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The Ability To Perceive Duration: Its Relation to the Development of the Logical Concept of Time

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Seventy-two children, ages 34 to 73 months, were presented with one of six different relative duration problems that involved judging which of two lights was on longer. In addition to the traditional 4- versus 7-s duration condition, each child was tested on a long (4- vs. 28-s) and a short (1- vs. 7-s) condition. Two of the problems were logically impossible to solve on the basis of nontemporal cues. Results showed that, contrary to predictions based on standard models of the logical time concept, long and short conditions were easier for children to solve than the traditional 4- versus 7-s condition. Furthermore, children were able to solve problems that are logically impossible to solve on the basis of nontemporal information. These results indicate that children have a perceptual experience of duration separate from one derived inferentially from nontemporal knowledge (e.g., start/stop relationships, speed, distance, and brightness) and that they can use this perceptual knowledge to solve relative duration problems. This suggests that the logical time concept involves the capacity to experience duration perceptually and that models of the time concept that do not acknowledge such a capacity (e.g., Piaget's) must be reassessed.

The question of the nature of time has fascinated philosophers and scientists for centuries (cf. Fraser, 1975), but no consensus concerning its nature has emerged. The most influential theory of the development of the concept of time is that of Piaget (1969a). In Piaget's model, the child constructs the concept of time from information extracted about speed and distance. According to Piaget, this construction is necessary because the child cannot perceive duration directly: Because perception occurs through inferential processes operating on *temporally discrete* sense data (Piaget, 1969b), the perception of time and its duration must be inferred from other knowledge—duration, by its nature, cannot be a temporally discrete perception. These presuppositions are reflected in Piaget's methodology for investigating the development of the concept of time, the classic two trains problem. In this paradigm, the child is asked to make relative duration judgments comparing the elapsed travel time of two trains, which may vary in terms of start point, stop point, speed, and distance covered.

It should be noted that there is a possibility of misunderstanding Piaget's commitment to the position that duration cannot be perceived, which is due, in part, to ambiguities in Piaget's writings. For example, at one point in *The Child's Conception of Time* he speaks broadly of an intuitive time sense that arises from "successions and durations given by direct perception" (1969a, p.2). This is inconsistent with the position that he takes throughout the rest of that book, however, in which he explicitly specifies (e.g., p. 44) that intuitive time arises out of the coordination of perceptual information about succession only. Even in this limited sense, intuitive time is held to be insignificant for the development of the logical time concept. In addition, a contention that Piaget intended intuitive time to include the direct perceptual experience of duration in some way would be inconsistent with his model of perception (Piaget, 1969b), with the major Genevan effort in the 1960s to research questions about time (e.g., Grize et al., 1966), and with Piaget's last major statement on the development of the time concept (Piaget, 1970) nearly 30 years after his initial work (Piaget, 1969a) on that question. There (Piaget, 1970), he unequivocally asserted that duration cannot be perceived: "A temporal duration, however, no matter how short it is cannot be apprehended all at once . . . any knowledge of time presupposes a reconstruction on the part of the knower" (p. 61). Instead, time (duration) requires a coordination of two more basic things: "Time is an intellectual construction. It is a relationship between an action . . . and the speed with which it is done . . . . This relationship is not a primitive intuition" (p. 70). He further states that "we appear to have a direct impression of subjective time, but on looking more closely, we see that . . . the same relationship is in play here" (p. 75). Thus, the logic of Piaget's position requires a coordination of speed and distance or some logical stand-ins whose coordination also yields time. That is, not only must time be constructed, it must be constructed from the coordination of more primitive percepts.

For Piaget, then, the intuitive time sense (1969a) cannot be involved in the development of the logical concept of time, be-

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cause it can only produce a notion that time has passed, not a sense of how much time has passed. That requires coordinations. These do not have to be coordinations of external events, but they do have to be coordinations. Piaget (1970) makes this point strongly when critiquing Fraisse's (1963) proposal that the subjective sense of time results from the number of events or changes that are noticed. Piaget points out that a notion of the frequency of events is necessary for Fraisse's model to work, because, for time judgments to be made, frequency (speed) information must be coordinated with knowledge of the number of events that are noticed. He concludes (1970, p. 74) that it is the *speed* of events that "seems to be playing the deciding role" in the judgment of duration. Most researchers after Piaget have maintained, or at least not challenged, this commitment to the nonexistence of, or the absence of a developmentally relevant role for, duration knowledge that is not inferentially constructed. This is evidenced by (among other things) the absence of investigations where the time parameters are variables of interest.

Piaget's model has come under considerable theoretical (e.g., Fraisse, 1963, Richie, 1982/1983), empirical (e.g., Berndt & Wood, 1974; Levin, Wilkening, & Dembo, 1984), and methodiological (e.g., Wilkening, 1981, 1982) criticism. This criticism resulted in acknowledgment by the Genevans that at least some modifications of the initial Piagetian stance were necessary and in attempts to make such changes (e.g., Montangero, 1977, 1979), but the assumption that there was no directly experienced duration component involved in making relative time judgments had remained unchallenged. The belief that time knowledge must be constructed from information other than experienced duration is the underlying assumption (most often implicit) of virtually all of the developmental research on the logical concept of time (e.g., Acredolo & Schmid, 1981; Levin, 1977; Siegler & Richards, 1979). The apparent reason for this belief is that most researchers, implicitly or explicitly, have accepted the same general type of model of perception as Piaget and, therefore, have been forced to the same general model of time perception. However, this traditional view that perception is based on encoded discrete sense data is not the only one possible, despite its continued dominance in contemporary approaches (e.g., information processing), and the arguments against it are powerful enough to make its continued uncritical acceptance counterproductive (e.g., Bickhard & Richie, 1983; Gibson, 1979).

Thus, although the question of whether children can noninferentially perceive duration is vital to the explication of the logical time concept (Fraisse, 1982), it has never been shown that children possess such abilities and can use them in relevant contexts. Standard models of the development of the logical concept of time deny that duration knowledge that is not inferentially constructed plays a role in that development. If one wants to make any developmental claims (Campbell & Richie, 1983) about the relationship between duration perception and the logical concept of time, it is necessary to test whether children can use noninferential duration information in contexts similar to those that require the logical time concept. The purpose of the present study was to conduct such a test.

It is known that children of 4 to 6 years of age can give correct relative time judgments if not presented with confusing nontemporal cues (Levin, 1979). All existing studies have used time intervals on the order of 5 s, with ratios (shorter to longer duration) of approximately 1:2 or 2:3. It is unknown if changing the perceptual characteristics of the traditional relative time judgment situations by changing the durations involved and their ratios would permit children to make correct relative time judgments. If a perceptual duration judgment capacity exists, extending the differential between the time units involved (or exaggerating their ratio—or both) could make this capacity salient enough that children would use it to make accurate time comparison judgments even in the face of confusing cues.

Levin (1979) had children make relative duration judgments comparing two lights, one bright and one dim, which had synchronous onset and dysynchronous offset, or vice versa. The intensity served as a distractor variable to make the task comparable with the standard two trains problems, which require coordination between speed and distance information in order to make relative duration judgments. Levin found that children's pattern of performance on these tasks was similar to their performance on the two trains version, thus showing that speed and distance per se were not necessary to duration inferences. The logical structure of the stationary-light problem allows for unambiguous control of all cues (because relative brightness is independent of elapsed time for suitably long intervals), thus making it possible to isolate experimentally the impact of varying the time parameter (i.e., Does it make a problem easier or harder?). Levin showed that children have the same difficulties on relative time judgment problems involving bright and dim stationary lights as they do with the analogous classical Piagetian task with two moving trains. Consequently, conclusions drawn about Levin's tasks should also apply to the classic linear motion form of the problem.

The experimental logic is simple. Because the brightness of the lights does not change as the time parameters change, conditions can be produced in which only the time parameter varies. The logical inference form of the solution to these problems need not be changed by such variations in the time parameter, so long as those variations do not alter the presumed grounds for the presumed inferences. For example, if B (bright light) turns on before D (dim light) and they turn off at the same time, then changing the length of time that B precedes D does not change the relevant inferential relationship ("B starts first, they turn off together, so B was on longer"). Traditional models view such an inferential relationship as the kind of percepts-and-inference pattern out of which the time concept gets constructed and in terms of which relative time judgments are made. Thus, if variation of metric time parameters within a given problem type makes correct relative time judgments more likely, this can be taken as evidence for some duration sense that can be used in the solution of these problems and that is separate from logical construction: Logical construction problem types are by definition invariant under such time parameter variations.

It should be noted that such a result would not constitute evidence for Levin, Gilat, and Zelniker's (1980) cue saliency model, because a claim that changing the time parameter merely makes the end or start point more salient implies (for traditional models) that saliency itself must be "coded" in memory in some way. But saliency is proportional to the time lapse involved, and time lapse involved is precisely what is at issue here: Because no cues exist out of which the increase or decrease in time involved could be deduced, the increased duration must be directly sensed.

In addition, evidence for a time judgment capacity that is not based on construction from nontemporal cues can be gathered by presenting a situation in which nontemporal cues are useless for determining relative duration. This condition is realizable by letting one light onset *and* offset first. According to the traditional view, children should not be able to answer this question. At best, they should adopt an end point strategy, because there is evidence (Levin, Gilat, & Zelniker, 1980) that end point is more salient to children than start point. However, if children are able to produce correct relative time judgments (i.e., which light was on longer), then they cannot be said to be doing so on the basis of succession or order information, for that is a logical impossibility.

Method

Subjects

The subjects were 36 boys and 36 girls, aged 34 to 73 months (*M* age = 54.3 months), who attended private day-care centers in the Austin, Texas area. There were 6 additional children (5 boys, *M* age = 47 months, and 1 girl, 59 months of age) who could not or would not perform the task and had to be dropped from the study.

Design

Subjects were presented with various conditions of the relative time judgment problem designed by Levin, Israeli, and Darom (1978) and Levin (1979). Children were shown a display consisting of two lights, one brighter than the other. The offset and onset times of these lights were varied systematically to produce the problem types (1–4) shown in Figure 1.

The time parameters of each of these problems were systematically varied, both shortening and lengthening the time units and ratios involved compared with those traditionally used (e.g., Siegler & Richards, 1979). If this manipulation made solution of a problem condition easier than in the trials run with the traditional time durations, then that was taken as evidence that subjects possessed the capacity to use some direct sense of duration to make relative time judgments, because nothing but the time component of the problem was being varied.

An additional set of problems was presented in which only sensed temporal information could be used to solve the problem correctly. These two problems are shown in Figure 1 as Problems 5 and 6. These problems were introduced in order to provide an even more direct test of the standard model. There is *no* onset–offset succession information that will allow correct solution of these problems. Thus, these problems lie outside the framework of the standard duration inference paradigm and should be impossible to solve according to any such onset–offset model. If subjects made correct relative time judgments on these problems, then that was taken as evidence that the duration perception ability exists separate from the ability to make use of succession information, because succession information *cannot* be used to give correct solutions to these two problems. At the time this study was carried out, no such nonstandard problem including a distractor variable had ever been reported, although Levin (1977) used a nonsynchronous onset–offset condition with no distractor varible. Since then, Levin, Wilkening, and Dembo (1984) (citing Richie, 1982/1983, on the possible role of duration perception in the development of the time concept) have also used this problem type.

In these two problems (5 and 6), unlike the others (1, 2, 3, and 4), the two lights were of equal intensity. The brightness distractor was superfluous in the design of these problem types because they should have been logically impossible according to the duration inference models whether or not the brightness distractor was present.

Because it has been shown that the order of presentation of problems like these influences the difficulty of any particular problem (Levin, Gilat, & Zelniker, 1980), at least within the standard time parameters, each subject was presented with only one problem type (e.g., a subject received either Problem 1 or Problem 2, but not both). Subjects were presented with three time conditions (1 vs. 7 s; 4 vs. 7 s; 4 vs. 28 s), which were counterbalanced for order of presentation.

Apparatus

Two light boxes were used to present time judgment problems with the added distractor variable of light intensity. The boxes were made of cardboard and covered with wood-grain contact paper. They measured 16⅛ in. (40.9 cm) in height, 12⅝ in. (31.6 cm) in width and 12⅝ in. (31.6 cm) in depth. A 3-in. (7.5 cm) by 12⅝-in. (31.6 cm) opening, covered with red cellophane, was cut in the front of each box, equidistant from the top and bottom. Each box contained a single, standard, soft white, 25-W incandescent light bulb. Each bulb was connected to a variable (600 W, 120V, AC) rheostat and a series of switches so that the experimenter could control both the brightness and on/off times. The bright light was produced by a full-scale setting on a rheostat. The dim light was produced by determining the lowest setting on a rheostat that would cause a bulb to burn each and every time that the bulb was

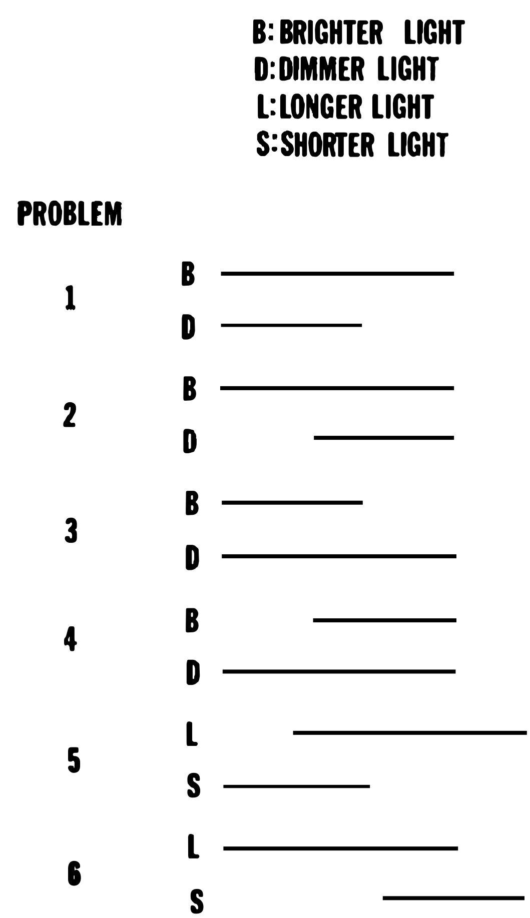

Figure 1. On/off sequence for each of the lights in Problems 1–6.

turned on. This was approximately two-fifths of the full-scale setting for these particular rheostats. There were three switches in the system: One switch turned both bulbs either on or off at the same time, and the other two switches each controlled an individual bulb. This set-up allowed the experimenter to present simultaneous and nonsimultaneous offsets and onsets of the lights.

Procedure

Each child sat a comfortable distance (approximately 4 ft) from the light boxes, which were placed side by side on the floor, facing the child, in a quiet room away from the classroom. The experimenter sat on the floor directly behind the light boxes.

The experimenter presented the situation as a game. Each child was asked to select a prize as a reward for having played the game (the selection was among cans of different colors of Play-Doh). Each child was then presented with three time conditions for one of the six problems discussed in the design section (there were no warm-up trials). The time conditions were 1 versus 7 s (short condition), 4 versus 7 s (traditional condition), and 4 versus 28 s (long condition). The order of the presentation of the three time conditions was counterbalanced between subjects, as were the positions (left or right box) of the bright and dim lights in Problems 1, 2, 3, and 4. The position (left or right box) of the light that was on longer in Problems 5 and 6 was counterbalanced. Within each time condition, either the offset or onset of the longer light occurred at the midpoint of the shorter light's duration. Problem type and position were counterbalanced by sex, as was order of presentation of the time conditions.

Each child received only one type of problem. After each time condition presentation, the child was asked, "Did the lights stay on for the same time or was one on longer?" Children could respond either verbally or by pointing. If the child responded that one of the lights was on longer but did not specify which, the experimenter asked, "Which one was on longer?" A response to this question was required (no prompting was ever necessary), and the response was recorded as either correct or incorrect. The child was then asked (after all three responses had already been made) "How did you tell?", and his or her response was recorded.

Results

The hypothesis that extreme duration conditions are easier to solve than the traditional 4- versus 7-s conditions (Hypothesis 1) was evaluated by a series of Cochran's tests (Hays, 1973).

Combined Analyses

After combining problem types, the intersubject pattern of performance showed that extreme duration conditions were easier to solve than the traditional condition: for the short condition (1 vs. 7 s), 66 of 72 were correct; for the long (4 vs. 28 s), 67 of 72 were correct; and for the traditional (4 vs. 7 s), 53 of 72 were correct, $Q(2) = 26.14$, $p < .001$. This was also the case when only Problems 1–4 (the analogues to the standard Piagetian two trains problems, containing an irrelevant cue, brightness) were considered: for the short condition, 45 of 48 were correct; for the long, 45 of 48 were correct; and for the traditional, 40 of 48 were correct, $Q(2) = 10.0$, $p < .01$. Separate short versus traditional and long versus traditional condition comparisons also reached statistical significance for Problems 1–4, $Q(1) = 8.33$, $p < .005$, for each comparison.

Table 1
Individual Problem Type Analyses

Problem	Time condition: total correct/total possible 1 vs. 7 s	4 vs. 7 s	4 vs. 28 s	Q^a	*p*
1	12/12	11/12	12/12	2.01	*ns*
2	11/12	11/12	11/12	0.00	*ns*
3	12/12	10/12	12/12	4.00	*ns*
4	10/12	8/12	10/12	4.00	*ns*
5	11/12	8/12	12/12	6.50	<.05
6	10/12	5/12	10/12	10.00	<.01

[a] $df = 2$.

Individual Problem Type Analyses

The results of individual problem type analyses are shown in Table 1. Although the overall analysis of Problems 1–4 was significant, none of the individual analyses comparing time conditions within any of the four problem types reached significance, probably because of insufficient statistical power. The individual analyses of Problems 5 and 6 revealed significant differences in difficulty between the traditional and extreme durations, and the 4- versus 7-s condition was the most difficult, as predicted.

The hypothesis (Hypothesis 2) that children can make accurate relative duration judgments in the absence of useful nontemporal information (i.e., succession cues) was evaluated by means of a simple binomial probability estimation to determine whether subjects were reliably solving Problems 5 and 6. The results showed that, indeed, children could answer these problems at far greater than chance levels: For Problem 5, 31 of 36 were correct, $p < .0001$, and for Problem 6, 25 of 36 were correct, $p < .01$. Examining the data for individual duration conditions, performance was above chance in the short (Problem 5, $p < .01$, and Problem 6, $p < .02$) and long (Problem 5, $p < .001$, and Problem 6, $p < .02$) conditions, but not in the traditional condition (i.e., *ns*, for both Problems 5 and 6). Thus, above chance performance on the "pure duration" problems was confined to the extreme duration conditions.

Discussion

It seems clear from these results that 3- to 6-year-old children do possess the capacity to perceive duration noninferentially, that is, without having to infer duration from nontemporal cues in the presented problem. If this conclusion is accepted, then the commonly held position (either explicit or implicit, e.g., Levin et al., 1978; Piaget, 1969a; Siegler & Richards, 1979) that because time cannot be perceived the logical concept of time must *necessarily* develop from the coordination of nontemporal perceptually based cues (e.g., succession, speed, and distance) is not viable. Standard methodological approaches have simply presupposed that duration must be inferred and have attempted to explore the form of that inference. Standard methodological restrictions to small duration disparities have artifactually precluded the observation of noninferential comparisons. This study directly addressed the supposition that duration judgments were necessarily inferentially based and found the supposition to be invalid.

It may be that the logical concept of time does, in fact, develop from the coordination of nontemporal cues and subsequent inferences, without any role for the perceptual experience of duration, but it is not a logical certainty. It is a matter for scientific test. The fact that children in this study could solve problems (e.g., Problems 5 and 6) that are logically impossible to solve on the basis of the nontemporal information suggests that the time concept does involve the capacity to perceive duration in some way, although the exact relationship is unspecifiable from the results of this study alone. Models of the time concept that do not allow for the results of this study and the assumptions underlying it must, at least, be reconsidered.

The positive findings in the combined analyses performed to evaluate Hypothesis 1 clearly indicate that making the temporal characteristics of these problems more extreme than the traditional 4- versus 7-s problem does make the problems easier for children of the age range tested. This was true for problems with and without irrelevant cues. Because duration was the only thing changing among conditions within a problem, the conclusion that must be drawn is that children are somehow perceiving (i.e., have direct experiential knowledge of) those time changes. They cannot be constructing them from nondurational information in the presented problem, for no such duration-redundant information exists.

Convergent evidence on this point is given by the results of the tests of Hypothesis 2. Children could clearly solve problems that were insoluble on the basis of the nontemporal information available. The only useful information available in these problems (5 and 6) was duration, and these children could, indeed, make use of it. Furthermore, it cannot be argued that children were simply adopting a saliency strategy and using end points to make their decision, because both Problem 5, where an end-point strategy would work, and Problem 6, where an end-point strategy would not work, were solvable by these children. Because Problem 6 seemed to be more difficult than Problem 5, however, it may be that end-point salience was aiding performance on the latter and hindering it on the former.

A remaining question is: Exactly why do children perform more poorly in the traditional time condition than in the long and short conditions? If children had the ability to perceive duration exactly, it would seem that they would be able to solve 4- versus 7-s comparisons with as much accuracy as 1- versus 7- and 4- versus 28-s comparisons. Because they do not, it seems likely that the ability to judge duration perceptually has limited discriminatory power. The duration perceptions that underlie the "longer than/shorter than" judgments are not very precise. Children are more likely to rely on inferential judgments that are based on nontemporal cues if the difference between durations compared is not great. However, as the perceptual distinction becomes greater, they are more likely to make use of the directly perceived temporal information (experienced duration). Thus, in the 4- versus 7-s condition, where the perceptual impact of the duration difference is presumably less than in the other two conditions, children with an intermediate level of sophistication in the use of time estimation heuristics can be misled or confused by nontemporal cues. As the impact of the perceptual duration difference increases, they are more likely to override or disregard such potentially misleading cues.

There is an additional point of interest in the data gathered in this study. These children could solve even the traditional conditions of Problems 2 and 3 with relative ease. The work of Levin's (1979) group has suggested that those two types of problems are difficult for 5- and 6-year-olds, but those difficulties were not apparent in this study, even though the children in this study were as young as 34 months. Related to this is the fact that only 6 children had to be dropped from the study because they could not or would not perform the task. There are methodological differences between the studies that might account for this, such as each child being expected to solve several different problem types in Levin's studies.

This investigation suggests several lines of research. Among the questions that need to be answered are: How does this ability to make relative duration judgments that are based on experienced duration develop and how does this ability relate to the suggestion of the existence of some sense of duration in infants (e.g., Allen, Walker, Symonds, & Marcell, 1977; Brooks & Berg, 1979; Chang & Trehub, 1977a, 1977b; Condon & Sander, 1974; Demany, McKenzie & Vurpillot, 1977; Trevarthen, 1977)? These questions are currently unanswerable because there is no research on children between the ages of 1½ and 4 years (Pouthas, 1981, is an exception), and because of the difference in the nature of the questions being asked by infancy researchers and investigators interested in the time concept. Finally, it is certainly of importance to determine the characteristics of the duration estimator. What are its limits? Is it quantized? How is it coordinated and integrated with the capacity to make relative time judgments based on inference? What is its mechanism?

One likely mechanism for the duration estimator would be some form of internal clock. If one or more ongoing sequences of internal events were produced by sufficiently reliable oscillators, and if those sequences could be monitored with regard to length, then this would provide a noninferential source of duration information. Potential forms of such an oscillator and how the information it might provide could be involved in the development of the logical time concept are discussed elsewhere (Richie, 1982/1983; Shaffer, 1982).

There are a number of additional interesting issues concerning the perception and cognition of duration. These include, for example, forms of memory storage and integration with other representational phenomena. Interested readers can find relevant presentations in, for example, Bickhard (1980), Bickhard and Richie (1983), and Campbell and Bickhard (1986).

The immediate implications of this study are that children do have a noninferential sense of duration and that standard Piagetian and non-Piagetian models that do not allow for such a sense need to be reconsidered. The further implications of that point, however, are that the discrete sense data models of duration perception that *require* such inferential models of perception may also be in need of serious reexamination (Bickhard & Richie, 1983).

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