Intervening stimulus effects on category judgments of duration

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Auditory pulses (1,000 Hz) occurring between the 500-Hz bounding markers of durations being judged were varied in their position and number over three experiments which examined the effects of these factors on measures of amount of filled-duration illusion (FDI) and inter-duration discriminability. The results establish that the locus of the FDI is postattentive, since some of the incoming sensory information, selected on the basis of simple physical cues, can be excluded from further processing. FDI decreases both when the intervening stimuli come from a different source (earphone channel) to the marker stimuli and when they appear as part of an ongoing sequence of background pulses. Discrimination of durations containing intervening stimuli is enhanced if the filler events are placed such that repetitions of a given subinterval result. Thomas and Brown's (1974) "chunking" model can account for the observed effects with the additional assumption that the error associated with encoding a given subinterval is sequentially modified as a function of number of recent encodings.

Stimuli occurring between the bounding markers of a temporal interval have been shown to increase its perceived duration relative to an interval containing less, or no, stimulation, an effect called the filled-duration illusion (FDI). Two recent studies on the FDI have shown both the number and dispersal of intervening events to be important factors determining the amount of illusion (Buffardi, 1971; Thomas & Brown, 1974). To account for the FDI, Thomas and Brown have proposed a "chunking" model, whereby n discrete intervening events are assumed to segment the total interval, t . Each subinterval, or chunk, thus defined, t_i , is encoded separately by the application of some function, $f(t_i)$, which is strictly increasing and at least twice differentiable. The summed subintervals then give perceived duration,

$$F(t) = \sum_{i=1}^{n+1} [f(t_i) + \epsilon_i], \quad (1)$$

where ϵ_i , the error associated with each encoding, is some value of an independent random variable with a mean of zero and a standard deviation, σ , which is independent of t . The model predicts that $F(t)$, and therefore amount of FDI, increases with n , and, for a given n , that amount of FDI is larger when event dispersal is regular rather than irregular, as noted by Grimm (1934).

The present paper considers further the effects of intervening event number and dispersal on measures of both amount of FDI and interduration discriminability, and the ability of the chunking model to account for the findings.

One problem that has not been resolved by previous studies is whether the locus of the FDI is preattentive or postattentive. This is because procedures have been adopted which have ensured attention to the intervening stimuli, although different relationships existed between the filler and marker stimuli. Buffardi used 1,200-Hz tone for all auditory stimuli, but Thomas and Brown differentiated between the two by using 900-Hz marker tones and 480-Hz filler tones. Using identical filler and marker tones compels attention to each discrete tone, since when timing durations demarcated by this method a subject could only know with certainty that the test duration had been terminated when a certain maximum interstimulus interval had elapsed, indicating that the tone last heard was to act as the end marker. When the filler material differs from the markers on some physical dimension, there is the possibility that subjects may not attend to it, but Thomas and Brown periodically questioned their subjects about the amount and patterning of intervening stimuli to control monitoring of the filler.

The purpose of the first experiment reported here was to determine whether the human timing process can be insulated from the effects of intervening stimuli occurring in the same sensory modality as the markers. If neural background pulses are cumulated as in the model outlined by Creelman (1962), stimulation coming in an otherwise empty interval may cause automatic registration of neural activity without modification by attention. Thomas and Brown's model assumes that if subjects could selectively attend to the markers the FDI would not occur, as intervening stimuli would be filtered out at the per-

ceptual and cognitive analyzer stage and not subdivide, or "chunk," the interval in the way required for experience of the illusion. To examine the effects of attention on the amount of FDI and on temporal discrimination, Experiment 1 employed durations containing only one or five intervening elements, Buffardi (1971) having shown these produce widely different perceived duration when placed in a 1,056-msec interval. The filler elements were differentiated from the markers by two methods designed to provide bases for selective attention.

EXPERIMENT 1

Method

Subjects. Seventy-five undergraduates enrolled at the University of New South Wales participated to fulfill an introductory psychology course requirement. They were divided into five groups, one sequence control and four experimental, and participated individually in a task which lasted approximately 45 min.

Apparatus and Stimuli. The stimuli were three durations, 800, 1,000, and 1,200 msec, bounded by two 20-msec, 500-Hz marker tones. Each duration contained either one or five 20-msec, 1,000-Hz intervening tones, which could occur (randomly) at any of the nine points defined by dividing the total duration into 10 equal segments. A Data-General-Nova computer was programmed to time all intervals and to switch two University VAG-220 audio oscillators set at the marker and intervening total frequencies. Output from the oscillators was equalized for intensity using an oscilloscope and recorded on separate magnetic tape channels. Subjects registered their judgments of the durations while seated in a sound-attenuated room listening over Peak MK IV stereo headphones.

Listening conditions. Appearance of the filler stimuli was manipulated by recording the filler tones as unitary with the markers on one tape, and as part of a continuing stream of background tones on another. For *unitary* appearance, the 4-sec intertrial interval after each test duration was silent, whereas under *running background* appearance, 12 additional 1,000 Hz pulses occurred (randomly) at any of 39 possible locations defined by equally subdividing the intertrial interval. As only one or five high-frequency tones intervened in any test duration, *running background* implied a rate of three such tones per second over the entire 396 trial sequence. Physical source of the filler and marker tones was varied by mixing or separating earphone channels. Subjects in the *stereo* condition heard the intervening signals on the left ear and begin and end markers on the right; those in the *mono* condition heard all tones on both ears. Intervening stimuli as either *unitary* or *running background* could be heard under either *stereo* or *mono* conditions, thus generating four independent groups in a two-factor design. By applying zero intensity to the intervening stimuli channel, a further group of subjects heard only the marker tones on both ears, as a control for sequential effects arising from the ordering of test durations (Ward & Lockhead, 1970). A category response scale was employed, as Thomas and Weaver (1975) have argued that such a scale provides more accurate measurement of *perceived* duration.

Procedure. Subjects made category judgments of the set of durations delimited by the low-frequency marker tones, grading each duration as presented on a one-to-five, short-to-long category scale. They were asked to use all five category numbers about equally often and to record their response during the intertrial interval. It was explained that the purpose of the experiment was to examine the effects of high-frequency stimulation on time judgments, but that the number and placement of these stimuli were unrelated to the dimension on which subjects were being

asked to make judgments, viz., the time that elapsed between the low-frequency begin and end markers. The subjects were then told that examples from the series covering the range of durations would be demonstrated, and 12 randomized practice trials were given in which all durations occurred twice with both one and five intervening pulses. These trials were not judged. During the experiment proper, each duration was presented on 66 occasions with each number of filler events.

Results

The results can be briefly described by obtaining the average response made to each duration when it contained one or five intervening stimulus events. These averages are presented in Figure 1. To analyze these data, three measures were defined,¹ one for the amount of FDI and the other two for interduration discriminability when one or five events intervened. Data from each subject were cast into a 6 by 5 confusion matrix, with Rows 1 to 3 representing the three durations when one high-frequency tone intervened, and Rows 4 to 6 corresponding to the same durations with five intervening tones (see Table 1).

If any two rows of this matrix are isolated, the cell entries can be converted to cumulative probabilities and a receiver operating characteristic (ROC) curve drawn. The proportion of the total area of the graph, $P(A)$, beneath the ROC curve is a measure of a subject's ability to distinguish between the stimuli corresponding to the two rows (Green & Swets, 1966), and will be .5 if two stimuli are judged as being the same. By nominating the pairs of rows to be compared, a measure I , of the amount of FDI experienced may be defined as:

$$I = \{[P(A)_{4-1} + P(A)_{5-2} + P(A)_{6-3}]/3\} - 0.5, \quad (2)$$

where $P(A)_{i-j}$ denotes the proportion of the area of the graph under the ROC curve formed by plotting Row i against Row j . The ability of any subject to discriminate between the durations when one high-frequency pulse intervenes, $D1$, was defined:

Table 1
Confusion Matrix Containing Average Cell Entries From
Condition Mono Unitary

Row	Filler Pulses	Duration (msec)	Response Category				
			short 1	2	3	4	long 5
1	1	800	26	27	9	3	1
2	1	1000	6	24	21	12	3
3	1	1200	5	15	21	15	10
4	5	800	7	19	27	11	2
5	5	1000	1	8	26	24	7
6	5	1200	1	3	19	26	17

Note—Illusion measures were obtained from $P(A)$ s comparing rows between the two kinds of filler, and discrimination measures from $P(A)$ s comparing rows within a given number of filler pulses.

$$D1 = [P(A)_{2-1} + P(A)_{3-2}]/2, \quad (3)$$

and similarly for five intervening pulses:

$$D5 = [P(A)_{5-4} + P(A)_{6-5}]/2. \quad (4)$$

Since $P(A)$ values have an upper limit of 1 and tend to be negatively skewed in their distribution, they were transformed by a $[2 \arcsin \sqrt{P(A)}]/\pi$ conversion before computation of the I and D scores. These transformed $P(A)$ scores are linearly related to d' over a wide range of values (McNicol, 1972). Mean I , $D1$ and $D5$ measures thus computed are presented in Table 2.

Measures for the sequence control group were obtained by separating the empty durations which corresponded to those containing one or five filler pulses and treating them in the same manner as the experimental groups.

A 2 by 2 analysis of variance, with factors Earphone Channel (mono or stereo) by Filler Appearance (unitary or background), was conducted on the I scores, and a 2 by 2 by 2 analysis on the D scores, the additional factor being within-subjects, type of Discrimination Score ($D1$ or $D5$). For the I scores, significant main effects were obtained for Filler Appearance, $F(1,56) = 28.01$, $p < .01$, with unitary presentation giving larger I scores, and for Earphone Channel, $F(1,56) = 4.77$, $p < .05$, where mono listeners showed a greater amount of illusion. Interaction between these two factors was not significant; $F(1,56) < 1$. The MSe for the three F tests was .019. Whether the intervening stimuli are perceived as part of the duration being judged is therefore a significant determinant of the amount of FDI, as is the physical source of the filler and marker tones, since subjects can make use of both factors to reduce effects of intervening stimulus events on perceived duration.

Discriminability analysis showed the difference between running background and unitary conditions

to be marginally significant, $F(1,56) = 3.84$, $p < .055$, because both D measures increased as the effects of the filler on I scores diminished. Product moment correlations between these three measures across all experimental subjects indicated that amount of illusion tended to be inversely related to $D1$ and $D5$ scores, $r = -0.39$ and -0.38 , respectively, and that performance with the two sets of duration stimuli was highly related, $r = +0.85$.

Discussion

The results establish that above-threshold auditory stimuli occurring in an otherwise silent interval must still be attended to for the FDI to occur, but that as attention to the intervening pulses increases, inter-duration discriminability deteriorates. While this performance decrement was unexpected, it could have been predicted by the chunking model. Since each pattern of n filler pulses was a random selection from a defined set of possible configurations, there would be many $F(t)$ for a given t . Experimenter-determined variation was therefore added in to the distribution of perceived duration. With less attended to pulses, less chunking occurred and fewer $F(t)$ were associated with any t .

The chunking model therefore predicts that removal of the variation in $F(t)$ attributable to multiple patterns of filler, by the method of equalizing sub-intervals, will increase both perceived duration (Thomas & Brown, 1974, Theorem 6.1.2) and discriminability when compared with durations containing n events randomly dispersed. Experiment 2 investigated the effects of regularity-irregularity of both one and five elements on the I and D measures defined in the first study. Hypotheses derived from the chunking model were (1) an increase in amount of FDI and $D5$ scores with five-element regularity, and (2) diminished FDI, but increased $D1$ scores, with one-element regularity.

EXPERIMENT 2

Method

Subjects. A further 60 introductory psychology students were tested, each being allocated randomly to one of four experimental conditions.

Apparatus and Stimuli. The apparatus used to generate the stimuli and make recordings was the same as in Experiment 1. Stimuli for the different groups were systematic variations of the regularity of the two sets of filler elements from mono-unitary condition in the previous experiment. Four tapes were made, on any one of which the five intervening high-frequency stimuli were either regularly or irregularly (randomly) placed, and the one intervening stimulus was likewise either regular or random. The stimulus conditions thus defined were designated 1Ra-5Ra, 1Ra-5Re, 1Re-5Ra, and 1Re-5Re, with random and regular abbreviated to Ra and Re, respectively. When the five stimuli were regular, they appeared at Positions 1, 3, 5, 7, and 9 (defined by dividing the duration into 10 equal subintervals) and one-regular appeared at Position 5. Otherwise, all positions had an equal chance of containing a pulse. Test duration sequence and

Table 2
Mean Illusion and Discriminability Measures Under the
Different Listening Conditions in Experiment 1

Listening Condition	Measure		
	I	D1	D5
Mono Unitary	.148 (.050)	.619 (.027)	.613 (.023)
Stereo Unitary	.084 (.045)	.617 (.028)	.630 (.026)
Mono Background	.020 (.036)	.653 (.023)	.647 (.028)
Stereo Background	-.007 (.016)	.642 (.022)	.636 (.019)
Sequence Control	.003 (.012)	.673 (.022)	.672 (.024)

Note—Standard errors of the means are in parentheses.

number of filler elements in any given durations were the same as in Experiment 1.

Procedure. All stimuli were presented to both ears and the high-frequency tones occurred only in the duration being judged. Otherwise the procedure and instructions were the same as in Experiment 1.

Results

Average response made to each duration under the four intervening stimulus conditions are presented in Figure 2, and mean I, D1, and D5 scores in Table 3. In a 2 by 2 analysis of variance on the I scores, with factors One Element (Regular or Random), and Five Elements (Regular or Random), the only significant effect was that associated with the one intervening element factor, where more FDI occurred with random placement, $F(1,56) = 15.5$, $p < .01$, $MSe = .046$.

Analyses with the same factors were conducted separately on the D1 and D5 scores and showed two significant results; one-pulse regularity enhanced only D1 scores, $F(1,56) = 28.4$, $p < .01$, $MSe = .003$, and five-pulse regularity enhanced only D5 scores, $F(1,56) = 16.8$, $p < .01$, $MSe = .005$.

Discussion

When sets of durations containing equal numbers of intervening elements are considered, regular spacing of the elements results in improved inter-duration differentiation, supporting the predictions derived from the chunking model about the effects

Table 3
Mean Illusion and Discriminability Measures Under the
Different Filler-Presentation Conditions in
Experiment 2

Configuration of One and Five Elements	Measure		
	I	D1	D5
1Ra-5Ra	.112 (.032)	.592 (.013)	.603 (.018)
1Ra-5Re	.098 (.072)	.559 (.015)	.665 (.039)
1Re-5Ra	-.005 (.080)	.661 (.027)	.624 (.026)
1Re-5Re	-.039 (.063)	.646 (.030)	.714 (.031)

Note—Ra = random, Re = regular. Standard errors of the means are in parentheses.

of removing some of the variation in $F(t)$. Other predictions about the amount of FDI generated by pulse number and regularity were not substantiated by the data, with the exception of the single-pulse regularity effect in condition 1Re-5Ra, which eliminated the FDI observed in 1Ra-5Ra. The hypothesis that amount of FDI increases with both intervening stimulus number and regularity can be maintained, however, by an account of the data which argues that the magnitude of simultaneous changes in apparent duration and discriminability with five elements regularly spaced was beyond the five-category response scale. This is because any increase in both discriminability and perceived duration will have competing response effects, one inclining the subject toward use of high response numbers, the other toward a wider use of the scale. One strategy which resolves this response conflict is the use of independent response scales for the two readily differentiable sets of filled durations, ignoring any differences in apparent duration between the sets. Average response data in Figure 2 for group 1Re-5Re are compatible with this explanation, but those for group 1Ra-5Re imply that no systematic resolution to the response conflict was adopted. With 1,200-msec intervals, average category applied under the two sets of filler in condition 1Ra-5Re shows the widest difference observed in the experiment, but at 800 msec, the two sets receive the same average response.

The regular-irregular paradigm, as a technique for investigating the FDI, is complicated by the fact that randomly allocating events within an interval generates configurations known to have different effects on perceived duration. Israeli (1930) found that the positive constant error in reproductions of visually defined durations declined towards zero as a single flash was moved from a position at one-fifth to one at four-fifths of the total interval. From subjects' comparisons of auditory durations,

Figure 1. Average response to duration stimuli under the different conditions of filler appearance and earphone channel, and to the same stimulus durations containing no filler. Filled circles plot responses to durations with five intervening elements, empty circles to durations with one intervening element.

Buffardi (1971) scaled intervals containing one to four intervening events and showed that durations containing configurations with pulses clustered toward the beginning were judged as being longer than those with end configurations, whereas symmetric (mirror-image) configurations caused intervals to be judged longer than end configurations, in an illusion which decreased as a function of number of elements. The regularity-irregularity distinction may therefore disguise two separate placement aspects of the FDI; the symmetrical vs. end configuration illusion and the beginning vs. end configuration illusion.

In Experiment 3, the effects of begin, symmetric, and end configurations of intervening elements on measures of the amount of placement illusion and interduration discriminability were examined with number of elements held constant within a session. Groups with the intervening elements either differentiated or undifferentiated by earphone channel were employed to determine whether the diminution in amount of FDI due to number of stimuli, observed in Experiment 1, could be replicated with the configuration aspects of the illusion. The chunking model predicts equivalent discrimination performance for all configurations of a given n elements, if D measures are determined specifically from durations containing one configuration, not a randomized set.

EXPERIMENT 3

Method

Subjects. Twenty-six students, aged between 18 and 27 years and enrolled at the Australian National University, responded to campus advertisements. They were paid \$10 for completing a hour-long experimental session on each of 5 consecutive days. Thirteen subjects were allocated to the mono condition and heard all tones on both ears; the other thirteen were allocated to the stereo condition and heard the markers on the right ear and intervening tones on the left.

Apparatus. The apparatus used to generate the stimuli was the same as that used in previous experiments. Four durations, 840, 960, 1,080, and 1,200 msec, were divided into six equal segments, thus defining five points between the 500-Hz markers at which the 1,000 Hz intervening tones could occur. Dispersal of the intervening tones over these positions was according to the end, symmetric, and beginning configurations described in Table 4. At each number of intervening elements, this procedure created 12 stimuli, i.e., four durations by three filler patterns. Separate tapes were made for one to four filler elements using a 480-trial sequence which was random with the constraint that all 12 stimuli occurred equally often. Intervening and marker tones were recorded on different channels of magnetic tape, so empty durations could be presented by reducing the intensity on the filler channel. Subjects listened in a windowless 2×2.5 m experimental chamber.²

Procedure. Wherever possible, subjects attended at the same hour on each of the 5 days. The first session was always the sequence control, in which all durations were empty, but thereafter subjects received different orders of the four tapes. A randomized practice sequence incorporating all durations under all configurations was given on each day to familiarize the sub-

Table 4
Relative Time of Occurrence in the Total Duration, t , of Intervening Elements Comprising End, Symmetric, and Beginning Configurations

Intervening Elements		Relative Time of Occurrence						
Number	Configuration	0	1 $t/6$	2 $t/6$	3 $t/6$	4 $t/6$	5 $t/6$	t
0	Empty	1						1
1	End	1					2	1
1	Symmetric	1			2			1
1	Beginning	1	2					1
2	End	1				2	2	1
2	Symmetric	1		2		2		1
2	Beginning	1	2	2				1
3	End	1			2	2	2	1
3	Symmetric	1		2	2	2		1
3	Beginning	1	2	2	2			1
4	End	1		2	2	2	2	1
4	Symmetric	1	2	2		2	2	1
4	Beginning	1	2	2	2	2		1

Note.—1 = marker pulse, 2 = intervening pulse.

ject with the range of durations and the filler for the session. Instructions regarding the nature of the task, the use of the 5-point response scale, and recording of responses in the 4-sec ITI were as in the previous experiments.

Results

Mean ratings made to each of the four durations when the differing number of intervening tones formed end, symmetric, and beginning configurations are presented in Figure 3. Data from each experimental session were cast into 12 by 5 confusion matrices and illusion and discriminability measures similar to those used previously were defined. Matrices were drawn up such that Rows 1 to 4 correspond to the four durations presented with an end configuration of intervening events, Rows 5 to 8 with

Figure 2. Average response to stimuli when the one and five intervening elements were either regularly or randomly spaced. Filled circles represent responses to durations with five intervening elements, empty circles to durations with one intervening element.

symmetric and Rows 9 to 12 with beginning configurations. The first illusion measure, I_{s-e} , reflects the extent to which durations with symmetrically-placed filler material were perceived differently to those containing filler clustered toward the end, and was defined as:

$$I_{s-e} = \{[P(A)_{8-4} + P(A)_{7-3} + P(A)_{6-2} + P(A)_{5-1}]/4\} - 0.5. \quad (5)$$

Amount of beginning over end configuration illusion, I_{b-e} , was similarly defined as:

$$I_{b-e} = \{[P(A)_{12-4} + P(A)_{11-3} + P(A)_{10-2} + P(A)_{9-1}]/4\} - 0.5. \quad (6)$$

The three discriminability measures, or D scores, De, Ds, and Db provide a measure of each subject's ability to distinguish between the four durations when the internal configurations were end, symmetric, and beginning, respectively, and are given by:

$$De = [P(A)_{2-1} + P(A)_{3-2} + P(A)_{4-3}]/3 \quad (7)$$

$$Ds = [P(A)_{6-5} + P(A)_{7-6} + P(A)_{8-7}]/3 \quad (8)$$

$$Db = [P(A)_{10-9} + P(A)_{11-10} + P(A)_{12-11}]/3 \quad (9)$$

Mean illusion and discriminability scores thus calculated appear in Table 5 and Table 6.

Analysis of variance on the I and D scores from the stereo and mono groups' sequence controls showed that there were no significant a priori differences between the sets of durations which later contained different configurations, or in the ability of the mono and stereo subjects to discriminate between the durations.

Table 5
Mean Placement Illusion With Varying Numbers of
Intervening Events Under Stereo and Mono
Listening Conditions

Number of Pulses	Illusion Type	Listening Condition	
		Mono	Stereo
0	I_{s-e}	.004 (.003)	-.001 (.003)
0	I_{b-e}	.001 (.005)	.003 (.005)
1	I_{s-e}	.125 (.031)	.087 (.027)
1	I_{b-e}	.075 (.032)	.080 (.030)
2	I_{s-e}	.124 (.032)	.111 (.044)
2	I_{b-e}	.056 (.032)	.119 (.043)
3	I_{s-e}	.027 (.022)	.014 (.023)
3	I_{b-e}	.092 (.023)	.035 (.022)
4	I_{s-e}	.059 (.025)	.008 (.019)
4	I_{b-e}	.022 (.009)	-.011 (.016)

Note—Standard errors of the means are in parentheses.

Table 6
Mean Discrimination Scores for Different Configurations
of Intervening Events

Number of Pulses	Discrimination Type	Listening Condition	
		Mono	Stereo
0	De	.639 (.013)	.638 (.011)
0	Ds	.643 (.012)	.632 (.008)
0	Db	.637 (.014)	.634 (.009)
1	De	.603 (.018)	.616 (.010)
1	Ds	.624 (.017)	.641 (.013)
1	Db	.610 (.019)	.616 (.012)
2	De	.611 (.014)	.629 (.016)
2	Ds	.616 (.015)	.625 (.017)
2	Db	.602 (.014)	.615 (.013)
3	De	.666 (.012)	.674 (.011)
3	Ds	.671 (.015)	.674 (.013)
3	Db	.644 (.012)	.675 (.010)
4	De	.675 (.018)	.681 (.013)
4	Ds	.670 (.021)	.692 (.013)
4	Db	.676 (.017)	.691 (.013)

Note—Standard errors of the means are in parentheses.

Illusion analysis. Data from the four sessions where the durations contained filler were analyzed by a series of orthogonal contrasts written across the repeated-measures factor, number of intervening events, and by a single contrast on the between-groups factor, listening condition. Decline in the amount of both I_{s-e} and I_{b-e} measures was shown to be related to increasing number of intervening pulses, as only the linear component of a trend analysis was significant, $F(1,24) = 10.7$, $p < .01$, $MSe = .019$. There were no significant differences between the two types of illusion, or in I scores from the different listening conditions.

Discriminability analysis. Contrasts involving the three components of the D scores revealed significantly higher Ds than De and Db scores, $F(1,24) = 5.65$, $p < .05$, $MSe = .0009$, but no difference between discriminability for durations containing end or beginning patterns of filler. Trend analysis of discrimination over number of intervening events gave significant linear, $F(1,24) = 25.03$, $MSe = .008$, and cubic, $F(1,24) = 9.69$, $MSe = .003$, components. The interaction contrast between the D-score differences and linear trend showed that the advantage of a symmetrical configuration for discrimination performance changed with n , so that Ds scores were greater than Db and De scores with one and two intervening elements, but not with three and four, $F(1,24) = 5.34$, $p < .05$, $MSe = .001$. Finally, discrimination scores, like the I scores, were not significantly affected by listening condition.

Discussion

After two intervening events, ability to distinguish between stimulus durations containing discrete filler pulses improved and the advantage of a symmetrical

Figure 3. Average response to stimulus durations under the two listening conditions with different numbers and configurations of intervening stimuli. Triangles represent symmetrical, squares beginning, and circles end configurations of pulses. Stimulus 1 = 840, 2 = 960, 3 = 1,080, and 4 = 1,200 msec.

configuration for interduration discriminability diminished, while the effects of the configurations employed on perceived duration declined linearly across n . In contrast with the reduction in amount of FDI and greater discriminability associated with channel separation in the first study, listening condition exerted no significant effects on either measure in Experiment 3. Factors unique to the subjects in the third study, such as experience with the empty control durations, and longer exposure to sets of intervening stimuli, may explain the stereo subjects' apparent attention to the filler.

Observed differences in the discrimination of durations containing different patterns of n filler events cannot be predicted by the chunking model in its present form, but a modification based on the work of Michon (1964) and Maloney and Calloway (1971), enables it to do so. These researchers have shown that intervals are more accurately perceived after repeated presentations, a finding which implies some sequential reduction in the variance of the distribution of ϵ with repeated encodings of the same t . Both repetitions of intervals in a pulse train (Pollack, 1952) and extended practice with a single interval (Renshaw, 1932) achieve this reduction. Sequential modification of ϵ by repetitions would account for the higher D_5 scores in condition 1Re-5Re of the second study, and the higher D_s scores in the third study. Data presented by Michon (1964, Figure 4) also suggest that, at least for auditory pulse-defined intervals, this reduction is unequal over the range of t . If t is between 100 and 250 msec, the Weber fraction with repetitions is half that for t between 333 and 1,000 msec. Dividing a given t into t_i in the first region should therefore result in markedly improved performance as the lower discrimination plateau is reached. Performance in sessions with

three and four intervening stimuli, where an interval one-sixth of the total duration (i.e., between 140 and 200 msec) was repeated either three or four times during stimulus presentation proved to be significantly higher (the cubic component in the trend analysis) than sessions with one or two intervening pulses, in which the most often repeated t_i are one-third t (between 280 and 400 msec) and one-half t (between 420 and 600 msec). By this account, intervening element symmetry is only effective if it results in repetitions of a subinterval, and I_{s-e} would be dependent on the amount of regularity in the symmetric and end configurations employed.

To explain I_{b-e} effects, Thomas and Brown have suggested that subjective pulses can terminate chunks at subintervals with an average length that is correlated with the first t_i , thus classifying the I_{b-e} as a variant of the effect due to number of pulses. As this aspect of the model is not developed further, it does not allow for comparative predictions of the amount of FDI due to regularity and small first t_i , or suggest how pulses coming just after a subjective subinterval termination affect the size of the succeeding chunk. The introduction of the concept of subjective pulses involves prediction, and implies a more active participation by the subject attending to a pattern of filler events in a duration than is involved in serially processing each subinterval and keeping a running sum of the transformed values. Subjects may hypothesize about the patterns, and if a particular configuration of filler events matched the memorial representation of some stored rhythm it could be processed more deeply and increase perceived duration according to Ornstein's (1969) storage-size hypothesis. Markers of a different frequency to the intervening stimuli add to the likelihood of further processing, since element accent as well as interval ratios can define a rhythm (Handel & Yoder, 1975).

In summary, the Thomas and Brown conceptualization of the encoding process involved in timing intervals containing discrete events can explain the effects of event number and regularity on perceived duration, and predict discriminability of regular vs. irregular dispersals randomly sampled, but cannot account for discrimination differences between different patterns of filler. Modification of the assumption of encoding error independence of t_i to one of dependence on amount of experience with a given t_i enlarges the competence of the model to explain the phenomena observed in the experiments reported here.

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NOTES

1. Initially, analysis was based on Schönemann and Tucker's (1967) maximum likelihood procedure for estimating signal detection parameters, but this was abandoned when it was found to be biased toward generating higher discrimination measures for higher numbered stimuli with the same row entries in the confusion matrix. As other estimation procedures use the same algorithm, the nonparametric measure of sensitivity, $P(A)$, was used as the basis of the measures of illusion and discriminability.

2. Experiment 3 was carried out at the Australian National University, Canberra. The author wishes to thank Professor C. Gibbs and Associate Professor G. Seagram for making the research facilities available.

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