Judging the relative duration of multimodal short empty time intervals

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Three experiments address the cause of the different performance levels found in time discrimination of empty intervals with durations near 250 msec. Performance differed according to the kind of sensory modality that marked the intervals. With a procedure in which the type of marker was randomized from trial to trial, it was shown that variability of discrimination judgments could not be attributed entirely to the variability of the criterion on which a judgment was based. Such a randomization slightly affects discrimination but provokes a reorganization related to marker conditions of the probabilities of judging an interval to be short or long. Moreover, it was shown that within intramodal conditions, physical characteristics of markers influence the discrimination performances. To account for the results generated with different marker-type intervals at 250 msec, we propose that two types of processor may be involved in duration discrimination: one is specifically related to a given sensory modality, whereas the other is aspecific and responsible for discrimination of intermodal intervals.

Much research has been devoted to the analysis of the processing of the time dimension. The extent of this research has given rise to many different theoretical points of view and to a large and somewhat confusing range of methods (Fraisse, 1984). Even within the more limited scope of the psychophysical approach to time, the field remains very large, and the methods are numerous. Allan (1979) suggested that there are two basic psychophysical methods of studying time perception: duration scaling and duration discrimination. In the first method, the researcher is mainly interested in subjects' perceived durations of intervals (Eisler, 1976). In the second, the analysis focuses on variability of a group of responses when observers try to discriminate among relatively short intervals that are liable to be confused. Indeed, even within the area of duration discrimination, research interests have varied from the examination of the effects of additional variables on perceived duration (Massaro & Idson, 1976; Thomas & Weaver, 1975), to the study of the constancy of the Weber

fraction through time in experiments with humans (Getty, 1975; Treisman, 1963) or animals (Gibbon & Church, 1984; Killeen & Weiss, 1987). In the present paper, we address the cause of variability in duration discrimination and reveal a special effect provoked when intervals marked by different sensory stimulations are compared.

Research shows that duration discriminations are not made on the basis of characteristics (intensity, frequency, or bandwidth) of the physical events that mark the intervals (Allan & Kristofferson, 1974). The observed variability of responses is then mainly attributed to the fluctuations of a central timekeeping mechanism. Many theoretical accounts have been provided to describe this mechanism. A classical view is that the timing process resembles a clock-counter system, also known as the pacemaker-accumulator model (see for review Allan, 1979; Killeen & Weiss, 1987). In such a model, a pacemaker generates pulses that are accumulated in a counter. The number of pulses accumulated during an interval, t , is the basis of the evaluation of the to-be-discriminated durations. Assumptions have been made about the rate and fluctuation of these pulses; variations in rates and fluctuations of the pulses are often reported to be a major source of variance in duration discrimination of short time intervals (Creelman, 1962; Divenyi & Danner, 1977; Treisman, 1963).

Other explanations of variance in duration discrimination have been reported by Kristofferson and his colleagues. For Allan, Kristofferson, and Wiens (1971), variability in time discrimination is not related to pacemaker variability but to the perceptual latencies of an "onset-

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offset" mechanism. They assume the pacemaker to have a zero variance, since the quantal pulses occur at regular intervals, and they assume the accumulator process to be error free. Kristofferson (1977) has further developed an alternative to the interval-timing framework. In his real-time criterion theory (RTC), errors in duration discrimination are all due to the variability in the criterion.

Whether the variance in duration discrimination is mainly attributed to some clock-system properties, to an "onset-offset" mechanism, or to a real-time criterion, there are still some fascinating phenomena reported in the duration discrimination literature that raise problems for a general theory of time estimation. Time-order-error and filled interval illusion are important and well-known phenomena (Allan, 1979; Fraisse, 1978). Another special effect has been observed in duration discrimination when empty intervals are bounded by signals provided by two different sensory modalities (Collyer, 1974; Rousseau & Kristofferson, 1973; Rousseau, Poirier, & Lemyre, 1983). The increased Weber fractions reported with intermodal markers remain unexplained, since they cannot be accounted for by properties of an internal clock or by the perceptual latency properties of one or both markers.

Our purpose in carrying out the present experiments was to gain a better understanding of the cause of the various levels of performance found for a given order of duration—namely, that around 250 msec—when different sensory stimulations mark the intervals. Experiments 1 and 2 both provide several opportunities for investigating the central timekeeping mechanism. More specifically, these experiments were designed for the purpose of testing predictions following the RTC theory (Kristofferson, 1977). Since all the variability of responses is attributed in this theory to the criterion on which the judgments are based, to create experimental situations in which different types of intervals are compared to each other should favor a reduction of the range of performance levels normally observed in duration discrimination. Indeed, let us focus on one aspect of the task when an observer has to discriminate short empty intervals presented according to the single stimulus method. During a given standard discrimination session, the observer is presented intervals marked by the same sensory stimulation for a whole block

of presentations and sometimes for the whole session or the whole experiment. In such a case, performance would be related to the efficiency of a criterion generated according to the properties of both markers involved in the block or session. On the other hand, randomizing the type of marker from trial to trial ought to lead to a utilization of a nonspecific marker criterion. Then, variability of this criterion should appear to a similar degree with each marker-type interval. Therefore, a convergence of the different levels of performance would be expected, since discrimination errors are all supposed to be due to the variability of the criterion.

This randomization, whose effect we tested in the first two experiments, also gives rise to a second prediction derived from the RTC theory. In his model, Kristofferson (1977) specifies that each energy pulse P that marks an empty physical interval causes an internal event B following an afferent latency α . P_1 will cause B_1 , which will trigger the criterion C after an internally timed delay I (see Figure 1). He also assumes variance of α_1 and α_2 to be zero but maintains that their latencies would probably not be identical. There is more reason to believe that these latencies will not be identical if different sensory modes provide P_1 and P_2 signals. Suppose two signals, X and Y , provide afferent latencies α_{X1} and α_{Y1} after P_1 and α_{X2} and α_{Y2} after P_2 . If α_{X1} and α_{X2} latencies are greater than α_{Y1} and α_{Y2} latencies, the probability of an observer's considering the interval marked by X – Y to be short is greater than the probability of judging the interval short with a Y – X sequence if the judgment is based on a common criterion. Randomizing the type of marker within a block of trials should produce a comparison on the basis of a common criterion and therefore permit the testing of an expected effect due to the relative duration of intervals.

In Experiment 1, two series of duration discrimination sessions were conducted. Subjects were required to discriminate between two short empty time intervals presented according to the single stimulus method. In the first series of sessions, the subjects knew the sensory modality in which the markers were delivered. In the other series, the uncertainty condition, the subjects were not informed, at any given trial, about the stimulation employed to de-

Figure 1. Schematic of the real-time criterion hypothesis (from Kristofferson, 1977).

termine the markers. Two different auditory signals and two different visual signals were all potential stimulations to mark the onset and the offset of the time intervals. Therefore, 16 different conditions were studied.

EXPERIMENT 1

Method

Subjects. Six volunteers, from 18 to 24 years old, participated in this experiment. They were paid \$5 per session.

Apparatus and Stimuli. The observers were seated in a chair in a dimly lit room and were asked to respond "short" (R_s) or "long" (R_l) by depressing the appropriate pushbutton. Beside each button, there was a small light providing feedback after each trial. The auditory markers were delivered binaurally via a headphone (Sony DR-5A). One auditory signal (A) was a 1-kHz tone with an intensity recorded at 96.5 dB for each ear. The other auditory signal (a) was a white noise composed of 80 random frequencies selected from a 20-kHz frequency range with an intensity recorded at 85.5 dB for each ear. There were two visual markers, each consisting of a small circular light-emitting diode situated about 1.1 m from the subject. One visual signal (V) was delivered in front of the subject and the other (v) was placed 20° in the left visual field. The experiment was completely under microcomputer control (Zenith ZFA-121-52) with timing accurate to about 1 msec.

Procedure. The observer had to discriminate between a 225- (S_0) and a 275-msec (S_1) interval presented according to the single stimulus method. Each trial began with a 500-msec visual warning signal, the same as V . After a 1-sec delay, two 20-msec auditory or visual stimulations marked the short or the long empty interval. The observer was then given 3 sec to respond. During a trial, the observer was asked to fix the eyes on the front light (V) and not to move them during the interval even when both markers were delivered at periphery.

In this experiment, there were 16 conditions for the markers, since four different stimulations could be used as either first or second markers. Two series of six sessions were conducted in this experiment. In the first series, there were 16 blocks of 16 trials in each session, all trials with the same marker condition (certainty condition). Within each block, S_0 and S_1 were delivered randomly with an equal probability of appearance. The order of presentation of the blocks was, for Sessions 1, 3, and 5, AA, Aa, AV, Av, aA, aa, aV, av, VA, Va, VV, Vv, vA, va, vV, and vv. For Sessions 2, 4, and 6, the order was simply reversed. Each block of trials was separated by a 10-sec pause.

In the second series, each of the six sessions contained four blocks of 64 trials. Before each trial, the observer was unaware of the marker condition (uncertainty condition). Within each block, each of the 16 marker conditions appeared four times, twice with both S_0 and S_1 , in a random order of presentation. There was a 25-sec pause between blocks. Finally, only the last four sessions of each series were considered in the analysis of the results.

Results

The first dependent variable analyzed here is the fineness of discrimination as expressed by an equal variance d' index of sensitivity reported in signal detection theory (Green & Swets, 1966) and as measured by the addition of the Z transform of $P(R_l|S_1)$ and $P(R_s|S_0)$. Table 1 shows these probabilities for each subject for each marker condition and each of the certainty and uncertainty conditions. In Table 2 are presented averaged d' and averaged total probability of responding long for each marker condition and each certainty and uncertainty condition.

An analysis of variance (ANOVA) was performed on the individual d' following a randomized block factorial design (2×16 ; see Kirk, 1982). Significant effects were found between subjects [$F(5,155) = 9.31, p < .01$], between certainty and uncertainty conditions [$F(1,155) = 11.17, p < .01$], and for marker condition [$F(15,155) = 54.42, p < .01$]. No interaction was significant ($p = .875$). The Tukey test ($p < .05$) conducted on the marker condition effect revealed that performance in each of all four intramodal conditions involving an auditory signal was superior to the performance obtained with any of the other 12 conditions.

The second dependent variable analyzed was the total probability of responding long [$P(R_l|T)$]. The subjective duration of the short and the long intervals appears to depend on the type of marker, and the effect is largely amplified in the uncertainty condition. A randomized block ANOVA (2×16) was conducted on the individual $P(R_l|T)$.¹ The analysis revealed no significant between-subjects differences [$F(5,155) = 2.16, p = .06$], but there were significant differences between marker conditions [$F(15,155) = 7.71, p < .01$] and between certainty and uncertainty conditions [$F(1,155) = 4.29, p < .05$]. An important significant interaction was found between marker condition and certainty-uncertainty condition [$F(15,155) = 2.16, p < .01$]. This interaction was analyzed with the Tukey test ($p < .05$) on each of the 16 marker conditions. The values of $P(R_l|T)$ were all greater in certainty in each of the AA, vA, va, and vv conditions than they were in uncertainty. It should also be noted that the AV and aV conditions both clearly show opposite trends. Indeed, the comparisons made between marker conditions within uncertainty condition revealed that AV and aV intervals were both perceived longer than vv, vA, and va intervals.

Discussion

Two predictions were made about the possible effect of the randomizing procedure: one on the discriminability and one on the relative duration of the different marker-type intervals.

Before discussion of the effect of uncertainty on discriminability, a few words should be said about the different levels of performance encountered with the certainty condition. It is interesting that, although no differences emerge from all eight intermodal conditions, with both auditory and visual intramodal conditions better performances were reached when both markers were identical. For example, vv intervals seemed easier to discriminate than Vv, which is surprising since the observer was asked to keep looking at V. Indeed the general trend reveals that even with an intramodal condition, sensory characteristics of the marker might be of some importance in the discrimination.

Some kind of convergence of discriminability with different marker-type intervals was expected in passing from certainty to uncertainty. This convergence should have led to an interaction, since a marker effect was expected with the certainty condition but not with the un-

Table 1
Individual $P(R_i|S_i)$ and $P(R_o|S_o)$ under Each Marker and
Certainty Condition in Experiment 1

Subject	Auditory Signal				Visual Signal			
	AA	Aa	aA	aa	VV	Vv	vV	vv
Certainty								
1 $P(R_o S_o)$	.9375	.8125	.7813	.9688	.8125	.6452	.4375	.5667
$P(R_i S_i)$	.9688	.9375	.9688	.8750	.7500	.8387	.6774	.7500
2 $P(R_o S_o)$	.9677	1.0000	.9375	.9688	.7500	.5000	.5938	.8065
$P(R_i S_i)$	.9688	1.0000	.9688	.9375	.8125	.8750	.6452	.8750
3 $P(R_o S_o)$	.9688	.9688	.9375	.9375	.8125	.6563	.5625	.6875
$P(R_i S_i)$	.8750	.9375	.9375	.9375	.9375	.6250	.7188	.6563
4 $P(R_o S_o)$	1.0000	.8387	.9063	.9688	.6875	.6250	.6875	.7188
$P(R_i S_i)$	.9375	.9375	.9375	1.0000	.6563	.5625	.4375	.6563
5 $P(R_o S_o)$	.9063	.9354	.8438	.9063	.5938	.6875	.7500	.7500
$P(R_i S_i)$	.9375	.9375	.9375	.9375	.9375	.5938	.6875	.7813
6 $P(R_o S_o)$	.8710	.6875	.7813	.8125	.7813	.5938	.7500	.6563
$P(R_i S_i)$	1.0000	.7813	.8438	.6250	.6875	.5625	.7188	.4688
Uncertainty								
1 $P(R_o S_o)$	.9688	.6250	.5000	.9063	.9375	.5000	.3750	.7813
$P(R_i S_i)$	.9688	.9375	.8438	.9688	.3750	.6563	.8387	.6250
2 $P(R_o S_o)$	1.0000	1.0000	.9688	.9688	.7188	.1875	.4688	.7068
$P(R_i S_i)$	.8750	.9688	1.0000	.9688	1.0000	.8387	.7500	.6563
3 $P(R_o S_o)$	.9688	.8750	.9375	.9688	.6452	.4375	.6452	.7813
$P(R_i S_i)$	.9063	.9688	.9688	.9063	.7097	.5000	.4688	.4375
4 $P(R_o S_o)$	1.0000	.9688	.9688	1.0000	.6563	.8125	.8750	.8750
$P(R_i S_i)$	.7813	.7188	.8125	.9063	.6250	.3750	.3125	.3750
5 $P(R_o S_o)$	1.0000	.9375	.8125	1.0000	.5313	.4839	.4688	.9688
$P(R_i S_i)$	.7500	.8125	.9063	.9688	.7188	.8125	.7500	.3548
6 $P(R_o S_o)$	.9375	.7097	.7097	.9375	.8333	.5625	.4667	1.0000
$P(R_i S_i)$	.7188	.7813	.7742	.8065	.5862	.4516	.5484	.0625
Intermodal Signals								
	AV	Av	aV	av	VA	Va	vA	va
Certainty								
1 $P(R_o S_o)$	.7500	.6563	.7500	.5938	.6250	.6250	.7813	.5938
$P(R_i S_i)$	.5625	.4688	.5313	.6875	.5625	.2500	.4375	.4688
2 $P(R_o S_o)$	.5300	.6875	.4375	.7188	.7188	.9688	.9063	.8438
$P(R_i S_i)$	.7813	.4063	.6875	.4688	.5313	.4375	.5000	.5000
3 $P(R_o S_o)$	.4638	.6563	.5625	.4375	.6250	.8125	.6250	.6250
$P(R_i S_i)$	.6563	.5484	.7188	.7500	.6563	.5625	.6250	.6139
4 $P(R_o S_o)$	.7500	.8387	.5625	.8125	.8125	.7500	.7500	.6250
$P(R_i S_i)$	.6875	.6875	.6250	.6250	.4375	.5625	.5161	.6129
5 $P(R_o S_o)$	.6250	.7188	.6250	.7188	.7500	.7188	.8750	.7813
$P(R_i S_i)$	.8125	.6250	.8065	.5938	.6563	.8125	.5000	.6563
6 $P(R_o S_o)$	.5000	.5484	.5938	.8938	.6563	.8438	.6250	.7188
$P(R_i S_i)$	.5938	.6875	.6250	.3750	.5938	.4063	.4063	.3750
Uncertainty								
1 $P(R_o S_o)$	.7188	.8750	.7813	.9063	.6875	.8125	.6875	.8438
$P(R_i S_i)$	.3488	.0625	.4063	.2500	.5000	.3548	.4063	.3125
2 $P(R_o S_o)$	.3438	.5625	.1563	.4063	.7188	.7188	.9688	.7813
$P(R_i S_i)$	.9375	.6875	.9688	.8750	.4688	.4063	.1875	.2500
3 $P(R_o S_o)$	.3125	.8438	.4375	.5625	.7188	.6875	.7500	.8125
$P(R_i S_i)$	.6563	.3750	.7500	.4375	.4375	.5000	.0938	.1563
4 $P(R_o S_o)$	.5625	.5625	.3438	.4063	.7500	.6875	.8125	.7500
$P(R_i S_i)$	.6875	.5938	.8750	.6875	.4688	.3750	.3750	.5000
5 $P(R_o S_o)$	.2813	.3750	.2188	.4063	.8750	.8125	.9688	.9375
$P(R_i S_i)$	.9688	.7813	.8750	.8438	.2813	.4688	.0625	.1563
6 $P(R_o S_o)$	.3125	.6452	.5484	.8125	.6250	.7188	.8125	.9063
$P(R_i S_i)$	.7188	.4063	.7188	.2903	.4688	.4516	.3125	.1563

Table 2
Mean d' and $P(R_1)T$ for Each Marker Condition with
Certainty and Uncertainty in Experiment 1

Marker Condition	d'		$P(R_1)T$	
	Certainty	Uncertainty	Certainty	Uncertainty
AA	3.29	2.98	.5084	.4271
Aa	2.52	2.26	.5274	.5066
aA	2.85	2.50	.5443	.5367
aa	3.02	3.30	.4974	.4806
VV	1.61	1.22	.5287	.4738
Vv	0.81	0.33	.5292	.5545
vV	0.69	0.47	.5076	.5307
vv	1.09	0.76	.5036	.2857
AV	0.77	0.59	.5392	.6485
Av	0.68	0.32	.4439	.4203
aV	0.68	0.88	.5380	.6739
av	0.75	0.49	.4479	.4902
VA	0.78	0.47	.4271	.3542
Va	0.81	0.47	.3750	.3428
vA	0.76	0.42	.3682	.2031
va	0.64	0.36	.4192	.2084

Note—A and a = auditory signals. V and v = visual signals.

certainty condition. Since no such interaction was found, thus revealing that the uncertainty effect was the same on each condition, the RTC theory cannot by itself account for the differences generally met with different marker-type intervals. Rather, for intervals as short as 250 msec, an interval-measure hypothesis of timing seems more appropriate at this point.

Finally, it should also be noted that the overall discrimination has been affected by the uncertainty condition. This effect seems quite reasonable, since uncertainty probably creates a set of different levels of attention readiness for the task. Indeed attention in time estimation is of major importance (Macar, 1980), but it has been studied much more in the context of production of time intervals (Rousseau, Picard, & Pitre, 1984) and in the perception of temporal order (Kristofferson, 1967; Sternberg & Knoll, 1973) than it has been studied in duration discrimination. In Experiment 1, attentional fluctuations were probably introduced in the overall operations involved in the discrimination process. Indeed, preparation for the task has often been reported to be of major importance in cognitive psychology (Posner, 1978). Moreover, some sort of uncertainty has already been reported as affecting duration discrimination. Penner (1976) studied the effect of randomizing (uncertainty) marker parameters, amplitude, and duration, on the discrimination of empty intervals presented with a forced-choice procedure. For 300-msec intervals, randomizing the duration of markers requires a very much larger ΔT than is the case in a fixed condition to reach a 75% level of discrimination. Randomizing amplitude only slightly affects performance.

The second main point to be made here, one of major importance, concerns the distribution of "short" and "long" responses for each marker-type interval. First, it is important that there is a significant effect; comparisons of different kinds of interval change the pattern of responses normally met in a blocked session. It is then

logical to believe that there is some kind of comparison between these different intervals that is based on the fact of a common criterion.

Intervals in which P_1 was v were in general those most affected by the uncertainty. Intervals vA, va, and even vv gave rise to much shorter responses in the uncertainty than in the certainty condition. In terms of the internal events described in the RTC theory, this would mean that v induces long latencies. This makes sense if we consider that the observers were asked to focus attention on signal V, since they had to keep looking at this marker. Even if v were easily detectable, being on the periphery could have altered the quality of the information (Downing, 1988). However—following the same line of reasoning—if this latency related to v has such an effect, it is surprising not to find an important trend of responding long when this marker is P_2 . Moreover, guided by a latency effect, it is hard to explain the significant effect in AA and the strong trend of responding "long" with both AV and aV (but not, e.g., in Av or av).

Note that these distributions of responses, which look as if they involve different perceived durations, emerge even in spite of the presence of feedback after each trial and, more especially, without the addition of any supplementary stimuli or information to process during the interval. Therefore, the effect is different from other phenomena like the classical filled-duration illusion or the sharing of attention between two sources of information (Allan, 1979; Thomas & Brown, 1974; Thomas & Cantor, 1978). Indeed, this effect is more like the one reported by Hocherman and Ben-Dov (1979): when an observer discriminates among empty time intervals with some sort of forced-choice presentation, the observer judges the first interval to be longer more often when the observer is presented with an A-V-A sequence than when presented with a V-A-V sequence.

At this point, the cause underlying these distributions of responses remains unclear but fascinating. Unfortunately, the results are difficult to analyze since many marker-type intervals are involved. It is interesting to point out, however, that, although the differences for the $P(R_1)T$ among the marker conditions were much more pronounced with the uncertainty condition, they correspond to some trends already apparent with the certainty condition. Having blocks of only 16 trials seems not to permit building a specific marker-type criterion independent of previous blocks. Finally, Experiment 1 also remains difficult to analyze because working with V and v may involve other theoretical implications, such as the possibility of the perception of movement (Collyer, 1977).

EXPERIMENT 2

Our main purpose in Experiment 2 was to test, with more restricted conditions of uncertainty, the replicability of the effect that provokes these different distributions of short and long responses. Moreover, the blocks were longer, the order of their presentation was more counter-

balanced, and the subjects were a little more trained within each marker condition, since there were only nine conditions. Indeed, these nine conditions derive from the combinations of three types of marker: A, V, and an electrotactile stimulation (T). There were also three series of sessions, the first one a condition with complete certainty so that it would provide for a first general comparison of performances of the same subjects on intervals marked by A, V, and T combinations. The other two series of sessions designated conditions in which uncertainty was placed on only the first or the second marker.

Method

Subjects. The subjects were 8 volunteers, between 19 and 30 years old, who were paid \$5 per session.

Apparatus and Stimuli. For this experiment, conducted in a different laboratory, each subject was tested in one of two sound-attenuated test chambers. The subject responded "short" or "long" by depressing one of two pushbuttons located on the right armrest of the chair.

Three different signals—A, V, or T—marked the intervals; they were all easily detectable. The auditory marker, presented binaurally through TDH-49 earphones, was a 1-kHz tone with an average continuous amplitude of 70 dB for each ear. The visual marker was a fast rise/decay pulse from a neon bulb (Ne-40) facing the subject at a distance of roughly 1 m. The tactile stimulation was provided by an electrocutaneous stimulation quite similar to those reported for cutaneous communication with a teletactor (see Saunders, 1974). The concentric electrode, put on the subject's forehead, had a 4-mm diameter at the active center and an 8-mm diameter with an isolating ring. The electric stimulus was generated by a source emitting a constant 10-mA train of pulses, with a frequency between 70 and 110 Hz and voltage at 50 V.

The warning signal before each trial was a 500-msec sound. The feedback was produced by one of two tungsten bulbs placed in a small box on the top of the visual marker. The experimentation was under control of a DEC PDP-8/F computer providing timing accurate to the nearest millisecond.

Procedure. The unfolding of a given trial and succession of trials was as in Experiment 1. Nevertheless, in Experiment 2, there were 9 blocks of 30 trials with a 15-sec pause between the blocks, and each session lasted about 42 min. Within each block, subjects were presented short (225-msec) and long (275-msec) intervals an equal number of times but in a random order.

Each subject participated in 18 experimental sessions, divided into three series of 6. These series corresponded to the following three certainty-uncertainty conditions: (1) The observer knew before each block the sensory modes in which both markers would be delivered (the certainty-certainty condition, or C-C); (2) the observer knew before each block the sensory mode in which P_1 would be delivered, but the observer did not know about P_2 (certainty-uncertainty condition, or C-U); and (3) the observer knew before each block the sensory mode for P_2 but not for P_1 (uncertainty-certainty condition, U-C). All observers began the experiment with C-C. In this series, each block corresponded to one of nine conditions: AA, VV, TT, AT, TA, VT, TV, AV, and VA. The order of presentation of these nine blocks is reported in Table 3. Four observers were involved in C-U series during Sessions 7-12 and in U-C during Sessions 13-18. The other 4 observers were run in the reverse order: U-C (7-12) and C-U (13-18).

For each series with an uncertainty condition, there were also nine blocks of 30 trials in a session. Each session was divided into three identical series of three blocks (see Table 3). Thus, one marker remained the same for the block (30 trials), and during this block, the other marker could vary from trial to trial, appearing randomly but equiprobably: five times in A with S_0 ; five times in V with S_0 ;

Table 3
Sensory Mode of Markers for Each Block of
Each Session in Experiment 2

Block	Sessions					
	1	2	3	4	5	6
Certainty						
1	VT	AT	AV	VT	AV	TA
2	AA	VV	TT	AA	TT	VV
3	TV	TA	VA	TV	VA	AT
4	AT	VT	TV	VA	AT	VA
5	VV	AA	AA	TT	VV	TT
6	TA	TV	VT	AV	TA	AV
7	AV	VA	AT	TA	VT	VT
8	TT	TT	VV	VV	AA	AA
9	VA	AV	TA	AT	TV	TV
Sessions						
	7-13	8-14	9-15	10-16	11-17	12-18
Uncertainty*						
1	A	V	T	T	V	A
2	V	A	V	A	T	T
3	T	T	A	V	A	V
4	A	V	T	T	V	A
5	V	A	V	A	T	T
6	T	T	A	V	A	V
7	A	V	T	T	V	A
8	V	A	V	A	T	T
9	T	T	A	V	A	V

Note—A = auditory signal, V = visual signal, T = tactile signal.

*The marker here is the one left unchanged during a whole block.

five times in T with S_0 ; five times in A with S_1 ; five times in V with S_1 ; five times in T with S_1 .

Only the last three sessions of a series provided the data considered for the analysis.

Results

Both discriminability, expressed by an equal variance d' , and $P(R_1)T$ have been calculated. Table 4 shows individual $P(R_1|S_1)$ and $P(R_0|S_0)$ of observers in each of the nine marker-type conditions and the three certainty conditions. Average d' and $P(R_1)T$ are reported in Table 5.

An ANOVA was performed on the individual d' following a randomized factorial block design (3×9 ; see Kirk, 1982). There was a significant effect between subjects [$F(7,182) = 10.91, p < .01$], and there were significant differences between marker-type conditions [$F(8,182) = 170.06, p < .01$]. No significant differences were found between certainty conditions ($p = .28$), and there was also no interaction ($p = .39$). The Tukey test reveals that discrimination was better in the AA condition than in any other. VV intervals were discriminated better than the seven other types of intervals, and TT discrimination was superior to all six performances observed in intermodal conditions. Finally, the AT condition provided better discrimination than did conditions TV and AV.

The statistical analysis of the $P(R_1)T$ was performed on the individual data according to a randomized block analysis of covariance design (see Kirk, 1982). The point of interest here is the relative distribution of short and long responses between marker-type intervals when they

are compared with each other. Each of the six uncertainty conditions—three C-U and three U-C—was analyzed separately, since they all provided different kinds of comparisons. In each of these cases, the $P(R_1)T$ in C-C for a given marker-type condition was considered as the reference value (the covariate) on the analysis of $P(R_1)T$ differences between the marker-type conditions with uncertainty.

In the C-U condition, no significant differences were found when P_1 was A [$F(2,13) = .82, p = .46$] or V [$F(2,13) = 1.34, p = .30$]. When P_1 was T, differences were significant [$F(2,13) = 11.14, p < .01$]. The Tukey test on the adjusted means reveals that the TA and TV conditions both involved more “long” responses than did the TT condition.

Table 4
Individual $P(R_1|S_1)$ and $P(R_0|S_0)$ under Each Marker and Certainty Condition in Experiment 2

Subject	AA	VV	TT	AT	TA	VT	TV	AV	VA
C-C									
1 $P(R_0 S_0)$	1.0000	.9333	.8222	.9111	.5857	.6444	.7111	.8889	.6889
$P(R_1 S_1)$	1.0000	.9778	.8667	.7778	.8000	.8000	.7555	.6667	.8159
2 $P(R_0 S_0)$	1.0000	.8445	.7111	.8000	.6571	.7048	.5333	.8000	.8429
$P(R_1 S_1)$	.9555	.9555	.8444	.7921	.6889	.6889	.7778	.5778	.5334
3 $P(R_0 S_0)$	.9778	.6000	.7742	.6159	.4667	.5333	.5111	.6444	.5353
$P(R_1 S_1)$	.9555	.8889	.7286	.8000	.7778	.6222	.5778	.6000	.6778
4 $P(R_0 S_0)$	1.0000	.8000	.8667	.6000	.5778	.6667	.7111	.5556	.5333
$P(R_1 S_1)$	.9778	.7556	.7556	.6889	.5778	.6444	.5111	.6667	.5333
5 $P(R_0 S_0)$	.9778	.8889	.7556	.6619	.5480	.8397	.6445	.6889	.8444
$P(R_1 S_1)$	.9778	.7333	.7333	.6889	.5905	.7556	.5556	.6222	.5111
6 $P(R_0 S_0)$	.9556	.8445	.8000	.6667	.7730	.7556	.7333	.6444	.7333
$P(R_1 S_1)$	.9556	.8667	.6889	.6667	.6889	.6444	.6889	.6889	.6222
7 $P(R_0 S_0)$	.9333	.7778	.7111	.6445	.6508	.6445	.6000	.6222	.6222
$P(R_1 S_1)$	.9111	.8444	.5778	.6000	.7111	.4667	.5111	.7556	.5778
8 $P(R_0 S_0)$	.9778	.8889	.7333	.5778	.7111	.5333	.5333	.4667	.6222
$P(R_1 S_1)$	.9778	.9111	.7778	.6667	.5778	.6889	.6222	.7333	.6000
C-U									
1 $P(R_0 S_0)$	.9778	.7556	.8000	.7778	.4445	.5778	.5111	.6000	.5318
$P(R_1 S_1)$	1.0000	.8889	.8667	.6365	.9555	.5778	.7333	.6667	.8445
2 $P(R_0 S_0)$	1.0000	.8667	.6444	.6667	.5476	.7333	.4222	.8000	.8445
$P(R_1 S_1)$	.9111	.9333	.7111	.7333	.9333	.6667	.8667	.3111	.6000
3 $P(R_0 S_0)$	.9778	.6000	.8174	.6667	.3556	.7333	.5556	.4000	.7778
$P(R_1 S_1)$	.8444	.9111	.6222	.7111	.8000	.6444	.6667	.7778	.6000
4 $P(R_0 S_0)$	.8666	.6445	.8667	.5111	.2667	.7556	.3778	.6222	.6445
$P(R_1 S_1)$	.9555	.8889	.5778	.8444	.8222	.4222	.7333	.6222	.7333
5 $P(R_0 S_0)$	1.0000	.8222	.7111	.7111	.4684	.8667	.5333	.6889	.6444
$P(R_1 S_1)$	1.0000	.7778	.8445	.7698	.7444	.3651	.6667	.5607	.6044
6 $P(R_0 S_0)$	.9333	.8873	.8445	.7333	.7079	.6841	.5111	.4444	.8413
$P(R_1 S_1)$	.9778	.7334	.7556	.7778	.6667	.6095	.9317	.7556	.6445
7 $P(R_0 S_0)$	.9778	.8000	.8667	.8667	.4000	.8667	.5333	.4794	.8667
$P(R_1 S_1)$	.8889	.7111	.4444	.4444	.8159	.4444	.4889	.7111	.4000
8 $P(R_0 S_0)$	.9778	.8667	.8222	.4000	.5333	.4000	.3822	.4667	.5778
$P(R_1 S_1)$	.9778	.8445	.7556	.8222	.8889	.7778	.8445	.7111	.5555
U-C									
1 $P(R_0 S_0)$	1.0000	.9333	.9111	.7778	.7333	.5556	.4000	.8667	.8444
$P(R_1 S_1)$	1.0000	.8000	.8222	.8445	.6000	.8000	.9111	.3778	.5556
2 $P(R_0 S_0)$	1.0000	.7778	.7333	.5778	.4000	.7555	.6000	.8222	.8889
$P(R_1 S_1)$	1.0000	.8445	.9111	.8222	.8667	.5905	.7667	.4079	.2222
3 $P(R_0 S_0)$	.9778	.8445	.8444	.4063	.1556	.8444	.6222	.4079	.6000
$P(R_1 S_1)$	.9555	.7556	.8445	.8666	.9555	.4889	.5334	.7334	.6000
4 $P(R_0 S_0)$	.9555	.8000	.8445	.4667	.6444	.7111	.3111	.3111	.8222
$P(R_1 S_1)$	.9555	.8667	.6889	.9333	.7555	.4667	.8444	.8666	.3778
5 $P(R_0 S_0)$	1.0000	.8667	.7778	.8413	.6302	.8222	.7555	.7555	.6143
$P(R_1 S_1)$	.9555	.8000	.8000	.5555	.7032	.5000	.6222	.3556	.7270
6 $P(R_0 S_0)$	.9778	.8349	.8222	.6889	.6143	.7556	.6667	.8222	.8889
$P(R_1 S_1)$	.9778	.7556	.8444	.8000	.8968	.5111	.8444	.6000	.4984
7 $P(R_0 S_0)$	.9333	.8889	.8000	.6341	.4222	.8222	.6000	.4889	.9778
$P(R_1 S_1)$	.8000	.5778	.6841	.6889	.7778	.7889	.7778	.6889	.3555
8 $P(R_0 S_0)$	.9778	.6286	.7778	.4667	.5778	.5936	.4857	.7095	.8222
$P(R_1 S_1)$	.8889	.7048	.6667	.7555	.7492	.5222	.7111	.5778	.3777

Note—A = auditory, V = visual, T = tactile. C = certainty, U = uncertainty.

Table 5
Mean d' and Mean $P(R_1)T$ for Each Marker-Type
Interval under Each Certainty Condition

Marker	C-C		C-U		U-C	
	d'	$P(R_1)T$	d'	$P(R_1)T$	d'	$P(R_1)T$
AA	3.74	.4931	3.52	.4903	3.58	.4810
VV	2.11	.5222	1.85	.5279	1.71	.4707
TT	1.44	.4877	1.41	.4503	1.73	.4844
AT	1.09	.5211	1.06	.5254	1.13	.5880
TA	.79	.5277	.93	.6814	.92	.6330
VT	.88	.4976	.74	.4307	.88	.4255
TV	.65	.5014	.66	.6316	.87	.5982
AV	.89	.5000	.54	.5621	.65	.4641
VA	.78	.4657	.95	.4534	.89	.3278

Note—C = certainty, U = uncertainty. A = auditory, V = visual, T = tactile.

In the U-C condition, when P_2 was V, there were no significant differences [$F(2,13) = 2.78, p = .10$]. When P_2 was T, differences were significant [$F(2,13) = 4.76, p < .05$]. The Tukey test on adjusted means signals a difference between the AT and VT conditions. When P_2 was A, there were significant differences [$F(2,13) = 9.46, p < .01$]. The same a posteriori test reveals that all AA, VA, and TA conditions differed from each other.

Discussion

Although the main point of interest in this experiment is the effect of uncertainty on the $P(R_1)T$, some interesting features emerge from the analysis of the discrimination level. First, there is quite a clear demarcation between intra- and intermodal conditions. The direct comparison of 8 subjects in these nine conditions replicates the general trend reported in other experiments about inter- and intramodal differences (Grondin, 1988; Rousseau et al., 1983). Moreover, intramodal conditions significantly differ from each other, whereas most of the intermodal intervals do not, except for AT. A second quite important feature related to the discrimination level is the nonsignificant difference between the C-C, C-U, and U-C conditions. As in Experiment 1, even if the uncertainty condition should have favored the utilization of a common criterion, there was no convergence in discrimination of the different marker-type intervals. Therefore, the main source of variance in duration discrimination of about 250-msec intervals is not the criterion itself, as supposed by Kristofferson (1977) for longer intervals (around 1,000 msec). On the other hand, since it was different in Experiment 1, it is surprising that this time there is no decrement of performance in the uncertainty condition. Indeed, different uncertainty effects in both experiments may depend on

the amount or on the type of uncertainty involved in each experiment; in Experiment 1, having both markers uncertain and four possible signals resulted in 16 possible intervals instead of 3 as in Experiment 2. Moreover, one of the four markers was a visual stimulation delivered in the periphery. This might have included in the processing of time a noisy component related to some visuospatial attention mechanism (Downing, 1988) or to a possible perception of movement (Collyer, 1977). Also, note that neither C-U nor U-C provoked a decrement of performance, in spite of the implication of the three sensory modes. It then becomes difficult to explain the performance differences between the marker conditions on the basis of a need to switch attention between input channels (Kristofferson, 1967) or on the basis of attention preparation for the task.

Even with a reduction of uncertainty in Experiment 2, the analysis of the $P(R_1)T$ shows, as in Experiment 1, that the distribution of "short" and "long" responses under uncertainty conditions varies according to the marker condition. Yet, it remains difficult to account for these results on the basis of the latency properties associated with a given sensory stimulation (Allan et al., 1971). One alternative hypothesis is to suppose that uncertainty affects the gating of time pulses, resulting in a loss of the accumulation of these pulses in a central counter. Such an explanation encounters severe problems when one considers that on the same block in U-C with A as P_2 , most of responses were "short" for a given type of interval and "long" for another type. An alternative explanation for the distribution of "short" and "long" responses is to suppose that it is based on a response bias. This possibility seems inadequate when we compute the $P(R_1)T$ for a given entire uncertainty condition. Table 6 shows the mean $P(R_1)T$ of the three conditions involved in an uncertainty condition. In each case, except in C-U with $P_1 = T$, the average value is near .5, which indicates that the effect is not simply a shift of the response criterion.

An Information Processing Model

Our main purpose in the present study was to get a better understanding of the different levels of performance in duration discrimination involving different marker-type intervals. After two experiments involving the uncertainty strategy, two main findings therefore emerge. First, the differences in the levels of performance remain constant in spite of the uncertainty. Therefore, what determines the fineness of the discrimination with some given marker conditions, mainly in intramodality, seems quite independent of what determines discrimination of most of the

Table 6
Mean $P(R_1)T$ under Each of the Six Conditions with Uncertainty in Experiment 2

C-U			U-C		
AA = .4903	VA = .4534	TA = .6814	AA = .4810	AV = .4641	AT = .5880
AV = .5621	VV = .5279	TV = .6316	VA = .3278	VV = .4707	VT = .4255
AT = .5254	VT = .4307	TT = .4503	TA = .6330	TV = .5982	TT = .4844
M = .5259	M = .4707	M = .5878	M = .4806	M = .5110	M = .4993

Note—C = certainty, U = uncertainty. A = auditory, V = visual, T = tactile, M = mean.

intermodal intervals. Second, whereas the $P(R_1)T$ distribution with intramodal intervals remains quite insensitive to the comparisons introduced with uncertainty, such is not the case with intermodal intervals. Taken together, these two findings strongly suggest that two different mechanisms could be operating during duration discrimination tasks. It is not unreasonable, then, to account for the results in these tasks with the following information processing model.

A pacemaker provides pulses that can be organized in two different ways. On the one hand, pulses are counted after an internal signal B_1 and, after B_2 , the resulting interval measure is stored in a working memory (WM). Let us call this operation *aspecific* (processor A). On the other hand, pulses are included within a P_1 - P_2 structure if P_1 and P_2 are delivered from the same sensory mode. This P_1 - P_2 structure triggers a *specific* operation (processor S), since the decision is made on the basis of a criterion kept in a reference memory (RM)—that is, in a more permanent store adapted to the given modality that the structure is made of. Properties of processor A and processor S also differ in that the second one operates via an automatic mode, whereas processor A requires the support of controlled attention (Johnston & Dark, 1986; Neumann, 1984; Shiffrin & Schneider, 1977). Fluctuations of attention to time during an interval t will increase discrimination error with processor A but not with S. Data from Rousseau, Poirier, and Tremblay (1984) support this cognitive interpretation of the difference between inter- and intramodality.

Processor S involves a whole structure that includes the markers. Variance in an intramodal condition may then reflect the specific efficiency of a given sensory mode in keeping intact a structure organized in time. The importance of the structure of particular events on time experience has been reported elsewhere (Jones & Boltz, 1989). What determines the quality of this retention remains unclear. Tentatively one may relate it on the similarity and the proximity of the successive events that form an organization, as stated in the Gestalt principles (Fraissee, 1952). For example, in Experiment 1, the AA and aa conditions both gave rise to better performances than did the Aa and aA conditions. VV and vv intervals also elicited better discrimination than did Vv or vV intervals. As long as similarity and proximity maintain the efficiency of processor S, there will be no need to refer to processor A, a resources consumer. On the other hand, it is not unreasonable to suppose further that rules of organization would be specific to a sensory mode. Posner (1978) reports some basic differences between sensory modes. Audition is more organized on the basis of frequency, whereas the tactile and visual modes are organized on the basis of spatial properties.

Processor A has the dual role of calculating pulses at a given moment and of maintaining in an active state a criterion nonspecifically adapted to a given modality. However, values in RM may influence the value in WM, especially with variations from trial to trial of intra- and

intermodal intervals. Contrary to processor S, no variance is associated with the organization between markers. In processor A, the marker only determines the internal signals B_1 and B_2 . The period of accumulation of pulses is then related to the latencies related to P_1 and P_2 . P_1 may have a more crucial role, since it gives signals to a time setting of the organism. Moreover, latency of a signal from a given sensory modality may well rely on its alerting properties (Posner, 1978). Since a visual stimulus is less efficient than a tactile or an auditory signal in producing alerting, the occurrence of a visual P_1 instead of T or A in duration discrimination with uncertainty should provoke a loss of pulses and lead to shorter responses. The data from Experiments 1 and 2 generally support this statement.

EXPERIMENT 3

The discrimination of durations within approximately 250 msec is not supposed to depend on energy cues (Allan & Kristofferson, 1974; Carbotte & Kristofferson, 1973). Effects of physical characteristics on discrimination have been demonstrated for very short intervals only. Abel (1972) has reported an effect of amplitude on the discrimination of temporal gaps, but this effect was more pronounced for durations of less than 160 msec. Woods, Sorkin, and Boggs (1979) have also reported the effect of stimulus context on gap discrimination bounded by auditory signals. Still, the base duration to discriminate in their experiment was small (< 100 msec)—that is, in a duration range within which the time discrimination is more sensitive to sensory effect (Allan & Kristofferson, 1974). However, if the efficiency of a processor S depends on the organization of successive events, then the physical characteristics of the markers, within a given sensory modality, might affect the performance. In Experiment 1, the results within the auditory modality tend to be better with an AA or an aa sequence than with an Aa or an aA sequence. The next experiment was designed for the purpose of testing, within the auditory modality, the existence of the effect of the physical characteristics of the markers. In this experiment, subjects were well trained, and the proximity between markers was changed.

Method

Subjects. The subjects were 6 volunteers, between 22 and 35 years old, who were paid \$5 per session.

Apparatus. The apparatus used in Experiment 3 was identical to that used in Experiment 1, but there were two modifications. First, the intensity levels of the markers were reduced so that the average continuous amplitude was 75 dB for the 1-kHz tone and 65 dB for the white noise. The second modification was a change in the duration of the intervals to be discriminated: $S_0 = 240$ msec and $S_1 = 260$ msec.

Procedure. The observer had to discriminate between two intervals presented according to the single stimulus method. The presentation of each interval was, as in Experiment 1, preceded by a warning signal and followed by a feedback with the same delay between those events. One session was subdivided into four blocks of 70 trials, with random presentation and equal probability of ap-

Table 7
Individual $P(R_1|S_1)$ and $P(R_0|S_0)$ under Each Condition in Experiment 3

Subject	AA		Aa		aa		aA	
	$P(R_0 S_0)$	$P(R_1 S_1)$	$P(R_0 S_0)$	$P(R_1 S_1)$	$P(R_0 S_0)$	$P(R_1 S_1)$	$P(R_0 S_0)$	$P(R_1 S_1)$
1	.9643	.8714	.9357	.8857	.9286	.9143	.8000	.9000
2	.8286	.8143	.6214	.8921	.8058	.7842	.8058	.7643
3	.9496	.7143	.7143	.8345	.7826	.8043	.5859	.7338
4	.9500	.8786	.7929	.8633	.8286	.9137	.7571	.9000
5	.9143	.8429	.7500	.9286	.8214	.9071	.8000	.8857
6	.9712	.9286	.6115	.8696	.8929	.8857	.7971	.8841
<i>M</i>	.9297	.8417	.7376	.8790	.8433	.8682	.7577	.8447
<i>M d'</i>	2.59		1.89		2.19		1.77	
$P(R_1)T$	.4565		.5700		.5124		.5437	

Note—A and a = auditory, *M* = mean.

pearance of S_0 and S_1 . Within each block, only one of the four marker conditions (AA, Aa, aa, or aA) was presented. There was a 25-sec pause between blocks. The presentation of the blocks was ordered according to a balanced Latin square design, and over the eight sessions of the experiment, each observer ran through two cycles of this Latin square. Only the last four sessions were considered in the analysis of the data.

Results and Discussion

In Table 7, individual $P(R_0|S_0)$ and $P(R_1|S_1)$, and average d' and $P(R_1)T$, are presented for each of the four conditions. An ANOVA performed on the individual d' following a randomized block design (Kirk, 1982) revealed significant differences between subjects [$F(5,15) = 6.49$, $p < .01$] and between marker conditions [$F(3,15) = 7.59$, $p < .01$]. The Tukey test ($p < .05$) showed that performance in AA was superior to performance in Aa and aA.

A randomized block ANOVA was also performed on $P(R_1)T$. There were significant differences between marker conditions [$F(3,15) = 7.58$, $p < .01$]. The Tukey test ($p < .05$) revealed that the observers responded "short" more often in AA than in Aa or aA. No differences were found between subjects.

The ability of an observer to discriminate short empty intervals is not independent of the physical characteristics of the markers that bound these intervals. The effect of frequency differences between tones on temporal resolution has been reported by Divenyi and Danner (1977) and Woods et al. (1979) but with time intervals smaller than 100 msec. It appears clear here that, even at 250 msec, the physical characteristics of the markers influence the duration discrimination. In terms of the information processing model described above, a processor S probably gains the advantage of the quality of organization between successive events, this organization being especially related to similarity between markers, a similarity of spectral composition (Bregman, 1978).

On the other hand, there was also a special distribution of "short" and "long" responses in this experiment, which occurred without uncertainty and in spite of three factors: 280 practice trials by the observer in each condition, a large number of trials per block, and the presence of feedback after each trial. This means that the responses in the different blocks of trials were not independent of each other. This dependence remained in spite of long

blocks of trials, probably because an intramodal sequence benefits from a long-term storage in reference memory—which is a characteristic of processor S. This is to say that chances would still be high for a good discrimination of the intramodal intervals even with presentation a trial every 5 min, whereas discrimination would not be possible with such a delay with any intermodal intervals and the same physical time to discriminate. Indeed, if a response criterion is common to the different auditory sequences, the tendency to respond "short" more often in AA may depend on the benefit gained by the offset marker from the priming effect provided by the presence of a similar onset marker.

SUMMARY AND CONCLUSION

We performed three experiments to gain a better understanding of mechanisms involved in the discrimination of durations. Many interesting empirical and theoretical implications or results of these experiments should now be pointed out. In Experiment 1, all intermodal intervals were poorly discriminated, whereas intramodal intervals seemed to gain advantage from special cases in which both markers were the same. It is also interesting that the effect of uncertainty on $P(R_1)T$ was replicated in Experiment 2. Just as there are classical differences reported for the apparent duration of filled versus empty intervals, or for apparent duration of filled intervals according to the signal—auditory, cutaneous, or visual—filling the interval, so does there appear to be a similar phenomenon with different kinds of empty intervals. This effect has been attributed to some properties of the sensory stimulations that mark the counting period of time. Nevertheless, the effect may depend on the possibility that the coding of time in the judgment of relative durations, like the judgment of absolute duration, incorporates some physical characteristics of the markers. The results of Experiment 3 strongly support such a hypothesis. Also of empirical interest are the results of Experiment 2, in which a direct comparison was made between nine marker-type intervals resulting from combinations of A, V, and T markers. The intermodal intervals were still more poorly discriminated than intramodal intervals; yet differences among the intramodal conditions persisted.

Finally, Experiments 1 and 2 were designed primarily for the purpose of testing some predictions of RTC theory for discrimination of short durations. Analysis of discrimination fineness and of the distribution of responses under certainty and uncertainty conditions both support an interval-measure hypothesis rather than the RTC theory in explaining the operation involved in the judgments of relatively short durations. A model founded on an information processing approach can account for most effects reported in Experiments 1-3. This model emphasizes the existence of two different timekeeping operations, with two levels of efficiency. Availability of the most efficient operator depends on whether or not an empty duration is marked by intramodal stimulation. Such a point of view indicates that to study time with intramodal intervals probably provides as much information about perceptual-cognitive organization within a processing space specific to a given sensory mode as about the properties of an internal clock.

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NOTE

1. Different assumptions must be made before running an ANOVA. One of them concerns the normality of the distribution of the scores. In Experiments 1-3, one dependent variable was the total probability

of responding long [$P(R_1)T$], which is a discrete variable. It is then important to notice that each individual score results generally from 64 (in Experiment 1; there were at least 60 responses, since there was some nonresponse), 90 (in Experiment 2), and 280 (in Experiment 3) presentations of interval in each experimental condition. Siegel and Castellan (1988) reported that for a large number of observations ($N < 25$), the binomial distribution tends toward the normal distribution.

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