Development of Graphic Skills

Research Perspectives and Educational Implications

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Chapter 6

Isochrony and accuracy of drawing movements in children: Effects of age and context

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The graphic execution of a geometric figure, whether it is simple or complex, involves coordinated participation of perceptual-cognitive mechanisms, devoted to the analysis of the figure to be produced, and perceptual-motor mechanisms, devoted to the planning and adjustment of the movement's parameters as a function of the characteristics of the intended figure. Thus, this motor behaviour — the drawing of a figure — appears appropriate for studying the relationships between perceptual, cognitive and motor aspects of behaviour.

A plethora of perspectives and methodologies can be used to study graphomotor activity. Consider for instance the drawing of a circle. One can be interested in different aspects such as the planning of this activity (eg, asking the subject to draw a unique, discrete circle of a given size) or, by contrast, the maintenance of an already current drawing activity (eg, continuously and repeatedly drawing a circle). This dimension, planning versus maintenance of a current activity, is related to the dimension contrasting the study of goal-aimed movement and the study of movement for itself (ie, at least partially released from constraints linked to the plan of action). Furthermore, whether discrete or continuous, a graphic skill can be performed under contexts that differ in the degree of constraint.

The present chapter reports an exploration of relations between perceptual, cognitive and motor aspects of a graphic skill, performed in a discrete mode and realized within different contexts. Our interest is related to the effects of context on the

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subject's ability to produce sizes and size ratios of a given value (spatial aspects), and on the subject's ability to regulate the movement's velocity as a function of its amplitude (ie the trace length in the case of drawing). The so-called *Isochrony Principle* (Viviani and Terzuolo, 1980, 1983) and its potential sensitivity to context effects constitutes the central focus of this chapter. Furthermore, a developmental perspective is proposed.

1.0 The isochrony principle

A general compensatory mechanism has been demonstrated for the timing of movements and seems to characterize motor acts as different as drawing or handwriting (Viviani and Terzuolo, 1980, 1982, 1983; Viviani and McCollum, 1983), manual pointing (Fitts, 1954), stroking (Michel, 1971) or kicking activity in infants (Thelen and Fisher, 1983). This mechanism, called the Isochrony Principle, has a long history in literature (Binet and Courtier, 1893; Freeman, 1914), and states that the velocity of a movement is proportionally tied to its linear extension (or trajectory's length), so that the execution time is maintained approximately constant. It has been suggested that this principle links velocity to the amplitude of a movement plan. In the case of curvilinear trajectories, however, perfect compensation between velocity and amplitude is never observed, which has been expressed by different laws, such as the One-Third-Power-Law (Viviani and Cenzato, 1985; Lacquaniti et al, 1983, 1984; Sciaky et al, 1987; Schneider, 1987; see also; Wann, 1989; Wann et al, 1988).

Isochrony is observed early in human development, and in very different motor tasks: cutting geometrical figures with scissors (Corbetta, 1989), manual pointing (Hay, 1981), visuo-manual tracking (Viviani and Zanone, 1988). Current developmental data are rather consistent with regard to the hypothesis of an invariant time structure of movement in motor skills (Wann, 1986; Wann and Jones, 1986; Pellizer and Hauert, 1989), and invariance in duration across variations in amplitude of movement (isochrony) may be expected to be present from a very young age. But the nature of the development of this characteristic is at present an open question.

Most experiments in visuo-manual tracking (Zanone, 1987; Pew and Rupp, 1971; Dunham et al, 1985) or experiments based on the coincidence-anticipation paradigm (Bard et al, 1981; Dunham and Reid, 1987) mention a general and gradual improvement in performance with age. In handwriting tasks, a *monotonic* increase in mean writing speed is usually described (Ayres, 1912; Sõvik, 1975; Ziviani, 1984; Rigal, 1976). A similar developmental trend is also shown in drawing tasks with geometric figures (Broderick and Laszlo, 1984, 1987, 1988).

Some measures of motor skill, however, contrast with this picture of motor development as conforming to monotonically increasing performance. A comprehensive set of studies of childrens' pointing by Hay (1978, 1979, 1981, 1984) suggested a *non-monotonic*, U-shaped developmental pattern for some movement's parameters (accuracy for instance) with an initial decline followed by later improvement in performance. Dividing pointing movements of children into three classes, according to kinematic criteria proposed by Brooks et al (1973), Hay (1979) observed a non-monotonic progression, starting with a predominance of fast *ballistic* movements at 5 years, followed by the emergence of *discontinuous ramp* movements (low and constant velocity, long durations), and *step* movements at 7 years, and leading to the appearance of *continuous*, medium speed and single step movements at 9 years. Further support for a significant developmental change at age 7 was derived from analyses of the corrections made by the children in their movements while wearing deviating prisms (Hay, 1981).

Similar discontinuities in motor control development can be found in studies examining lifting movements for objects of different weights (Hauert, 1980; Gachoud et al, 1983), visuo-manual tracking performances (Mounoud et al, 1983, 1985), pointing movements at lateralized targets (Pellizer and Hauert, 1989) as well as in the acquisition of handwriting skill (Wann, 1986, 1987; Meulenbroek and van Galen, 1986, 1988). A general conclusion based on these studies might be that the age at which the decline in performance occurs, as attested by different measures, differs as a function of the complexity of the motor skill.

2.0 Context and age effects in drawing movements

The present chapter describes an analysis of potential context effects on the child's drawing parameters when geometric figures (circles) of different perimeters were to be produced. Consistent developmental milestones have been established for drawing geometric figures, and circles are the first figures children can draw. Many children succeed in these activities by 3 years of age (Arnheim, 1956; Piaget and Inhelder, 1969; Blöte et al, 1987). However, in our studies the drawing situations were more complex. Different sizes of figures were required and biomechanical conditions for drawing changed as a function of the required circle perimeter (eg, a finger movement, wrist movement, arm movement).

Two independent experiments were conducted, and three different experimental contexts were selected: 1) drawing circles of different perimeters in a random order of execution with regard to the size (first experiment: *random* context); 2) drawing circles of different perimeters, presented as a series of circles in an increasing order of size (second experiment, part A: *seriation* context); 3) drawing circles of different perimeters and spatially assembled in such a way that they represented a bear (second experiment, part B: *bear* context).

We chose to study the age range from 5 to 9 years. This was particularly relevant for the seriation context, because within this range, the cognitive ability which underlies the mastering of the seriation operation undergoes well-documented development (Piaget and Inhelder, 1941). Different stages have been described, and success at the closest seriation task of Piaget and Inhelder (seriation of sticks of different lengths) with regard to our own drawing task was achieved at around 8–9 years.

Within this perspective, we suggest that the random context is predominantly *perceptually* loaded, in that it is the least constrained of our experimental tasks and perceptual processes involved in this task can be carried out in a relatively free context. By contrast, the seriation context is *logically* loaded in that the task is logically structured on the basis of the seriation operation. Finally, the bear context could be considered as mainly *spatially* (and cognitively) loaded. In copying the bear, the main problem the child encounters is mastering the spatial relationships the different sub-elements of the figure have with each other. Both perceptual and cognitive determinants are important. As an interdependency between cognitive and motor development has been documented (Hauert, 1980; Gachoud et al 1983; Mounoud, 1986), the differential load of cognitive determinants in our drawing tasks might be manifested by different age effects on movement parameters.

Different working hypotheses may be suggested for context and age effects on drawing movements. In general, we hypothesized non-monotonic development of the relationship between velocity and trace length, but postulated that isochrony might also be affected by the different contexts of drawing. Isochrony we expected should be higher in the random task than in the other ones, as each figure was presented alone, without any systematic size relations with regard to the previous and successive figures. Relations between velocity and amplitude might thus be expected to be facilitated because of the lack of extraneous interference in the estimation of perimeter. Furthermore, we expected accuracy to be worse in the bear task than in the others, because of the effects of overlap between components of different sizes. Finally, we expected the invariance of the size increment over the series of circles (the perimeter progression) to be respected only at around 8 to 9 years in the seriation task, (ie, when children are able to cognitively master the corresponding operation). By contrast, in the random task, we expected this index would be either consistently good over age, or would improve with age, depending on the development of the ability to reproduce sizes in drawing.

2.1 Subjects

Two separate groups of right-handed children were studied for the two experiments. Subjects were drawn from public schools in Geneva. Summary statistics on sex and age range as a function of task are presented in Table 1.

Drawings of 19 other children (9 girls, 10 boys, age range: 5 to 8 years) were eliminated because of too much distorted curvature in the circles produced or particularly inaccurate size reproductions due to the subjects

TABLE 1: Subject sample for each task in terms of sex and age range (years) for each age bracket.

Age group	Task: Seriation and Bear *N*, Sex	Seriation and Bear Age range	Random *N*, Sex	Random Age range
5	10f, 12m	4.7–5.3	7f, 4m	4.6–5.3
6	11f, 13m	5.7–6.4	4f, 5m	5.7–6.3
7	10f, 11m	6.7–7.3	6f, 3m	6.7–7.2
8	12f, 20m	7.6–8.3	3f, 7m	7.7–8.4
9	10f, 10m	8.7–9.4	6f, 6m	8.7–9.3
Total	119		51	

choosing to locate the drawing in a space without enough room for the components. We paid particular attention to the problem of inadequate spacing because various studies have revealed that size reproduction in children's drawings may be a function of the space they left free after they had executed a first figure (Silk and Thomas, 1988; Thomas and Tsalini, 1988).

In addition to the children listed in Table 1, a sample of 20 right-handed adults (10 women, 10 men) was added for the seriation task only. The average age was 28 years, ranging from 21 to 42 years. These adults were unaware of the aims of the study and were drawn from the Faculty of Psychology in Geneva.

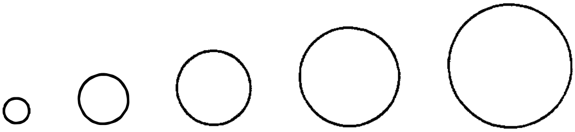
2.2 Apparatus

A special kind of Edison pen was used in these experiments. This pen, when moving, perforates a sheet of thermic paper at an adjustable frequency. Frequency was selected according to the child's spontaneous rhythm of tracing and ranged from 25 to 50 Hz. This apparatus might be considered rather archaic, but it is very easy to use with children as young as 4 years old. The models given to the subjects are reproduced in Figures 1 (A: seriation task, B: bear task) and 2 (random task).

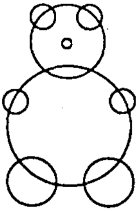
The circles were drawn in china-ink on an A3 format white sheet of paper. Circles were presented in an increasing order of size and aligned with regard to their bases in the seriation task. In the random task, 5 different models were used and randomly assigned to the subjects in order to avoid eventual systematic effects of neighbouring in the child's perception of the sizes. Respective perimeters of the circles were of 6, 12, 18, 24 and 30 cm in the seriation and random tasks (perimeter progression of 6 cm), and of 3, 6, 12, 24 and 30 cm in the bear task (perimeter progression varying, 3, 6 and 12 cm).

2.3 Procedure

Both experiments (seriation and bear tasks, random task) were based on the same factorial experimental design with two between-subject factors (age, sex), and two within-subject factors (trial, circle size).



A: SERIATION TASK



B: BEAR TASK

FIGURE1: Model of the seriation task and the bear task.

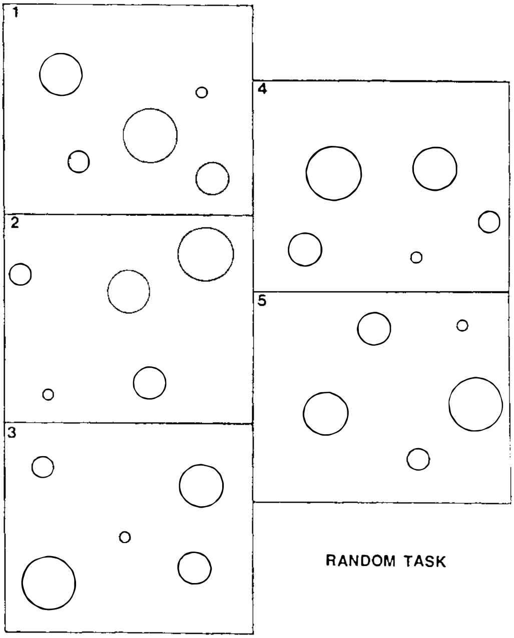


FIGURE 2: Models of the random task (5 different designs).

Each subject was asked to draw the figures on a white sheet of paper of the same format as the model. No starting rule (Kirk, 1985) was imposed (where to initiate the execution of the figure, up or down for instance) and the direction of the drawing movement (clockwise or anticlockwise) was free. Both were noted by the experimenter. The circles, however had to be performed in one single movement, without stopping, under a spontaneous and natural rhythm of drawing. If subjects stopped drawing in the course of the execution of a figure, they were asked to draw it again. Instructions given to the subjects focused attention on the expected accuracy of the size of the circles' reproduction, as well as the regularity of the curvature of the figure. Before starting the experiment, a practice period of several trials was needed to ensure a good understanding of the instructions by the child and to train the subject to produce regular shapes. Instructions were repeated by the experimenter several times during the experiment, in particular with respect to the requested accuracy of the reproduction size.

In the seriation task, the children had the model (Figure 1) in front of them continously, and were asked to reproduce the series of circles in an increasing order of size. Three trials were required, each being performed on a separate sheet. The procedure was identical for the adult sample. Then, the bear model (Figure 1) was introduced to the children, who had to copy it, starting with the circle of their choice. No progression rule (Kirk, 1985) was given with regard to the order of execution of the circles, and the experimenter had to note the sequence choosen by the subject. Two trials were required for the bear task.

In the random task, the child was shown one of the models (see Figure 2) and was asked to attentively observe the range of sizes of the figures he would have to copy. Then, the experimenter indicated the first circle to be drawn, masking the other ones during the copying. Once the figure was complete, the second circle was shown, again masking the non-target ones on both the model and the subject's sheet. This procedure was repeated until the five elements of the series were drawn. No active comparison between the different sizes of either the figures drawn, or the model figures was allowed during the task. Thus, each circle was copied in isolation. Three trials were requested and ten different orders of execution of the series of circles were used, randomly assigned to subjects and trials. Then, a control-seriation identical to that reproduced in Figure 1 was also required, to estimate any discrepancies between the two samples of subjects selected for each experiment.

2.4 Measures

The X and Y coordinates of the points made by the discharges of the Edison pen were digitized by means of a Calcomp 9000 digitizer table (spatial resolution of 0.1 mm). Measures recorded were the trace length (P), time taken (T) and average velocity (P/T) for each circle. (We should point out that the Edison pen presents a major limit for the study of graphomotor activity because of its low sample rate. A consequence of this limit is that it is not possible to compute derivatives such as tangential velocity, acceleration, etc. What is called velocity corresponds to an average speed of execution obtained by directly dividing *P* by *T*.) The measures obtained for the circles of identical sizes in the bear task (see Figure 1B) were averaged, when it was established that this procedure did not introduce any bias in the data. Thus, 15 circles for each child were obtained in the seriation and random task (plus 5 circles in the control-seriation task), and 10 in the bear task.

Two analyses were carried out, one concerning isochrony (understood here as a simple principle assessing constancy of execution time), the other being related to the accuracy of reproduction of size.

2.5 Quantifying the accuracy of drawing

The spatial gain index (the ratio of the length of each produced trace to the corresponding length of the trace in the model) was computed. Then, relations between the sizes of the different circles produced within each series were analysed by computing the mean trace length progression (normalized with regard to the model trace length progression), and its coefficient of variation. This progression index corresponds to the mean of the ratios between observed serial trace increment (difference in trace length between two consecutive circles when they are ordered according to size) and model serial increment (the value of which was always 6 in the seriation and random tasks, but which varied in the bear task; 3, 6 or 12).

2.6 Determining the degree of isochrony

A simple expression for isochrony is

$$T = k P^{\alpha} \qquad (1)$$

where the power index α should tend toward 0 for complete isochrony (constancy of time). Considering that $V = P/T$ in our study, Equation (1) can also be expressed as

$$V = k'P^{\beta} \qquad (2)$$

with perfect isochrony implying that the exponent should be 1. A logarithmic regression of the V—P relation allows a precise estimation of the parameters by expressing equation (2) as

$$\log V = k' + \beta \log P \qquad (3)$$

The slope β of this logarithmic regression, as well as the coefficient of correlation between the two variables, were individually estimated for each child.

3.0 Results

2355 cases were collected for the seriation task, including the adults' performances and the control-seriation data (38 outliers were then eliminated). The bear task includes 1132 cases (30 missing values, 28 outliers ejected), and the random task includes 801 cases (9 outliers eliminated). Outliers were eliminated on the basis of an inspection of the entire data distribution, without any knowledge of the experimental task and/or age group which they belonged to. Analyses of variance (SPSSX) were carried out for the different dependent variables to examine age and context effects. We report in Table 2 only the significant effects, which are explained in the results section.

TABLE 2: Results of analyses of variance

Analysis	Effect	Statistic	p-level
Isochrony; slope index	Context	$F(2,253) = 40.77$	.001
	Age	$F(4,253) = 4.08$	.003
	Linear trend	$t = -3.08$	.002
	Quadratic trend	$t = 2.55$	.011
Accuracy; gain	Context by age	$F(8,744) = 2.35$	.017
	Context	$F(2,744) = 12.92$	.001
	Age	$F(4,744) = 8.26$	.001
	Linear trend	$t = 4.23$	.001
	Quadratic trend	$t = 3.90$	.001
Accuracy; mean trace progression	Context by age	$F(8,744) = 3.13$	.002
	Context	$F(2,744) = 60.08$	.001
	Age	$F(4,744) = 10.63$	.001
	Quadratic trend	$t = 6.25$	.001
Accuracy; coeff. of variation	Context	$F(2,744) = 4.47$	.012
	Age	$F(4,744) = 22.03$	.001
	Quadratic trend	$t = 4.12$	.001

Before discussing the results, we should point out that no effect for sex on the dependent variables was found. Nevertheless, if the entire set of data was examined, girls appeared to draw faster than boys, whatever the age and task. Data on sex differences for speed are controversial in the literature. Usually, no sex effect is reported for speed of handwriting or drawing (Harris and Rarick, 1959; Smith and Reed, 1959; Meulenbroek and van Galen, 1986; Sciaky et al, 1988), although some studies have revealed faster speeds for girls than for boys (Groff, 1961; Sõvik, 1975; Ziviani, 1984).

3.1 Analysis of size accuracy

The analysis comprised two parts: First, the accuracy of size reproduction was examined; second, the trace length increment

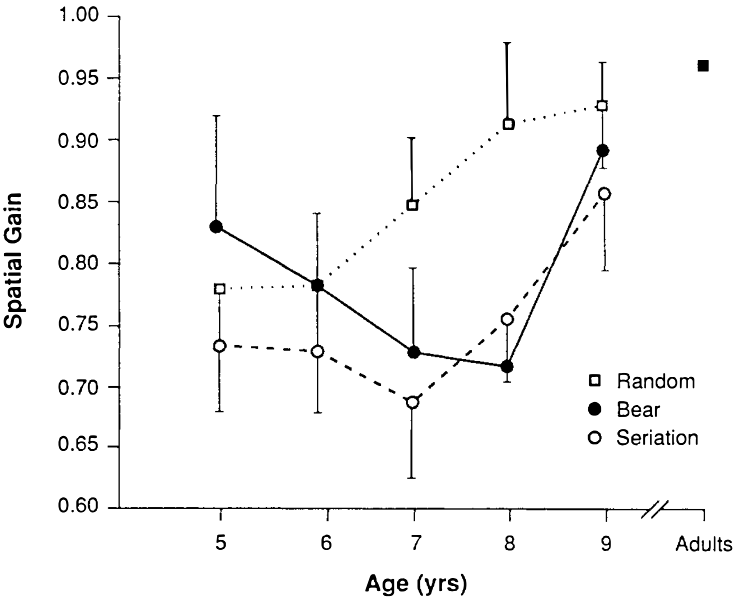


FIGURE 3: Analysis of accuracy: spatial gain (mean and 95% limit of confidence) as a function of age.

over the series was analysed. Figure 3 displays the results for the spatial gain as a function of age and task.

Because the gain index was less than 1, the produced sizes always underestimated those of the models. As expected, the adult value was the highest one, and close to 1 (.96). Figures were significantly more accurate in the random task than in the other ones, which is in line with our hypothesis. The worst performances were recorded in the seriation task, whereas we had expected them to be observed in the bear task. A significant age-by-task interaction should be pointed out: differences between tasks mainly characterized the 7- and 8-year-old children, while they were essentially negligible at 5, 6 and 9 years. A general improvement of accuracy with age was observed, although the quadratic (U-shaped) trend was significant in the seriation and bear tasks; The geometrical gain decreased between 5 and 7 or 8 years, and increased again between 7 or 8 and 9 years.

Mean normalized perimeter progression was computed. This value is equal to 1 when the observed mean progression is identical to that of the model. The coefficient of variation provides information on the regularity of the progression indice over the series. Figure 4 presents the results as a function of age and context (upper: mean trace progression; lower: coefficient of variation).

The perimeter progression varied significantly as a function of context. The highest values occurred in the random task, and the lowest in the seriation task. Although these differences were systematic, they appeared more important with age, as indicated by the significant age-by-context interaction. Again, a clear U-shaped relation was observed (see upper part of Figure 4). Progressions decreased between 5 and 7 or 8 years, and increased again between 7 and 9 years. Similar results were mentioned by Thomas and Tsalini (1988) with size scaling effects in the drawing of a man. In the random and bear tasks, the results were, moreover, better at 9 years than at 5 years.

In agreement with our hypothesis, children succeeded in accurately reproducing sizes in the random task by adequately copying the performed perimeter from the model. Indices such as the spatial gain and the mean perimeter progression were indeed consistently the highest in the random task. But, contrary to our expectation, the bear task seemed to be an intermediate task, which usually led to accurate results close to those obtained in the random task, while the biggest deviation with respect to the model sizes (underestimation) was found in seriation.

Of course, in the random and bear tasks, the good fit between the progression index and the model shown in Figure 4 resulted from the rather accurate size reproduction (see Figure 3). We thus may suspect that the inaccurate performance of children in the seriation task with regard to the value of the mean progression index was partly due to their tendency to keep constant the perimeter increment over the series. If true, a

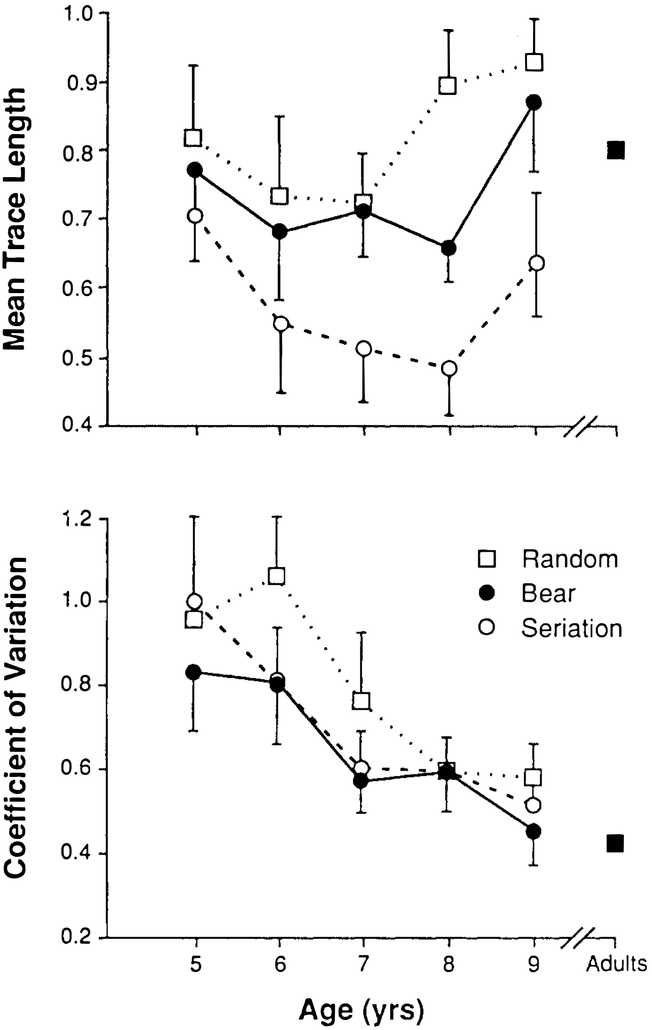


FIGURE 4: Analysis of accuracy: mean trace length progression (upper) and its coefficient of variation (lower) as a function of task and age (mean and the 95% limit of confidence).

dispersion index of the mean progression should reflect the special status of the seriation task with respect to the other conditions. The lower part of Figure 4 displays the coefficients of variation of the perimeter progressions as a function of age and context.

The context effect was significant; a greater variability of the perimeter increment was observed in the random task than in the seriation condition. This gives some support to the idea that, in seriation, the lower values of the different parameters qualifying performance with respect to accuracy resulted from the child's goal to keep constant the trace length increment. Nevertheless, if this hypothesis turns to be correct, then the absence of differences between the seriation and bear tasks is rather unclear. But an order effect may account for this absence of differences (recall that the children drew the bears after they had performed the seriation task three times).

The lower part of Figure 4 also reveals that, whatever the task, the coefficients of variation decreased significantly as a function of age. The dispersion of the perimeter progression was maximal at 5 years, indicating a great irregularity in the perimeter increment over the series, although there was accuracy in the mean. This is not the case at 9 years, at which age the mean index appeared to be at least as accurate as at 5 years (Figure 4 upper), but was associated with regular and stable serial perimeter increments (Figure 4 lower). These results suggest that the seriation task induced a global planning of the perimeter to be performed, possibly based on comparisons between successive pairs of figures, whereas more local planning was elicited by the random and, possibly, the bear tasks. The specific problem encountered by children in the seriation task was to coordinate the two requirements of a regular increment with accurate size reproduction.

3.2 Analysis of isochrony

Because no significant differences in average speed or trace length as a function of age were found between the control-seriation task (performed after the random task) and the main seriation task, the two samples were combined except for analyses in which the trial factor was considered a within-subjects factor.

As expected, a strong covariation between velocity and trace length was observed whatever the experimental task.

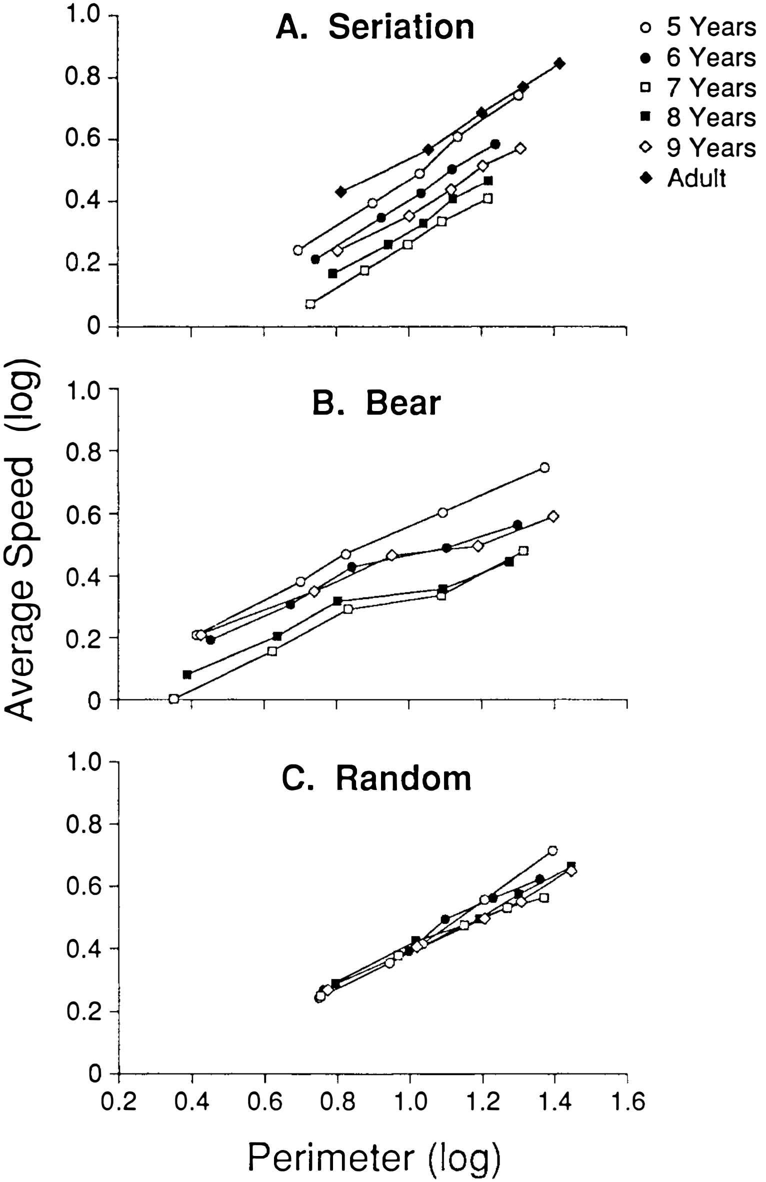


FIGURE 5: Plots of observed velocities and observed perimeters (both axes in log units) as a function of task and age. Note that the model size range is different for the bear task.

Correlations computed on the entire set of data equalled .66 for the seriation task, .67 for the bear condition, and .68 for the random task. The observed perimeters and velocities (logarithmic values) as a function of age and task (seriation; bear; random) are plotted in Figure 5. This clearly demonstrates that the age effect was more important in the seriation and bear tasks than in the random task. Results obtained for the different ages were completely differentiated in the seriation task, while overlapping was common in the random task. More specifically, Figure 5C shows that, in the random task, there was perfect overlap in relation to the smallest range of sizes (from 0.7 to 1.1 in log). Age differences emerged only with respect to the highest range of sizes, which may suggest that it is more appropriate to analyse age effects in the isochrony principle by using large rather than small figure sizes. The main effect in terms of age was the decrease of average speed between 5 and 7 years, followed by a regular increase between 7 and 9 years. Average velocity in adults was higher than in 9-year-old children, which suggests a further increase of speed after age 9. This result, the clear decline of speed at 7 years, is in agreement with Hay's results.

TABLE 3: Coefficient of correlation between V and P and percentage of variance accounted for by regression

Age (years)	*r* values			r^2x100		
	Seriation	Bear	Random	Seriation	Bear	Random
5	.89	.87	.84	80	75	70
6	.87	.81	.81	76	66	66
7	.87	.79	.81	76	63	65
8	.82	.76	.84	67	58	71
9	.87	.83	.90	76	68	81
Adults	.92	-	-	85	-	-

The parameters of the log-regression between velocity and perimeter were computed individually for each subject. Figure 6 displays the mean values of the slope, and Table 3 lists the coefficients of correlation, as well the percentage of the variance explained by each regression (r^2x100). The latter may be considered as a measure of the statistical reliability of the slope estimates.

Whatever the age, the correlations were rather high (from .77 to .90), which suggests some general global influence linking velocity and perimeter. The r^2 values show that at least 58% of the variation of velocity was explained by the variation of perimeter (or vice versa), and 85% at maximum for our data. There was no significant effect to be reported with the correlations. Turning to the slope of the function relating velocity and perimeter, it will be recalled that a slope value of 1 is expected for a complete isochrony. Mean slope values ranged from .41 to .80 in children and they strongly distinguished between the different experimental tasks. They were significantly higher in the seriation task than in the two other tasks, and higher in the random task than in the bear task.

Dynamic compensation between speed and trace length was thus strongly affected by the context within which the drawings

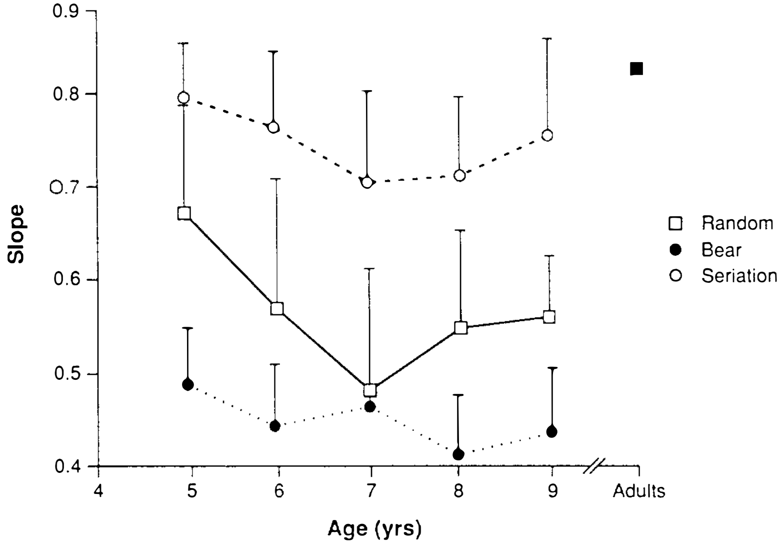


FIGURE 6: Analysis of isochrony: slope of the velocity-perimeter regression (mean and the 95% confidence interval) as a function of task and age.

were performed, and the results appear rather counter-intuitive: the velocity-trace length covariation was optimal, ie, tended towards complete isochrony (slope = 1), when a strong constraint was imposed on the regularity of the trace length increment, as in the case of the seriation task. It might have been more intuitive to expect a good covariation in the random task, where the velocity-trace length compensation was free of any supplementary constraint. Furthermore, speed-perimeter regulations were considerably disorganized in a classical drawing task, such as that of a bear drawing. We will further elaborate on this context effect within a more critical perspective.

A significant age effect for the slope values was also evident where the distribution tended toward a U-shaped function (the quadratic trend was significant). Slopes decreased between 5 and 7—8 years, and increased again between 7—8 and 9 years. Interestingly, isochrony seemed to be higher at 5 years than at 9 years whatever the task, such that data from the adult sample did not differ from those obtained at 5 years. These results related to age support our hypothesis of a non-monotonic evolution of isochrony, and are in line with other developmental data related to skill acquisition.

4.0 Discussion

The greater isochrony of movements in the seriation rather than the random task was quite unexpected. Different hypotheses may account for this result. One is based on a methodological and economic argument. The order in which the circles were drawn in our tasks was, by necessity, different; the smallest one for the seriation, any size for the random task, and systematically one of the two biggest (head or trunk) for the bear task. We observed that drawing increasingly larger circles (seriation) was the most favorable condition for observing isochrony, whereas drawing increasingly smaller figures (the bear task) was the least favorable. When a series of circles is to be drawn, it is possible that the first figure would be drawn with maximally controlled movement, involving a lower velocity than would be spontaneously selected for tracing a figure of that given size. Underestimating the velocity for a small size (seriation) might be a favorable condition for isochrony, because velocities will necessarily increase afterwards both because of the increasing size and a weaker control of movement. By contrast, underestimating the velocity for a big size (bear) might have the reverse effect on isochrony. From this line of reasoning, the random task would constitute the more appropriate context for measuring isochrony, and the context effect we reported here would mainly be due to an anchoring effect on the first executed figure.

Asking the subject to draw a series in decreasing order of size would be an important test of this hypothesis and was done in a pilot study (Mounoud et al, 1985). However, the results reported there do not lend support to our present methodological argument. Isochrony was also high in that drawing context, and a developmental trend similar to the one we observed in the present study was reported. Thus, a more substantial hypothesis may be suggested. We may argue that the seriation context constrains the subject to globally planning movement over the entire series. The subject's goal is seen not as the execution of a particular movement size, but as the execution of a particular size increment which does not change through the series. A corresponding velocity increment would be associated with the selected amplitude increment, and would remain approximately unchanged over the series. A good covariation between perimeter and velocity would result from such global planning. The seriation task would be a facilitating context for isochrony but the random task would be neutral. The bear task might appear to be a non-facilitatory task because of the predominance of local size differences.

Our results show that if isochrony characterizes movement from an early age, it undergoes non-monotonic development. This was clear in both the random and the seriation task, where a decrease between 5 and 7 years and then an increase in performance was observed. Isochrony surely constitutes a very basic property of human motor organization; however, it cannot be conceived of as an automatic compensatory mechanism. The kind of development that it undergoes during childhood shows that determinants of a higher order intervene in this process. The explanations offered currently to account for this discontinuity in motor skill acquisition are all interesting, but, in our opinion, none may be sufficient.

Hay (1981) suggested that the decline in performance at around age 7 was mainly due to the use of visual and kinaesthetic feedback processes to calibrate movement. Consistent behavioural evidence lends support to this hypothesis (see, for instance, Corbetta, 1989, for a similar finding in a bimanual coordination task), but it is also known that infants go through a similar developmental progression for reaching movements. They strongly rely on visual feedback processes between 4 and 5 months of age, and again between 7 and 10 months (Bushnell, 1985; von Hofsten, 1980; Mounoud, 1983; Lasky, 1977; McDonnell and Abraham, 1981; Vinter, 1990). If the use of visual feedback to calibrate movement inevitably involves a decline in performance, and thus is non-monotonic in development, what must be explained is why such phases are recurrent in development. Therefore the question remains: why does movement need to be visually calibrated several times during development? And why do the non-monotonic periods always occur after a phase of competence in which movement is correctly pre-programmed?

Wann (1986) stated that a non-monotonic trend in handwriting acquisition may be due to the fact that at a certain time in the acquisition process, writing pressure (on the pen) may be responsible for the dysfluency of stroke production. Writing pressure would be higher at a certain time of development because, in learning to write, the child has to perform smaller and more continuous strokes, involving the more distal parts of hand and finger muscles. This factor may be important, but it is strictly linked to writing skill. However, a non-monotonic trend seems to characterize many motor skill acquisition processes, with rather conclusive evidence for a critical period at around 7 years.

Meulenbroek and van Galen (1988) suggested that the decline in performance observed in handwriting with respect to some parameters (number of velocity inversions) may occur because children at this age try to produce more accurate shapes of the graphemes. We did not observe more accurate size reproduction at 7 years, but nevertheless reported greater regularity for the spatial aspects of drawing movements at this age than earlier. The implicit hypothesis of Meulenbroek and van Galen is that decline at one level benefits progress at another level. A non-monotonic trend would emerge as long as higher control is put on some aspects of movement without the capacity to integrate or coordinate these specific aspects with the other. From this perspective, a fundamental determinant of discontinuity might be searched in the manner that behaviour (or movement) is segmented. The segmentation problem is certainly one of the important questions in developmental psychology (see Mounoud, 1986; Vinter, 1988), but it still remains unclear why behaviour should undergo a segmentation process several times in development.

Mounoud (1981) stated that different coding systems appear during development at defined ages (the conceptual coding system appearing at around age 2), implying a repetitive process of knowledge construction. Motor skills would not escape this recurrent re-building process. Therefore, during childhood, conceptual factors transform characteristics of the perceptual-motor coordinations that already exist or that are established during this time. Thus, behaviour is always under the control of at least two organizations that depend on the coding system upon which they are based. Although appealing, this model does have an important shortcoming in regard to the discontinuity problem, because it does not take into consideration the role that the level of complexity of motor skills can play in the appearance of these non-monotonic periods.

How can we account for our results with this latter perspective? The performance of the 5-year-old children, which seems optimal with regard to isochrony, may be controlled by the previous perceptuo-motor behavioural organization, and not yet be affected by the re-building process that characterizes developing conceptual organization. When children become sensitive to the logical structure of a seriation task, with respect to the property of length, (which requires a primitive understanding of transitivity and occurs at around 6 years according to Piaget and Inhelder, 1941), a temporary disorganization between temporal and spatial aspects of movement may result. Seven-year-old children would be completely focused on the necessity of producing a regular trace length increment, adopting in consequence a stronger control of movement, with a strategy of constant velocity. Visual feedback is strictly needed at that time. Then, between 8 and 9 years, movement can be released from this control, and children can focus on accuracy and learn to coordinate absolute with relative size reproduction. At that point, movement can again manifest one of its natural and spontaneous characteristics (isochrony).

In conclusion, beyond the developmental aspect, our study suggests that context plays an important role in the assessment of drawing skill, although this role may interact with age. Detailed task analysis appears indispensable for such an assessment, and may constitute a fruitful direction of research for the understanding of motor skill acquisition.

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