Subjective duration of simultaneous events

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When a subject is required to combine the subjective durations of two events that occur sequentially, the perceived durations are combined linearly. However, when two events occur concurrently, the perceived durations appear to combine in a nonlinear manner. The conclusion of a nonlinear composition rests on an assumption that the perceived duration of each interval occurring in a pair is equivalent to the perceived duration of the same interval presented alone. Forty subjects gave separate ratings to each member of pairs of intervals presented simultaneously. The time intervals ranged from 0.5 to 10.0 sec. Plots of the ratings did not exhibit converging trends previously found when subjects were required to judge the combined durations of pairs of intervals. The ratings were also close to linear with ratings of the intervals presented individually to an independent group of 30 subjects. The results indicate that the nonlinearity previously found when subjects evaluated combined durations enters into the relation at a later stage of processing after the subjective durations of the intervals have been monitored.

When a subject judges the combined duration of two time intervals, mathematical descriptions of how the subjective durations are combined depend upon whether the time intervals are presented successively or concurrently (Curtis & Rule, 1977; Rule & Curtis, 1985; Rule, Mahon, & Curtis, 1983). For successive intervals, a linear rule describes the subjective combination of the two perceived durations. For example, when subjects are asked to judge the average duration of two successive intervals, the responses are consistent with the following arithmetic averaging of subjective durations of each interval:

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

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, judgments of average durations of simultaneous events are consistent with the following nonlinear composition rule:

$$\psi_{ij} = .5(\psi_i^c + \psi_j^c)^{1/c}, \quad (2)$$

in which the exponent c is greater than 1.0. Figure 1 illustrates the trends to be expected from Equation 2. The plot is of artificial data computed with the exponent c set at 1.75, a value in the neighborhood of estimates reported previously from real data. The points on the curve correspond to values for time intervals employed in the present study. An important feature of the plot is the tendency for the curves to converge toward the right. This trend does not depend upon the particular units of mea-

Figure 1. Plot of ratings predicted from Equation 2 against physical times for durations employed in the present study.

surement for the independent and dependent measures appearing in the example. It is a consequence of the exponent c 's having a value greater than 1.0. When c is set to a value less than 1.0, the trend reverses, giving divergent curves. Equation 1 is a special case of Equation 2 for which $c = 1.0$. In this case, the curves are parallel, the trend that has been found for successive presentations (e.g., Blankenship & Anderson, 1976).

Rule and Curtis (1985) examined differences in trends for successive and simultaneous presentations when judgments of average durations of both presentation conditions were intermixed within the same series of judgments. Subjective measures of duration were obtained by subjecting the combined data to a nonmetric analysis. In the analysis, Equations 1 and 2 were fitted to the common ordinal data for the two presentation conditions to yield a single

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set of measures that satisfied the two expressions. Subjecting the data to a common solution provided sufficient constraints to solve for the measures of subjective duration with ratio-scale invariances as well as an estimate of the exponent c from the rank order of the combined data.

An important assumption of the analysis was that a single scale of subjective duration describes the monitoring of duration for both presentation conditions. The difference in results from simultaneous and successive presentations of time intervals was assumed to be due to differences in how duration information is combined in the two conditions, rather than in how it is perceived. Hence, the interaction found for simultaneous events was assumed to stem from processes for integrating information from the two events in determining a single judgment of average duration, rather than from individual processing of each event.

In the present study, subjects gave separate judgments for each of the two time intervals that were presented concurrently. If the nonlinearity given in Equation 2 reflects interactions in the monitoring of the duration of each of two concurrent intervals, similar interactions are to be expected when separate responses are given to each interval. Alternatively, if the nonlinearity enters into the relation at a later stage of processing when the duration information from the two intervals is combined to yield a single response, the converging interaction illustrated in Figure 1 would not be expected. Instead, judgments of each time interval in a pair would be expected to be similar to judgments of intervals presented individually.

METHOD

Subjects

Seventy undergraduate students participated as subjects in two experiments to fulfill a requirement for an introductory course in psychology. Forty students participated in Experiment 1, and 30 students participated in Experiment 2.

Apparatus and Stimuli

The stimuli were two luminous red targets whose durations were timed by a programmable clock controlled by a laboratory computer. The durations were seven intervals, which are equally spaced when raised to the 1.25 power: 0.50 sec, 2.61 sec, 4.31 sec, 5.85 sec, 7.30 sec, 8.68 sec, and 10.0 sec. These durations are the same as those used by Rule and Curtis (1985) and were employed in the present study to provide comparability of results. A yellow light on the display panel served as a ready signal.

Procedure

Two experiments were conducted. In Experiment 1, the subjects judged the duration of each of two lights that were lit concurrently. The two lights were turned on at the same time and were turned off asynchronously, depending upon the difference in the two durations. The stimulus set consisted of all 49 pairs of time intervals obtained from crossing the set of 7 durations with itself. On each trial, the subjects judged the duration of each of the two stimuli. Twenty subjects judged the duration of the left light first, followed by a judgment of the right light, and 20 subjects gave responses to the two stimuli in the reverse order. The series of 49 pairs was presented twice to each subject in random permutations. In Experi-

ment 2, 30 subjects judged the duration of the seven stimuli presented one at a time. The series of seven durations was presented four times to each subject in random permutations.

The subjects in all conditions were run individually. They judged the duration of a light by assigning an integer from 1 to 11. Responses were given orally. Subjects were cautioned to avoid counting and other strategies as aids in making their judgments. Practice trials were provided to familiarize the subjects with the task and the range of durations to be presented.

RESULTS AND DISCUSSION

Figure 2 displays median judgments of duration as a function of the physical time of the interval. The data are plotted separately in the left and right panels of the figure for subjects who responded first to the left or to the right target in each pair of intervals. Separate curves correspond to the durations of the target with which the rated target was paired. In each panel, the median ratings of durations of the left and right targets are nearly identical, indicating that which target was judged first had little or no effect on the subjects' ratings. The important feature of the curves is that they are close to parallel. They do not exhibit the converging interactions, illustrated in Figure 1, that have been found when subjects are required to judge the combined duration of the two intervals (e.g., Curtis & Rule, 1977). In order to increase clarity of the displays, successive curves have been displaced vertically by 2 units, and hence the separation between curves is not meaningful.

Figure 3 presents the median ratings as a function of the intervals with which the rated intervals were paired. That is, judgments of the right target are plotted as a function of the duration of the left target, and judgments of the left target are plotted as a function of the duration of the right target. In most cases, the curves are flat, indicating little or no effect of the duration of the target with which the judged interval was paired. Exceptions to the horizontal trend appear as small dips in the uppermost curves in each panel, which show a slight tendency for lesser judgments when longer durations were paired with time intervals in the middle range.

In Experiment 2, the subjects rated the durations of the intervals when they were present individually. A power function was fitted to the median ratings, and a least squares solution was provided by

$$Y = 0.72X^{1.09} + 0.89,$$

where Y denotes median ratings and X is physical time. The estimate of 1.09 for the exponent is somewhat greater than what is usually considered its average value (0.9 to 1.0) (Allan, 1979; Eisler, 1976; Kristofferson, 1977). It is close to the average estimate of 1.04 reported previously for category ratings of duration (Curtis & Rule, 1977), and it is within the range of previous estimates from both category ratings (Curtis & Rule, 1977) and ratio-judgment methods (Eisler, 1976). Curtis and Rule have noted that estimates of exponents from category scales of duration are similar to those obtained from magnitude es-

Figure 2. Median ratings of duration plotted against physical times of the intervals. Lines connect points associated with a common duration, given by the parameter, of the target with which the rated interval was paired. Successive curves have been displaced vertically by 2 units. Separate plots are presented for subjects who judged the left target first and those who judged the right target first.

timation and related techniques. This is in contrast to the typical finding that category scales of prothetic continua are related by a negatively accelerated function to scales based on ratio judgments (Stevens & Galanter, 1957).

Experiment 2 was conducted as a control condition to determine whether the evaluation of an interval presented as a member of a pair was similar to its evaluation when it was presented individually. Of primary interest was the

relation between judgments of intervals presented in pairs from Experiment 1 and those presented individually in Experiment 2. To evaluate this relation, the ratings from paired presentations were averaged over all occurrences of an interval by taking arithmetic means of the median responses plotted in Figure 2. The average ratings of paired presentations are plotted in Figure 4 against the median ratings of intervals presented individually. The

Figure 3. Median ratings of duration plotted against physical times of the intervals with which the rated intervals were paired. The parameter is the duration of the rated interval. Solid lines connect points associated with ratings of the left target, and dashed lines connect points associated with ratings of the right target. Separate plots are presented for subjects who judged the left target first and those who judged the right target first.

Figure 4. Ratings of durations of intervals presented in pairs (Experiment 1) against ratings of durations of intervals presented individually (Experiment 2).

plot is close to linear, which is consistent with the interpretation that the central evaluation of an interval when it is a member of a pair is close to its evaluation when it appears alone.

The nearly parallel curves in Figure 2, along with the nearly horizontal curves in Figure 3, indicate that the duration of the interval with which a stimulus is paired has little effect on its central evaluation. This result, together with the approximately linear relation exhibited in Figure 4, supports Rule and Curtis's (1985) conclusion that the nonlinearity found when subjective durations of two simultaneous intervals are combined stems from a later stage of processing, a stage between the subject's monitoring of duration and the subject's judgment. That is, interactions found in judgments such as judgments of average duration of two simultaneous events are due not to how the two durations are perceived, but to how the perceived durations are later combined to yield a composite response. When separate responses are permitted, no interactions are found.

An alternative interpretation has been noted by Birnbaum, Parducci, and Gifford (1971) for data from a similar experimental design. According to this interpretation, it is possible that perceptual processing is in fact affected when subjects are asked to judge the combined magnitude of two stimuli but the interactions do not appear in the data from judgments of individual magnitudes because the judgment task induces a different perceptual set. According to this position, a subject attends to both stimuli when evaluating their combined magnitude, but attends to only one of a pair of stimuli when evaluating its in-

dividual magnitude. In the present study, it was hoped that this possibility could be avoided by requiring subjects to judge both stimuli in a pair. Because of the nature of the stimulus for subjective duration, a subject must monitor the two stimuli continuously throughout the presentation interval; this does not permit attention to one stimulus and not the other. An alternative research approach relevant to the issue would be to obtain both judgments of average duration and separate judgments of each stimulus on the same trial. However, there is a danger with this approach that subjects might employ extraneous judgment strategies, such as rating each stimulus separately and then averaging the ratings. Because of the likelihood of such carryover effects between judgment tasks, this alternative should be treated with caution.

Given that the interactions are not perceptual in origin, it remains to be shown why perceived durations are combined nonlinearly when monitored simultaneously, but not when monitored sequentially. Perhaps the difference stems from differences in the number of clocks or monitors that are required to perform the tasks. One would be sufficient for successive presentations, but two would seem to be needed for simultaneous monitoring, which may require more complex processing of duration information and thereby introduce nonlinearity into the mathematical description of how the information is combined.

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