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ONTOGENESIS OF TEMPORAL LEARNING IN THE CHILD EXPERIMENTAL EVIDENCE AND PERSPECTIVES

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This article presents a critical overview of the studies on the development of temporal learning in children aged 1 to 7 years by the present author and her collaborators. To "question" subjects as young as this, a non-verbal method was used, adapted from temporal operant conditioning procedures. The first set of studies shows that up to the age of 4 1/2 learning to regulate one's actions in time takes place through shaping by reinforcement contingencies. It is not before the age of 7 that learning is controlled by rules, which themselves are based on both the knowledge of what a time interval is, with initial and final boundaries, and a mastery of chronometric units. The group's more recent studies on children aged 4 to 7 show that they can use both this knowledge and chronometric counting in "enhancing" contexts (with appropriate instructions and duration indicators). This suggests that there is no discontinuity between the conditioned temporal regulations acquired by the younger children and the rule-based regulations acquired by older children. Lastly, it is argued that to further increase our knowledge of how later temporal abilities relate to earlier ones, there is the dual necessity to both confront data obtained in recent studies with various methodological and theoretical approaches, and to study the maturation of internal timing mechanisms.

INTRODUCTION

The original motivation for the research programs described in this paper was to fill certain theoretical and empirical gaps in the field of the developmental psychology of time. Piaget's (1937; 1946) pioneering works showed that the notion of time is mastered relatively late in development, even though his own observations indicate that the infant gradually becomes aware of temporal order and duration through his or her actions. Further, what emerged from works by Fraisse (1957; 1982) was the dual idea that there is an early intuition of time and that the mastery of time is an achievement specific to human adults. For these reasons it was worthwhile to further explore the ways in which the young child, roughly between the ages of 1 to 7, performs on tasks which require perception and appropriate estimation of the passage of time. This period of development is beyond the infant's primary (i.e. reflex and a-causal) circular reactions, yet is before the acquisition of reflexive thought and abstraction characteristic of adult knowledge of time.

This article presents a critical overview of the series of studies conducted with my coworkers over the last ten years. These works were aimed at analyzing the development of temporal behavior in children from the age of 8 months to 7 years, and were designed to answer the following question: Is the adult notion of time the outcome of a continuity in evolution, whose roots can be traced to early temporal behavior or, on the contrary, does the adult notion result from a reorganisation of processing mechanisms due to acquisition of the symbolic function and development of cognitive processes? This overview is followed by a description of current avenues of investigation we are engaged in to further explore the responses we have obtained on this difficult question.

Investigative context and choice of methodology

The lack of studies ten years ago on the temporal behavior of children between the ages of 18 months and 5 years was not only the outcome of theoretical orientations, but was also connected to the problems encountered by researchers in developing appropriate procedures for "questioning" young children about their abilities and knowledge. Piaget (1946) himself pointed out that "there is a period ranging from the age of 1 1/2 years to the age of 4 during which time questioning is impossible". However, ingenious solutions have recently been developed to overcome this methodological obstacle. These include, for example, delayed imitation techniques of short action sequences or the narrative method for determining the abilities of 2- and 3-year-olds to represent and describe event temporal order (Bauer & Mandler, 1989; Nelson, 1986; O'Connell & Gerard, 1985).

Our approach to study how young children adapt to duration (i.e. perceive and estimate duration of actions or intervals between actions) was to use temporal conditioning procedures drawn from operant methodology. These procedures are non-verbal but, as discussed below, can also be used with older children having greater language mastery. The first studies employed a Differential Reinforcement of Low Rates schedule (DRL) in which the subject must learn, after having emitted a response, to wait until a certain interval has elapsed before making another response. We felt that this task would be suitable to study changes in adapted conditioned responses to duration as the child acquires the "tools" which enable him or her to self-represent what a time interval is and how to measure it. The DRL situation associates two components: "waits" and estimate of duration. Waiting behavior, the step which, according to Janet (1928), separates need and its gratification, is something children encounter when they are very young, for example waiting for the bottle. Can however young children regulate their activity to adapt to the temporal constraints placed upon them? Which means do they use to estimate the delays? Do these means change over time? Studies conducted using the DRL provided a certain number of answers to these questions.

CHANGES IN CONDITIONED RESPONSES TO DURATION OVER THE COURSE OF CHILDHOOD

The main findings, which are presented in much greater detail in Pouthas (1985), can be summarized as follows. Between the ages of 8 and 24 months, children can learn to space their responses in time until they obtain a pleasant event (reinforcer). Acquisition of this temporal regulation is enhanced by the production of gross motor activities which fill the waiting interval. However the regulation acquired through these collateral activities, which are concurrent to the operant response, tends to be inaccurate, and the "waits" are much longer than the target duration (DRL 5 sec.) as is shown by the interresponse interval distributions (see Figure 1 A).

Between the ages of 4 and 7 different types of performance coexist. Some 4 1/2-year-olds cannot regulate their actions in time and their interresponse intervals are, like those of younger children, too short or too long (Figure 1B). Instructions which focus their attention on the temporal features of the task considerably improve performance (Pouthas & Jacquet, 1987). Other children at the same age can accurately estimate the waiting interval without specific instructions (Figure 1C), most of their responses approximate the target duration. In addition, some of these children exhibit fine finger movements. The fact that the number of these movements was directly related to the duration of the interresponse interval (Pouthas & Jacquet, 1987) suggests that these finger movements may have been an early form of counting.

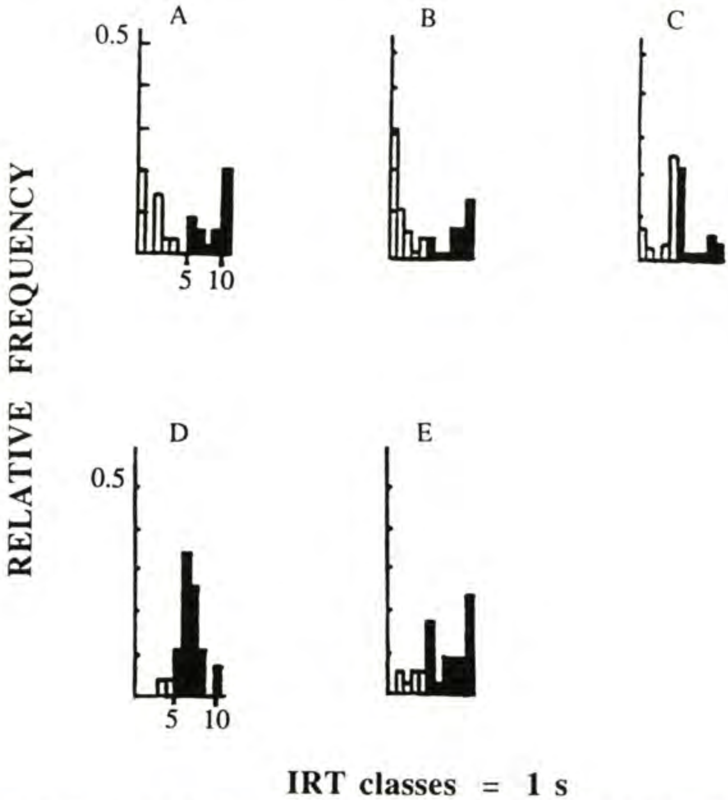

Figure 1. Examples of individual interresponse time distributions for the last DRL 5 s training session. A: 2-year old subject; B , C: 4 1/2-year-old subjects; D, E: 7-year-old subjects. Shaded columns indicate reinforced interresponse times.

However, any interpretation of the overall results for the 4 1/2-year-olds should be made with caution. Whether they received instructions specifying the temporal features of the task, or whether they developed forms of "counting", none of these children could describe the "rules of the game" at the end of training. Rather, they could only show how they had played.

All the 7-year-old subjects learned to delay their responses. Some waited longer than necessary (Figure 1E) as though they were incorporating a "margin of error", whereas others estimated the waiting interval accurately (Figure 1D). However none of the subjects mentioned that they used counting as a means of measuring the interval.

EMERGENCE OF COGNITIVE REGULATION OF ACTION

The data summarized above show that some complex forms of temporal learning such as those required in DRL (estimating the waiting interval during which one's action must be delayed before execution) are possible as of early childhood. However these data also show that these acquisitions are not based on complex representations of time (a quantifiable dimension) until middle childhood. This is congruent with findings obtained in other theoretical frameworks (Piagetian and Psychophysical) and with other methodologies (comparison and reproduction of durations). This prompted us to delve further into the issue which first stimulated research in this area; namely, what are the ties between adaptation to time in the very young children and the complex temporal judgments of older children? A new series of studies on 4 1/2- to 7-year-olds was therefore initiated.

The operant situations were maintained, but in order to better focus on the emergence of temporal knowledge in this age period and on its role in the transition from conditioned regulations to more cognitive ones we provided the subjects with "cognitive assistance" in the form of various types of information: verbal, demonstrations or duration indicators, or external clocks. The hypothesis was that this information would encourage the children to use recently acquired knowledge (concept of the time interval with initial and final boundaries, and the concept of measurement). The studies described below illustrate this approach.

In a first experiment (Pouthas, Droit, Jacquet & Wearden, 1990) using a response duration production task, which required making the response last a certain amount of time, 4 1/2-year-olds were shown to exhibit temporal differentiation under minimal instructions which did not refer to the temporal dimension of the task. However, without an explicit temporal instruction, operant behavior at this age was clearly shaped by the dependency relations between response and reinforcement, and was not the behavioral expression of an explicit rule related to key-press time. In this minimal instruction condition, correct performance was not associated with verbalizations on duration until the age of 11. Seven year-olds were in most cases guided by an irrelevant rule such as amount of pressure on the key. In a further study we examined the role of instructions which focus young children's attention (aged 4 1/2 and 6) on the temporal constraints of the task (Lejeune, Pouthas & El Ahmadi, 1992). The working hypothesis was that (i) verbal instructions ("to play well you must press for a certain amount of time") or (ii) demonstration (the experimenter performed the correct response three times) would enhance the formulation of temporal rules by children under seven, and that these timing rules would be associated, as is the case for older subjects, with adapted temporal behavior. The findings confirmed this hypothesis.

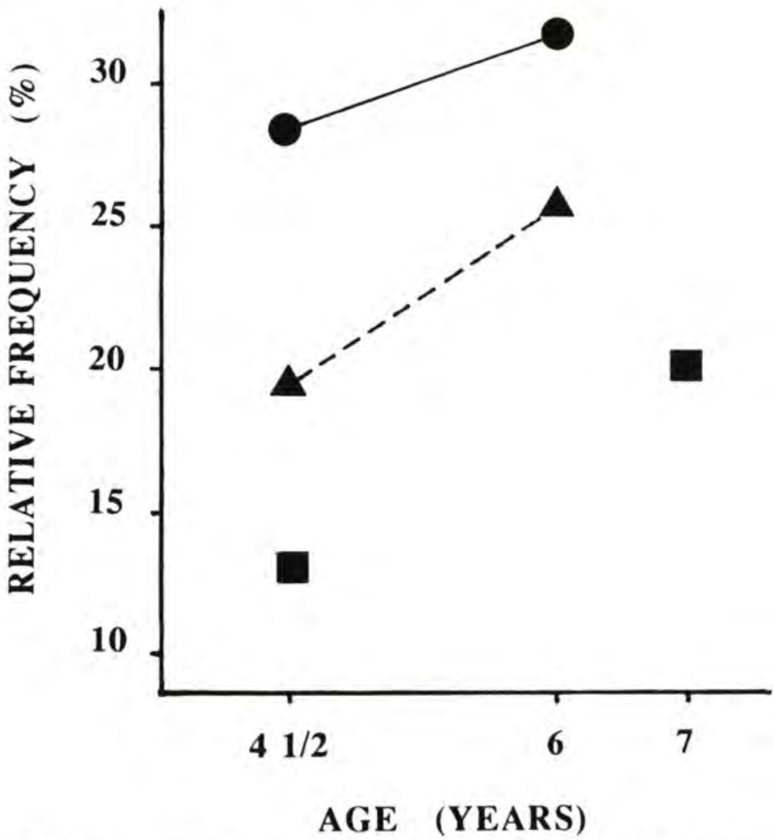

Figure 2. Mean percentage of correct response durations as a function of age and instruction type (dots: instructions by demonstration; triangles: verbal instructions; squares: minimal instructions). (Redrawn from Lejeune, Pouthas, & El Ahmadi, 1992).

The mean percentage of correct responses was higher in subjects who received instructions than in 4 1/2-and 7-year-old control subjects who were only given minimal instructions on a similar task (Figure 2). In addition, there were significant correlations between the percentage of correct responses and the percentage of temporal verbalizations in 4 1/2-year-olds under verbal instructions (Rho = +.719, $p<.005$) and in 6-year-olds for both types of instructions (verbal instructions: Rho= +.863, $p<.001$; demonstration: Rho = +.471, $p<.05$). Six year-olds were able to explain the rule they used, not only when they were given explicit verbal instructions, but also when they only had demonstrations. These data thus strongly suggested that operant temporal behavior could be controlled by rules with explicit reference to time even before the age at which children are assumed to reach the level of complex temporal knowledge and differentiated cognitive representations.

In another series of experiments we tested whether children aged 4 to 6 could extract temporal information from duration indicators. In the first study (Droit, Pouthas & Jacquet, 1991), 4 1/2- to 6-year-olds were given four DRL training sessions. During the first two sessions, a luminous array composed of small diodes went from green to red to indicate the time course of the wait. The two final sessions were run without the array. Performance at the end of the first two sessions were comparable for the two age groups. Age-related differences appeared when the external timer was suppressed. The performance of the 6-year-olds which demonstrated acquisition of temporal regulation derived from awareness that the luminous array was a "duration counter", as was shown by verbalizations recorded during the interviews conducted after the last "clock" session. The subjects explained that "you have to wait until the buttons (diodes) are all red". In contrast there was a rapid decline in performance in the 4 1/2-year-olds when the "clock" was suppressed. The verbalizations of 4 1/2-year-olds indicated that they only used part of the available information; namely, the response signal when the last diode turned red. They said for example that "you have to press because the red is at the end". They did not take the other piece of information into account — the duration of illumination of the entire array — which provided a measure of the waiting time.

We then conducted a second experiment (Pouthas & Jacquet, 1993) with an approach parallel to one developed by Wilkening, Levin and Druyan (1987). These authors conducted an experiment showing that children use counting to estimate a duration, well before the age of ten — the age at which it is generally assumed that children are able to do so. In their experiment, 5-, 6-, and 7- year-olds were asked to reproduce the total duration of illumination of a bulb (which went on twice successively) in the presence of a metronome which beat once per second. The metronome (rhythmic segmentation) was found to enhance access to a counting strategy in some of the 5-and almost all the 6-year-olds, who did not use this strategy spontaneously. We trained 4 1/2-year-olds and 6-year-olds on a DRL 5 sec. schedule for four sessions with an "auditory-visual metronome" (which produced a flash and a beep every 800 ms, hence between 6 and 7 events for a 5 sec. delay), and then two additional sessions without the metronome. The rationale was the following: (i) the metronome did not provide a perceptually salient signal of the end of the waiting interval because it only stopped when the wait was equal or superior to the required interval; (ii) the metronome could help younger subjects (4 1/2) trigger a "behavioral clock" such as a motor rhythm (feet or hand tapping in synchrony with the metronome) or finger movements, both of which are precursors of counting. The metronome was also thought to prompt 6-year-old subjects to count its beats to estimate the response interval, since it has been shown that counting is not observed before the age of 11 when no metronome is provided (Pouthas, 1985). The performance of the two age groups was comparable both at the end of the four training sessions and during the fifth and sixth sessions, as shown in Table 1.

Table 1. *Percentage of Reinforced Interresponse Times for the Fourth, Fifth and Sixth DRL 5s Training Sessions in 4 1/2- and 6-year-old Children*

	Session 4	Session 5	Session 6
4 1/2-year-olds	60	57	55
6-year-olds	65	61	65

Note. Session 4: with the metronome. Session 5, 6: after suppression of the metronome.

On particular interest is the performance of the youngest (4 1/2-year-olds). In contrast to what was observed in the luminous array experiment, their temporal regulation did not deteriorate when the metronome was suppressed. The subjects used the temporal information provided by the metronome, as is shown by the comparison of their performance to that of same-age subjects (Table 2) who were given instructions to wait between each key press (verbal instructions) at the start of training and subjects who received no information on the temporal constraints of the task (minimal instructions) before performing it. At the end of training they performed as well as the wait-instruction subjects and were better than the no-temporal instruction subjects.

Table 2. *Percentage of Reinforced Interresponse times for the First and the fourth DRL 5s Training Sessions in 4 1/2-year-old Children*

Session	Conditions		
	Minimal Instructions	Verbal Instructions	Metronome
1	38	66	36
4	35	71	60

What emerges from the metronome condition is that from the first to the fourth session 4 1/2-year-old subjects learned to estimate the duration of the wait. This learning was probably made possible because the subjects extracted information from the metronome (for example, by perception of a certain quantity of events?), even though they did not refer to this in the interview conducted after the fourth session. In addition, when mastered via exposure to the metronome, this temporal regulation was stable since it was maintained at a comparable level when the metronome was suppressed.

These studies, along with others which cannot be reported here, show that when provided with instructions or appropriate means (such as measurement and duration devices) children can employ knowledge which is generally believed to be acquired or mastered much later in development. This suggests that young children have actually acquired this knowledge, but have trouble implementing it or generalizing it to the set of situations and contexts they are asked to deal with.

New directions

The initial experiments provided data on young children's temporal behavior between the ages of 8 months and 7 years, an area in which experimental data were scanty. Later experiments delved more deeply into the core issue at hand by focusing on the age period of 4 1/2 to 7 years. However, what remains unresolved is the way in which the transition takes place between the temporal regulations acquired by the youngest subjects, which we termed conditioned or automatic responses, and the rule-governed regulations of older subjects presumably based on a more complex representation of the task (Droit & Pouthas, 1992). It is difficult to go any further in disentangling the role of acquisition of linguistic tools and the role of acquisition of specific temporal knowledge in this transition, because we run up against a methodological difficulty in that the interview imposes high demands on subjects' verbal skills. It would be erroneous to argue that because children below the age of six do not know how to explain what knowledge they are implementing to learn how to accurately time their actions, they do not have an implicit awareness of what a temporal interval is and how to measure it, since we have empirical evidence that they understand and follow appropriate verbal temporal instructions given by the experimenter (Lejeune et al., 1992; Pouthas & Jacquet, 1987). Similarly, Levin (1989) stresses that it is not because children do not use counting spontaneously that they do not view time as a measurable quantity since they count more frequently in the presence of a metronome. This commonality of conclusions between works from different theoretical frameworks using different methodologies opens up new heuristic directions. These consists of comparing and contrasting recent studies with a diversity of approaches which have attempted to place young children in "contexts" enabling them to use their knowledge and representations of temporal order (Bauer & Mandler, 1989; O'Connell & Gerard, 1985) or duration (Richie & Bickhard, 1988; Friedman, 1992). Synthesizing the data from these studies should constitute a further step in understanding of how the abilities that appear late in development, such as cognitive and symbolic representations of time, relate to earlier developed abilities in experiences of enacted and perceived time.

In closing, it should be stressed that the approach described above is not sufficient to account for the factors underlying changes in temporal behavior during childhood. The role of maturation should not be overshadowed, whether it concerns temporal mechanisms per se or inhibitory mechanisms. The latter are indeed involved in the acquisition of temporal regulation of activity. In particular, motor timing presupposes the ability to delay actions or make them last (in other words, not interrupt them). Several studies suggest that there is dramatic development of inhibitory abilities between the ages of 5 and 7 (Lovaas, 1964; White, 1964) and correlatively an improvement in the ability to space two responses in DRL (Stein & Landis, 1978). Only speculative hypotheses can be put forward regarding the maturation of temporal mechanisms (oscillators or "clock(s)"), since there is practically no data in this area. Hicks (1992) suggests that changes observed in timing after 5 years of age may be related to the maturation of Contingent Negative Variation (CNV) a slow negative potential which, in the adult, is recorded in waiting situations, response preparation, and estimates of delays (Macar & Vitton, 1980; Macar, Vitton & Requin, 1976). The scarce available data on the child show that CNV is rare (Walter, 1971) or tends to be positive (Otto & Reiter, 1984) before the age of 5 and that it takes on the adult form at age 6 (Cohen, 1973).

These new directions for future research exemplify how important it is to further increase an interdisciplinary (psychobiological and cognitive) approach so as to characterize the multiple factors underlying the development of time estimation and timing of actions over the course of childhood.

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