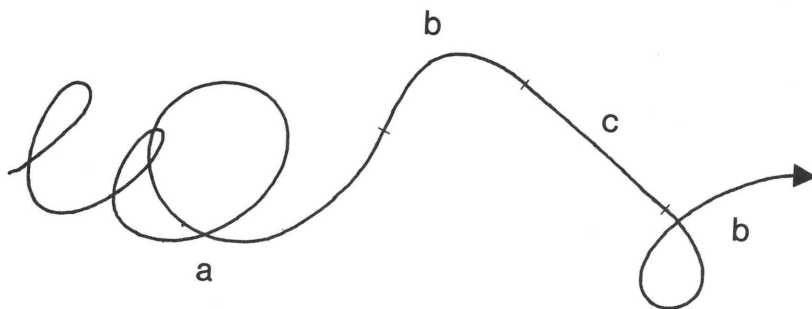


Figure 4. Hypothetical fragment of scribbling with sections of counterclockwise (a), clockwise (b), and effectively no curve direction (c).

tive control, also over the motor side of graphic performance. It may be assumed, perhaps, that if in a continuous mechanical writing task of the latter type a directional preference is present, this preference finds its origin in the motor system itself rather than in its cognitive control.

The present study will investigate to what extent the basis of the direction preference reported in the literature and observed in our own earlier experiments is to be found in the executing motor system or in its higher cognitive control. In tasks where the latter control is strongly reduced (e.g., by requiring a very high writing speed and non-figurative writing products) any pure motor preferences should become more obvious. If they remain similar to the ones observed under higher-control conditions, there is reason to postulate their common origin in the "peripheral" motor system. If, however, rapid non-figurative writing displays a different directional preference, or shows a lack of it altogether, the reported preferred direction in drawing and writing may be due to factors at more central levels.

Rapid non-figurative graphic behaviour may, for example, involve drawing repeated loops or circles in two directions. We found, however, that such tasks are hard to perform adequately by children under the age of six. But it remains possible to let the children scribble freely and to collect samples of "handwriting" reflecting the preferences that we are after. Now, if the child (or the adult, for that matter) is urged to scribble freely at maximum speed, he will, as a result of the instruction as well as of the continuous character of the task, perform writing movements which are to a large extent determined by any obtaining peripheral preferences among the various motoric alternatives.

the two other tasks involving rapid, non-figurative movements were considered to represent, to a large extent, pure-motor performance (C and D). The experimental results are analyzed in terms of the above theoretical considerations with respect to the origin of directional preference in these two types of graphic behaviour.

Subjects. Four groups of subjects took part in the experiment: two groups of kindergarten children ($N = 6$, $N = 7$), primary school children ($N = 6$), and students ($N = 7$). The two youngest groups with age ranges from 4.4 to 4.11 and from 5.1 to 6.2 (median ages were 4.5 and 5.10, respectively) were recruited from the kindergarten belonging to the psychological laboratory; these children have some experience in participating as subjects in studies of various kinds. They had not had any formal writing instruction. The primary school children were from the first form of a local primary school. They had received instruction in writing for approximately eight months. Their ages ranged from 6.9 to 7.6 with the median at 7.3. All subjects were right-handed, except for one child of the youngest and three of the next youngest group.

Apparatus. All the tasks were performed on an xy-writing tablet (Vector General Data Tablet) connected to a computer. The writing surface of the tablet is 44 x 44 cm. The attached stylus has a ball-point tip; its diameter is 11 mm and its weight 25 g. The stylus is connected to the top of the tablet by a flexible wire. The stylus also contains a press switch. The automatic recording of the writing movements was employed only in parts C and D. The position of the pen was determined at a frequency of 200 Hz with an accuracy of better than 0.2 mm. The subjects were seated on an adjustable chair at a comfortable height.

Procedure. The experiment consisted of four parts, as follows.

- A Drawing circles and crosses
- B Drawing a rhombus, a triangle, and an inverted V
- C Prolonged, rapid scribbling
- D Continuously drawing circles at maximum speed

Part D was not performed by the two youngest groups. The parts were presented to the subjects in a random order; each part was

entirely performed twice, once with the left hand and once with the right, also in a random order.

The materials for part A were six sheets of paper with three diagonal crosses with a line-length of 15 mm, surrounded by a circle with a diameter of 30 mm. On each sheet there was either a cross or a circle missing. The subject's task was to complete the sheet after indicating where the cross or the circle was missing. The task implied drawing three circles and three crosses, alternately. The subject drew on a new, semi-transparent sheet of paper which was placed over the stimulus sheet for each trial. The experimenter noted starting point and rotation direction of each circle and the starting points and sequence of execution of the lines of each cross. He counted the number of circles drawn in a counterclockwise direction and the number of crosses built up following a counterclockwise strategy. The latter was considered to apply if the transition from the end of the first line to the beginning of the second line of the x followed an imaginary counterclockwise curve.

The materials for part B were three sheets of paper on which were pictured a rhombus, a triangle, or an inverted V respectively (Figure 2). The apex was always 60 degrees. The length of the lines of the rhombus was 5 cm, that of the other patterns was 7 cm. The sheets were presented once in a random order. The subject's task was to copy the pattern on a separate sheet on every trial. The starting point and the sequence of the lines were noted for each pattern drawn. The number of patterns was counted where the starting point was at the top and where, given this starting point, the first line was drawn towards bottom-left. Moreover, it was counted how often a pattern was built up following a counterclockwise strategy. The latter was considered to apply if the first line drawn had a counterclockwise direction with respect to the imaginary centre of the pattern.

The scribbling task of part C was performed on a plain sheet of paper, size 21 x 30 cm, placed in a horizontal position. (This was also the size and the position of all the other sheets of paper in this experiment). Scribbling was introduced to the subject by means of a long woollen thread which was tangled by the experimenter. The subject was asked to draw such a tangled thread after having been shown an example of a drawing of the type required. During his attempt, the subject was encouraged to continue at a high rate and to use the whole sheet for his drawing. The subject

Table IV. Proportion of circles and crosses of Part A drawn in a counterclockwise direction.

Age group Md. years	Left hand		Right hand	
	<i>circles</i>	<i>crosses</i>	<i>circles</i>	<i>crosses</i>
4.5	0.67	0.22	0.50	0.28
5.10	0.38	0.43	0.52	0.52
7.3	1.00	0.33	0.94	0.39
adults	1.00	0.43	0.81	0.57

was required to continue scribbling in this way for 47 s. During that period, ten continuous 4 s samples were taken, separated by intervals of 700 ms. For every 4 s record the net running angle was computed automatically. The algorithm designed for this purpose neglected segments of scribbling in which the speed of the stylus remained below $\frac{1}{30}$ of its maximum speed during that 4 s interval. Subsequently, the number of records was counted where a counterclockwise movement was predominant, as shown by a positive value of the net running angle.

The materials for part D were sheets of paper on which were drawn two parallel horizontal lines, 5 mm apart. The subject was instructed ten times to draw as fast as possible a continued repetition of circles, staying on the same spot and fitting them approximately between the lines. He could himself determine the moment of recording his writing attempts by pressing the pen. The record was begun 1 s after initiating the first subsequent writing movement and lasted 4 s. The ten trials involved five clockwise and five counterclockwise attempts. The pertaining instructions followed a random order. For each trial the mean time needed to complete one circle was computed. The algorithm designed for the purpose calculated the time intervals between the successive moments at which the pen position was at its lowest position.

Results

Part A *Circles and Crosses.* The proportion of circles and crosses drawn in a counterclockwise fashion according to the described criteria is given in Table IV, which presents the data for each age group for the left and right hand separately. The results for the

Table V. Proportion of patterns of Part B copied in a counterclockwise direction, together with the observed probability of obeying the starting and progression rules.

Age Group Md. Years	counter- clock- wise	Left hand		counter- clock- wise	Right hand	
		<i>P</i> (rule 1) (start)	<i>P</i> (rule 2) (progress)		<i>P</i> (rule 1) (start)	<i>P</i> (rule 2) (progress)
4.5	0.56	0.56	0.80	0.56	0.28	0.60
5.10	0.62	0.71	0.60	0.19	0.76	0.19
7.3	0.77	0.77	1.00	0.83	0.83	1.00
adults	0.38	0.38	0.50	0.29	0.29	1.00

circles indicate that, indeed, there is an increased overall tendency with age to draw in a counterclockwise direction, and that, more specifically, the strong increase in this directional preference between the ages of 5 and 7, which has repeatedly been reported in the literature, is replicated in the present study. The left-hand results of five-year olds in fact provide an exception to the almost monotonic relationship observed for circles. There are, furthermore, no striking differences between the hands. The results for the crosses follow the same trend. There is an increasing counterclockwise preference, which is approximately the same for the two hands.

The proportions of counterclockwise crosses are, however, in general somewhat lower than in the case of circles. Moreover, the strongest increase now seems to occur between the ages of 4.5 and 5.10, i.e., around the age of five.

Part B Rhombus, Triangle, and Inverted V. The proportion of patterns copied in a counterclockwise direction following the criterion described is given in Table V, for the four age groups and for each hand separately. The table also presents the proportion of attempts adhering to the starting and progression rules mentioned above. If the adults are left out of consideration, the other groups show an increase in counterclockwise directional preference also in these patterns. Similarly, there is an increasing tendency to behave according to the two rules. As in Part A the five-year olds once more provide an exception in places by deviating from the

Table VI. Proportion of 4 s periods during which counterclockwise curves prevailed in the free scribbling task of Part C.

<i>Age group</i> <i>Md. years</i>	<i>Left hand</i>	<i>Right hand</i>
4.5	0.30	0.62
5.10	0.57	0.40
7.3	0.48	0.40
adults	0.63	0.24

trend. There are, again, no further big differences between the hands. Puzzling are the copying attempts by adults. They tend to draw neither counterclockwise nor following the grammar rules. Only with their right hand (which was the preferred hand in all these subjects) did they obey conditional rule 2 at the high probability reported by Goodnow and Levine (1973).

Part C Rapid Scribbling. Table VI presents the proportion of the sampled periods in which counterclockwise curves prevailed. The most striking feature of the scribbling data in the table is that the direction of the strong age effect depends entirely on the hand performing the scribbling task. If a young child's right hand preferably makes counterclockwise scribbles, his left hand seems to prefer exactly the opposite. Similarly, if an adult's right hand tends to scribble in a clockwise direction, this preference will be in the opposed direction for the left hand.

Part D Circles at Maximum Speed. The results of this speed task — which could only be offered to the oldest age groups — are presented in Table VII. The data represent the proportion of subjects in which counterclockwise rotations were faster than clockwise rotations. In some cases, these differences were significant within subjects. It seems as if the results of part C are here replicated on another scale. The younger subjects show a tendency to make rapid counterclockwise movements with their right hand, whereas this tendency is reversed in adults. Thus, again, there is an interaction between age and hand.

Table VII. Proportion of subjects performing repeated counterclockwise circles at a higher speed than clockwise circles in Part D.

<i>Age group</i>	<i>Left hand</i>	<i>Right hand</i>
7.3 years	0.00	0.50
adults	0.86	0.29

Discussion

The results of our experiment, which was limited in many respects, may tentatively be summed up in the following dichotomy.

1 Writing tasks which require or allow careful planning (on every trial there is a single, different letter or pattern to be written or copied, such as in Parts A and B) show little difference in directional preference between the two hands. The preferences themselves become increasingly counterclockwise with age, and with age they follow more and more the rules specified in the "grammar of action" by Goodnow and Levine. Five-year olds form an exception in some respects, but a specifically strong increase tends to occur between the ages of five and seven. The strange adult behaviour on the apex patterns of task B can in part be explained by pointing out that these subjects nearly always wrote the inverted V (or the capital lambda for them) without pen-lifting and starting bottom-left, which is scored clockwise and in conflict with the rules. Also in the other patterns, however, there appears to be a tendency to start at the left rather than at the top and to continue in an upward direction.

2 In contrast to the above are tasks which do not require, or even allow, careful planning, such as the fast arbitrary scribbles (which yielded on average approximately 100 cm distance per 4 s period) of Part C and the rapidly repeated circles of Part D where the subject's maximum speed was required. In these tasks there was a strong hand-effect, the direction of which was dependent on age. Thus, a finding of great importance is that in these tasks most of our adult subjects show a clockwise preferred direction with their preferred (right) hand. This means that, although a fully developed counterclockwise preference has been shown to exist in drawing single circles accurately, the latter turns into a clockwise preference when more liberal and rapid movements are per-

formed. It is in line with our earlier discussion to hold the more peripheral mechanics of the motor system responsible for movements of the latter type and to predict strong hand effects for these. These hand effects were indeed observed; their direction implies that in adult writing the motor system at its "lower" levels tend to favour "extension first." In young people this peripheral mechanism appears to be developing from an initial tendency towards "flexion first," which results in a counterclockwise preference in the right hand of the youngest children.

The latter situation may also explain the results of the five-year olds, which show up as an exceptional group in various studies, including ours. If a primitive flexion-first preference (which in right-hand writing appears as a counterclockwise preferred direction) is present in the youngest children of, say, four and younger, that preference will determine all their graphic behaviour, irrespective of its required precision or its possible symbolic nature. Now, suppose the later development of a higher-order writing motor system — dealing with the more precise and perhaps symbolic functions — implies the development of different, complex innervation patterns (which follow more abstract grammar rules and which are less dependent on the performing hand) and suppose this development starts at the age of four or five. This would be especially disturbing to the five-year olds, because in them the old system, which is at that age developing towards an extension-first strategy, would tend to confound with the recently developing new system. Especially the right-handers among them would be in great difficulty because of the fact that the new motor system happens to favour counterclockwise movements which their initial motor system, developing toward extension-first, has just left behind. The two underlying systems themselves may be entirely different, but still their interaction in writing at this critical age may be extremely disturbing.

We are now in a position where the main questions of our research can be answered in a speculative way. There are, conceivably, two motor systems: one for rapid and non-figurative tasks, the other for accurate and symbolic purposes. The former, then, may be described as a more primitive system, "pure motor" in character and concerned with an early neuro-muscular tendency towards flexion-first, which from the age of four or five slowly develops into an extension-first tendency. Description of the resulting writing movements in terms of preferred direction would for

this system result in the hand effects that we observed, especially in the youngest and the oldest subjects. The latter motor system in these considerations follows a different development under a higher degree of cognitive control, taking place especially rapidly between the ages of five and seven and being less dependent on the performing hand. It would be biased towards a counterclockwise preferred direction which is perhaps, but not necessarily, induced by educational influences starting at that age. These intriguing suggestions, of course, need further exploration in greater detail. As a first step we shall in a following study scrutinize the individual data on a larger set of tasks, obtained from selected right-handed and left-handed subjects. Although this has not affected the present results in any systematic way, their numbers were unequally divided over the age groups in the above experiment. We will need the results of further experiments if we are to arrive at firm conclusions on the issue of handedness and individual performance on the two types of graphic behaviour tentatively distinguished here.

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