Composition rule for perceived duration of simultaneous events

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When a subject is required to monitor the duration of two events that occur simultaneously, the perceived durations of the events are combined in a nonlinear manner. This is in contrast to evaluations of duration of successive events for which the composition rules are close to linear. In each of two experiments, 20 subjects judged the average duration of pairs of temporal intervals varying in duration from .5 to 10.0 sec. For one condition the intervals were presented simultaneously, and for the other they were presented successively. The simultaneous condition differed from that in our previous studies in that the intervals of the pair shared a common offset rather than a common onset, a modification suggested by Eisler, who hypothesized that our previous finding may have been due to an offset asynchrony. Results were consistent with a nonlinear composition rule for describing parallel monitoring of temporal information of simultaneous events and a linear rule for monitoring duration of successive events.

The research to be reported follows from research we have conducted previously which deals with the perceived duration of simultaneous events (Curtis & Rule, 1977) and from a modification of those experiments suggested by Eisler (1981). In the Curtis and Rule studies, subjects rated pairs of temporal intervals with respect to their average duration, their total (summed) duration, or their difference in duration when the intervals making up the pairs were presented either simultaneously or successively. The question of interest concerned the form of the composition rules describing the ways in which the subjective relations were represented in judgments of averages, sums, and differences. For successive presentations, the data were well described by linear expressions consistent with the arithmetic operations set forth in the instructions to subjects. For example, judgments of average duration were consistent with expectations if information concerning the duration of the two intervals was combined according to the rule,

$$\psi_{ij} = \frac{\psi_i + \psi_j}{2}, \quad (1)$$

where ψ_{ij} represents the subjective measure of the conjoint effect of stimulus i and stimulus j , and ψ_i and ψ_j denote the subjective magnitudes of the two durations. In contrast, when the durations evaluated were presented simultaneously, the data suggested a

markedly nonlinear composition rule. For example, judgments of the average duration of two simultaneous events were consistent with the rule:

$$\psi_{ij} = \left[\frac{\psi_i^c + \psi_j^c}{2} \right]^{1/c}, \quad (2)$$

in which c is greater than unity. The data yielded estimates of c of 1.85 from judgments of averages and 1.94 from judgments of the sums of durations fitted by an analogous expression.

On the basis of the nonlinearity of the relation described by Equation 2, we (Curtis & Rule, 1977) questioned a theoretical position advanced by Eisler (1975). According to Eisler's parallel-clock model, the durations of serially presented intervals are monitored by two sensory registers operating simultaneously. One register monitors the total duration from the onset of the first interval to the offset of the second, and the other register begins at the onset of a second interval and continues to monitor duration until both intervals terminate. We argued that if one assumes that the evaluation of a pair of intervals is based on simultaneous monitoring regardless of whether the intervals are sequential or simultaneous, different composition rules would not be expected to apply to sequential and simultaneous presentations—linear for one and nonlinear for the other.

Eisler (1981) has questioned the relevance of our simultaneous condition to his parallel-clock model on the grounds that, because the two intervals shared a common onset, the two clocks would not continuously monitor the intervals throughout the presentation sequence. Because the shorter interval terminated before the longer interval, the register associated with the shorter interval would not have continued to be active until the time that a response

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was required. The subject needed to compare the contents of the register monitoring the longer interval with a representation of duration stored in memory.

Eisler (1981) also suggested that a modification in the experimental procedure that we used would make the experiment more relevant to the question at issue. The suggestion was to employ a common offset in the simultaneous conditions such that the two intervals started asynchronously and terminated simultaneously. This procedure would permit both registers to monitor the intervals during the entire presentation sequence. The purpose of this paper is to report the results of such a modification. Two experiments were conducted. In one, subjects rated the average duration of two intervals presented sequentially, and in the other, they rated the average duration of two intervals presented at the same time with a common offset.

METHOD

Subjects

Forty undergraduate students participated as subjects to fulfill a requirement of an introductory course in psychology.

Apparatus and Stimuli

The stimuli were two luminous red targets whose durations were timed by a programmable clock controlled by a laboratory computer. A set of seven durations, ranging in equal steps from .5 to 10.0 sec, was crossed with itself to yield 49 pairs of time intervals. A yellow light on the display panel served as a ready signal.

Procedure

Twenty subjects judged the average duration of pairs of lights that were illuminated successively, and 20 subjects judged the average duration of the pairs when they were presented simultaneously. In the simultaneous condition, the lights in each terminated at the same time. Their onset asynchrony depended on the difference between their durations. For successive presentations, the onset of the second stimulus followed immediately on the termination of the first. The subjects in both conditions rated the average duration of the pairs on a scale of 1 to 11. They were cautioned to avoid counting or the use of other strategies as an aid to making their judgments and to avoid assigning a number to each interval in a pair and averaging the numbers. Ten practice trials were provided to familiarize the subjects with the task and the range of durations to be presented. In the experimental series, each of 49 stimulus combinations was presented twice. The subjects were run individually, and the order of presentation of the pairs was randomized independently for each.

RESULTS

Successive Presentation

The data from successive presentations are presented in Figure 1, in which median ratings are plotted as a function of the duration of the second interval. Separate curves are presented for each of the durations of the first interval. The curves are close to parallel, which indicates that the composition rule for judgments of average duration of successive intervals can be described by an additive relation. This result is consistent with previous findings reported by Blankenship and Anderson (1976) and

Figure 1. Category judgments of average duration, successive presentation, as a function of the duration of the second target. The parameter is the duration of the first target.

Curtis and Rule (1977) for sequentially presented intervals.

A scale of subjective duration was derived by subjecting median ratings to a nonmetric-scaling analysis. The analytic method used was Roskam's (1977) UNICON, an algorithm for solving polynomial conjoint structures from ordinal data. A solution was achieved with a stress (Formula 2) of .03. A plot of the derived scale values as a function of physical duration is presented in Figure 2. The trend in the plot is consistent with a linear psychophysical function for subjective duration.

Curtis and Rule (1977) specified a general descriptive model for the relation between subjects' judgments and the durations of pairs of intervals as follows:

$$Y_{ij} = a[wX_i^k + (1 - w)X_j^k]^m + b, \quad (3)$$

where Y_{ij} represents a judgment of the conjoint effect of durations with measures X_i and X_j . The coefficients w and $1 - w$ allow for unequal weights to the stimuli in a pair to account for time-order error. Curtis and Rule obtained estimates of the exponents k and m that were approximately equal to unity. When Equation 3 was fitted to the present data, a least-squares solution was provided by similar estimates.

$$Y_{ij} = 1.0(.51X_i^{1.00} + .49X_j^{1.00})^{.99} + .82,$$

in which X_i and X_j denote the durations of the first and second targets, respectively. The finding that the

Figure 2. Scale values yielded by a nonmetric-scaling solution plotted as a function of stimulus measures for successive presentations.

exponents are close to unity is to be expected if the psychophysical relation between subjective duration and measured duration is approximately linear and if the composition rule for evaluating average duration is additive.

Simultaneous Presentation

Median judgments for simultaneous presentations are plotted in Figure 3. The plot is not as simple as the one for successive presentations. Two trends are evident in these data, one characterizing the data from stimulus pairs of equal duration and another for data from pairs of unequal durations. The points associated with equal durations (solid circles) deviate considerably from the other points. It seems likely that the deviations stem from the difference between presentations of equal and unequal durations with respect to onset asynchrony. Specifically, only the pairs of equal duration had a common onset and offset for the two stimuli. Consequently, the subject needed to evaluate only a single interval. An interpretation that only a single interval was evaluated is consistent with the near-linear trend representing responses to pairs of equal durations in Figure 3 (solid circles).

The trend for points associated with pairs of intervals of unequal duration can be seen more clearly in Figure 4, in which the observations associated with equal pairs are omitted. In contrast to the near-parallel curves presented in Figure 1 for sequential presentations, the curves for simultaneous intervals converge to the right. This trend is similar to the trend in Curtis and Rule's (1977) data for intervals with a common onset and asynchronous offset, and it is consistent with a nonlinear composition rule for the subjective counterpart of an average duration.

To evaluate the composition rule for judgments of average duration of simultaneous events, Equation 3 was fitted to the data for pairs of unequal durations. Because no time-order error was expected for simultaneous presentations, the weight, w , in Equation 3

Figure 3. Category judgments of average duration, simultaneous presentation, as a function of the duration of the right-hand target. The parameter is the duration of the left-hand target. Solid circles denote judgments of pairs of intervals of equal duration.

Figure 4. Category judgments of average duration, simultaneous presentation, for pairs of intervals of unequal duration plotted as a function of the duration of the right-hand target. The parameter is the duration of the left-hand target.

Figure 5. Scale values yielded by a nonmetric-scaling analysis plotted as a function of stimulus measures for simultaneous presentations.

was set equal to .5, and a least-squares solution to the equation was obtained by the expression:

$$Y_{ij} = .76(.5X_i^{1.50} + .5X_j^{1.50})^{.67} + .98,$$

which accounted for 96% of the variance of the responses.

The positively accelerated function indicated by the estimate of 1.5 for the exponent k also appears in the results of a nonmetric scaling analysis. When the data from simultaneous presentations of unequal durations were subjected to Roskam's (1977) UNICON, a solution to an additive model yielded the scale values plotted in Figure 5 with a stress of .05. The plot is concave upward, which is in contrast to the near-linear relation in Figure 2 for sequentially presented intervals.

DISCUSSION

The results of the present study are essentially similar in their main features to those reported by Curtis and Rule (1977), although they differ in some particulars. The data from the successive-monitoring task are consistent with both Blankenship and Anderson (1976) and Curtis and Rule (1977) in suggesting that a linear model describes information processing when temporal intervals are serially pre-

sented. The present results also tend to confirm our previous conclusion that the composition rule describing judged average duration is nonlinear when the intervals are monitored simultaneously. Apparently, these are robust effects that reflect differences in the requirements of the two tasks, parallel processing of temporal information in the latter instance and sequential processing in the former. They conflict with Eisler's (1981) suggestion that the nonlinearity of the judgments of simultaneous intervals was attributable to the requirement that a currently monitored (longer) duration be compared with a remembered (shorter) duration. The nonlinearity holds when the two intervals terminate simultaneously as well as when they terminate asynchronously. The data provide no greater support for Eisler's parallel-clock model than did our previous findings.

Nevertheless, the present results differ from the previous data in a possibly important way. In Curtis and Rule (1977), we found that the values of the parameters k and m estimated from the data of the simultaneous-monitoring task were close to 2.0 and .5, respectively, suggesting that the perceived average duration was approximately a quadratic mean, or a vector-sum of the subjective magnitudes of the two intervals. Estimates of the respective parameters from the similar data of the present study were 1.5 and .67. These values are inconsistent with a composition rule described by a quadratic mean or vector sum, although a reciprocal relation between k and m is maintained, consistent with Equation 2. Why such a discrepancy should obtain is not clear. Possibly, the specific values of the two parameters may vary, depending on the overlap or onset asynchrony of the long and short durations making up the stimulus configuration.

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