THE DISCRIMINATION OF SUCCESSIVE SENSORY IMPULSES

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By

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SCOPE AND CONTENTS:

Preliminary experiments were conducted to evaluate a theoretical model for predicting temporal numerosity data. The model was based on a hypothetical central unit of duration. It described the gating of sequentially presented auditory pulses. Experiment 1 offered partial support for the prediction that events occurring within one unit 50 milliseconds in duration would be perceived as simultaneous. Results of Experiment 2 suggested that empty duration units occurring between sequential events would not affect number reported. The estimate of the unit was 60 milliseconds. Experiment 3, an attempt to improve methodology, suggested values of the unit of approximately 75 and 106 milliseconds.

Inadequacies of the model were discussed. Control experiments were considered to eliminate such cues for discrimination as duration and intensity differences.

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INTRODUCTION

The study of temporal numerosity, the "counting" of successively presented sensory stimuli, has recently been reviewed by Carroll T. White (1963). Experiments conducted by White and his co-workers were designed to investigate the possibility of a "periodicity in the perceptual process" as suggested, for example by Stroud (1955). According to White the notion of a duration unit has two basically similar implications for temporal acuity - the ability to discriminate temporally distinct events. First, "temporally discrete events occurring during any one unit of duration should be perceived as simultaneous". Second, "there should be a definite limit to the perceived rate of stimulation" (p. 5). These statements, implications for perception, appear to be, in addition, predictions for *S*'s behavior (e.g. verbal reports).

White's experiments, essentially number-rate designs varying both number of pulses appearing in a sequence and rate of presentation of elements, offer support for the latter implication. In the *visual* modality, trains of 2, 3, 4, 5, 6, 7, 9, 11, 13 and 15 flashes were presented at the rate of 25 flashes per second (25/sec.). The obtained numerosity function, a comparison of number of stimulus flashes reported with number presented, was composed of two segments: (a) from the onset of stimulation up to a train duration of 250-300 milliseconds (msec.), and (b) from about 250-300 msec. on. The first segment was initiated by a fusion period during which presentation of 1, 2 and sometimes 3 stimuli resulted in report of one flash perceived. The rates of increase in the modal number reported as a function of train duration were 12-13/sec. for the first segment and 6-7/sec. for the second. Although the exact form, e.g. duration and slope, of the first segment was influenced by such peripheral factors as locus of stimulation and level of adaptation, the slope of the second segment was not so affected. It was concluded that both the constant rate of increase of the second segment and the maximum attainable rate observed during the first segment were determined by a central process. The possibility that the same central factors might be implicated in both was not discussed.

A re-examination by White in 1963 of the results of an <u>auditory</u> study conducted by Cheatham and White (1954) supported the above conclusion. Presenting trains of 1 to 15 square wave pulses, each 11 msec. in duration and 70 decibels (db.) in intensity, Cheatham and White found that at rates of 10, 15 and 30/sec.

1) <u>O</u>s underestimated the number of pulses in all conditions;

and 2) for a given rate the disparity between number presented and number reported increased linearly as a function of number presented.

A plotting of modal number reported as a function of time taken to present a sequence indicated a temporal numerosity function composed of two segments. The first segment of the auditory function like that of the visual function showed a rate of increase in number reported of 12-13/sec. (i.e. one unit every 75-80 msec.) for the first 300 msec. The second segment showed again a relative levelling off in rate of increase. For the auditory data a phenomenon similar to the initial fusion period in vision was described. While at the rate of 30/sec. Ss could discriminate two pulses, they were not able to perceive the addition of a third event.

The data presented in White's monograph in support of his second prediction are suggestive of an alternative explanation in terms of duration discrimination. It could be argued that Ss were not "perceiving" additional stimuli at a constant rate but that they were perceiving increments in the duration of the stimulus train. These judgments could then be labelled in terms of additional units perceived. That the latter interpretation is a reasonable one is suggested by the results of experiments conducted by George A. Miller (1956). To be more specific, Ss in White's study were required to withold their reports until completion of the pulse train, which, as indicated above, sometimes contained as many as 15 pulses. According to Miller (1956, p. 90)

> "There is a clear and definite limit to the accuracy with which we can identify absolutely the magnitude of a unidimensional stimulus variable. I would propose to call this limit the span of absolute judgment, and I maintain that for unidimensional judgments this span is usually somewhere in the neighbourhood of seven.....however,..we have a variety of techniques for....increasing the accuracy of our judgments. The three most important of these devices are (a) to make relative rather than absolute judgments; or, if that is not possible, (b) to increase the number of dimensions along which the stimuli can differ; or (c) to arrange the task in such a way that we make a sequence of several absolute judgments in a row."

Verification of White's first prediction that "temporally discrete events occurring during any one unit of duration should be perceived as simultaneous" would lend weight to an argument for the utility of positing the hypothetical internal flow of units of duration. Experimental evidence for perceptual simultaneity, supporting the notion of a unit of duration or quantum of time, has been presented by A. B. Kristofferson (1967a), who has suggested that information transmission in the central nervous system is controlled by a "clock" which "generates a succession of equally-spaced points in time....independent of the time of occurrence of an external signal" (p. 93). Data supporting the hypothesized internal time base were derived from experiments on successiveness discrimination, using a two-alternative, forced-choice method. On each trial two light-sound pairs appeared in succession. The offsets of stimuli in one pair were simultaneous while those in the other differed by a variable duration of t msec. Ss' choice of the pair in which the light offset preceded the sound offset allowed calculation of the probability of a correct response, P(C), for each value of t. The successiveness function, so defined, increased linearly from P(C)=.5 for t=x msec. to P(C)=1.0 for t=x+M msec. M, that value containing the linear segment of the function, was estimated as approximately 50 msec. This value was suggested as the value of q, the period of the theoretical time base.

Further support for the existence of the unit and the value implied by the successiveness discrimination function was derived from experiments on the effect of channel uncertainty on discrimination reaction time (Kristofferson, 1967a). A comparison of trials on which S was informed of the modality to which he was to attend for relevant information with trials on which he was uncertain allowed a computation from which the increment of time added by uncertainty could be inferred. The results of the experiments indicated that the increment was approximately 50 msec.

Although the data published by Kristofferson support the notion of a constant unit of duration they raise two problems for the present investigation;

1) The theory has been supported only for the gating of pairs of qualitatively different afferent signals;

and 2) the value of the quantum does not agree with that suggested by White's data.

In spite of these problems it may be fruitful to extend the theory to allow prediction of temporal numerosity data and assuming the validity of the theory to estimate the value of the unit of duration.

THE COUNTING MODEL

The model to be developed for predicting temporal numerosity data will consist of a set of three primary assumptions. Given the hypothesis of an internal time base, that is, of a succession of internal units of duration, it is assumed first that where two or more signals occur within one unit of duration (or quantum of time) these will be "counted" as one event. Second, number of pulses reported by S is assumed to equal the total number of quanta "counted". Third, the first pulse in a train of pulses may arrive with equiprobability at any point during the ongoing (hereafter referred to as the first) quantum. So that the model can be used to make specific predictions about performance. **Two secondary assumptions will be stated tentatively. These do not follow directly from the primary assumptions and require extensive empirical support.**

a) the total "count" will be defined as the number of quanta, total or partial, falling between the onset of the first pulse in the sequence of pulses presented and onset of the final pulse;

b) both quanta containing events and empty quanta occurring between events will be "counted".

Given that a quantum of time equals q msec., it follows that within a particular channel at most one sensory signal can be "counted" every q msec. Rates of event presentation greater than [(1000 msec.) / (q msec.)] pulses per sec. will result in information deficits or a loss of afferent information.

The model of event processing described allows prediction of responses to pulse trains reflecting variation in three dimensions: (a) number of pulses in the sequence, (b) rate of pulse presentation and (c) assumed value of q. For each condition (a, b, c) the probability of every possible response can be calculated. A sample prediction of response and associated probability follows.

A Sample Prediction of Possible Responses and Their Associated Probabilities

Let us suppose that four pulses are presented at the rate of one pulse every 33 milliseconds (or approximately 30 pulses per second) and that the value of the quantum is 50 milliseconds. If the first pulse of the sequence occurs at the last millisecond of the first quantum, then the last pulse in the sequence must, according to the five assumptions stated, occur during the third quantum of time. More specifically, the time from onset of the first to onset of the last of the four pulses is 99 milliseconds. If the first pulse occurs at the last millisecond of the first quantum then the final pulse must occur 99 milliseconds later or at the last millisecond of the third quantum. Since three quanta are involved between presentation of the first and fourth pulses in the sequence, the predicted report will be three.

More generally, if the first pulse occurs during the last 49 milliseconds of the first quantum, the last pulse will occur during the third quantum. Thus the probability of three quanta being occupied is 49/50 or .98. Only when the first pulse occurs at the first millisecond of the first quantum does the fourth pulse occur during the second quantum. Thus the probability of two quanta being involved during presentation of the train is .02.

Predicted modal response, defined as that response category with the highest predicted probability of occurrence, is three.

The present study is an attempt to test the modal outlined and to develop it further. The consequences of the assumptions will be subjected to empirical test. Of specific interest is the tentative assumption that the number of stimuli reported will equal the number of quanta assumed to occur between presentation of the first and final events in a sequence. It implies that given a constant number of quanta, or more empirically, a constant duration for presentation of the train of pulses, the _S_'s _modal_ report will in no way be affected by changes in either the number of stimuli presented or the rate of presentation.

In order to increase the probability that _Ss_' judgments will in fact reflect only the "count", number of pulses will not exceed Miller's estimate of his span of absolute judgment.

EXPERIMENT 1

METHOD

Subjects:

The subjects, one male and one female, were undergraduates of McMaster University. Neither had had previous laboratory experience in making the judgments required in the study.

Apparatus:

The subjects, tested individually, were seated in a darkened sound-proof experimental chamber. At the start of each trial a two-second warning signal, consisting of a tone of 2000 cycles per second (Hz), was delivered by an audio-frequency generator through a speaker located above the S's head. Two seconds after the offset of the tone a train of auditory pulses, generated by a Timing and Stimulus Intensity Control Unit located in a control room outside S's cubicle, was delivered binaurally through a pair of earphones. The pulses, each 10 msec. in duration, were pure tones of 2000 Hz and approximately 66 db. referred to .0002 µbar. The Unit was built specifically for experiments of this nature by Bolt, Beranek and Newman of Cambridge, Massachusetts. The time intervals from the onset of the warning signal to onset of the first pulse in the train were controlled by two Hunter timers connected with the Unit.

Design:

The independent variables manipulated in the study were (i) number of auditory pulses in the stimulus train (i.e. n equal to 2, 3, 4 and 5) and (ii) the total presentation time of the train. Since in previous studies (Kristofferson, 1967a) the length of the temporal quantum, q, was estimated to be about 50 msec., in the present study it was decided to use durations that were multiples of values in this region. Specifically, for assumed quantum durations of 40, 50 and 60 msec. total durations were to be 2C, 3C, and 4C, where C represented the number of units totally or partially included between the onsets of the first and final events in the sequence. Combination of assumed values of q and C yielded a set of nine durations within which each of the four values of n could be presented. The resulting 3 x 3 x 4 factorial design composed of 36 cells is presented in Table 1. Cells of the design in which the value of C exceeded the number of stimulus pulses (n) were omitted. Thus 27 cells remained.

To determine the rate of presentation in each cell three factors were taken into consideration:

(i) number of pulses in the train

(ii) the assumed value of the unit

and (iii) the duration allowed for presentation of the train.

A sample calculation follows:-

Sample Calculation of Rate of Presentation for Design Cells in Experiment 1

Suppose that q, the duration of the quantum, is equal to 40 msec., n, the number of pulses presented, is 4, and C, the number of total and partial units of duration assumed to fall between the onsets of the first and final pulses in the train, is 2. Since q equals 40 msec. then to satisfy the condition that C equals 2 the first 3 pulses of the train plus the onset of the fourth pulse must span at least 41 msec. That is,

$$3x + 1 = 41,$$

where x represents the duration of one pulse plus the duration of the interpulse interval immediately following it, and

$$3x = 40$$
$$x = 13.33$$

No matter where the first pulse coincides with the ongoing quantum, the onset of the last pulse will always occur within the second

Table 1

Design for Experiment 1

No. of Pulses (n)	Presentation Time (between onsets of first and final pulses) 2C			3C			4C		
2	16.6+	20	25	--	--	--	--	--	--
3	32	40	50	16.6	20	25	--	--	--
4	50	60	75	25	30	37	16.6	20	25
5	72	80	100*	33	40	50	22	27	30
Assumed value of q (msec.)	60	50	40	60	50	40	60	50	40
Approx. presentation time from onset of first to onset of final pulse (in msec.)	61	52	41	121	101	81	181	150	127

\+ Rate of Stimulus Presentation (per second)

* Equivalent to one steady pulse

-- Will be omitted from further discussion quantum. Thus the probability of satisfying the condition that the duration be 2C is 1.00.

Rate of presentation, then, will be 1 pulse every 13.33 milliseconds or 75 pulses per second.

Where several rates were acceptable, the rate giving the highest probability that the train would span durations of exactly (q+1) msec., (2q+1) msec., or (3q+1) msec. for the three values of C, was chosen. For no condition was this probability less than .95.

Procedure:

(a) Practice

The first six sessions, each one hour in duration, consisted of practice trials. During each session 200 judgements were required. Fifty trains of 2, 3, 4 and 5 pulses respectively were presented in a random order at the rate of 10/sec. (i.e. one event every 100 msec.). A trial consisted of presentation of the stimulus, S's report of the number of pulses, and feedback, E's report to S of the number actually presented. Short rest periods were given after blocks of 50 trials.

The purpose of these initial six sessions was to familiarize S with experimental materials and to allow him to practice applying numerical response categories to trains of auditory pulses. The rate of presentation used was slower than those appearing in the experimental design.

(b) Test Sessions

Ten sessions, each one hour in duration, were given on separate days over a period of two weeks. During each session, two randomized blocks of 108 trials were presented. A block consisted of four presentations of each of the 27 experimental treatment combinations. Thus 80 responses were obtained for each cell of the design. A trial was composed of presentation of the train, and S's report. No information was given about the accuracy of performance. Ss were allowed a short rest period after sets of 54 trials.

The instructions given prior to both practice and test sessions were:

> This is an experiment in auditory perception. On each of (   ) trials, following a warning buzzer, I will present a number of auditory pulses. You will be required to report via the intercom the number of pulses which you have heard. (I will then report back the correct number.)
>
> Your progress in this experiment will be compared with that of others, so please give the task your full concentration.
>
> You will be given a short break after each set of (   ) trials.

RESULTS

A. Practice

Per cent correct responses plotted for blocks of 50 trials within each of the six sessions are presented in Figure 1. The graph indicates that both Ss were responding accurately on at least 70 per cent of the trials by the third day, with little improvement for the final three sessions.

Average response distributions for these final three days of practice are presented for stimulus trains of varying length in Figure 2. For each distribution shown, the sum of the mean number of responses in each category is 50, the number of trials on which the given stimulus train was presented within a practice session. Comparison of the distributions obtained for both Ss for the four conditions shows

FIGURE I PER CENT CORRECT RESPONSES OVER BLOCKS OF 50 PRACTICE TRIALS

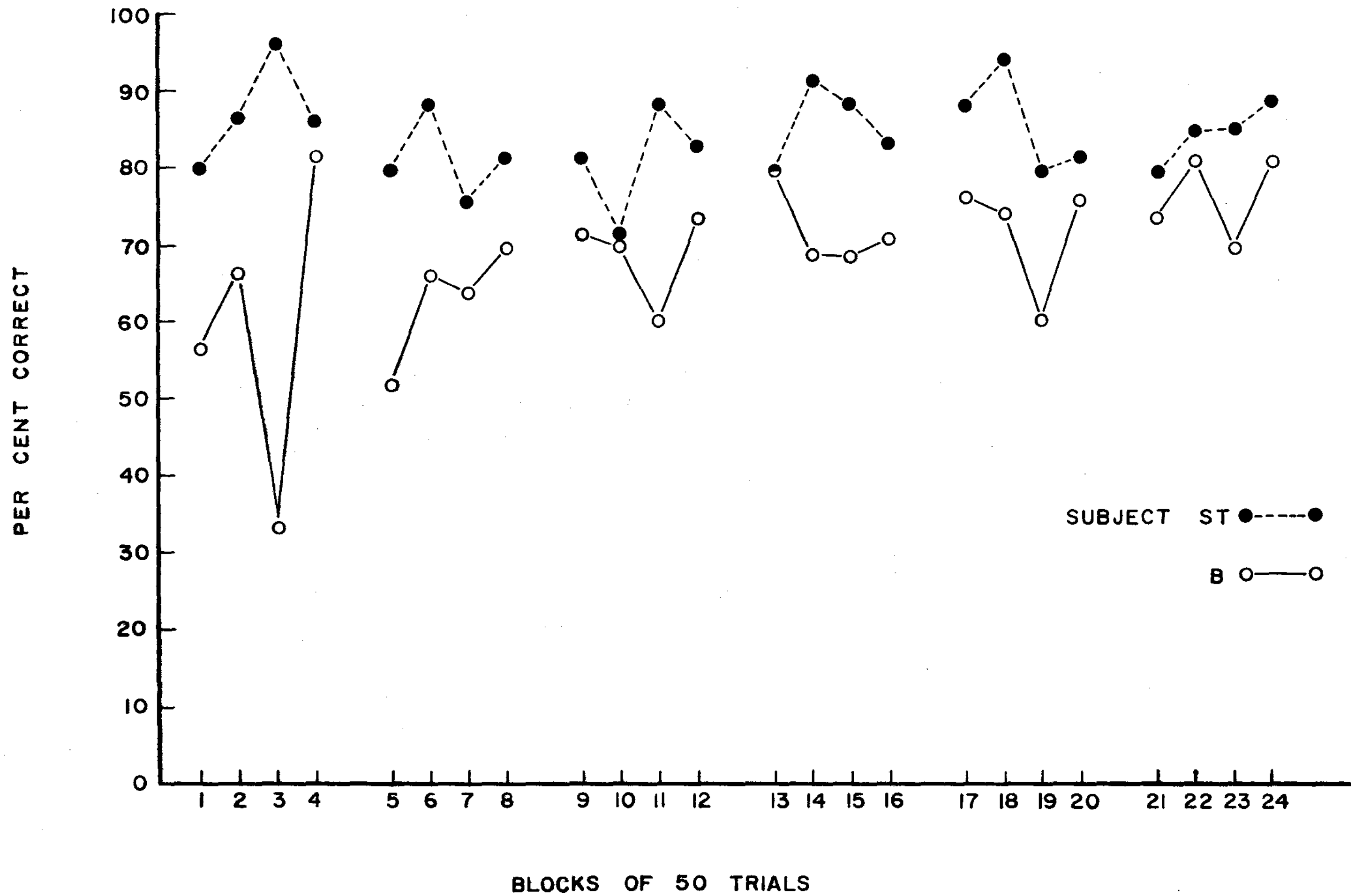
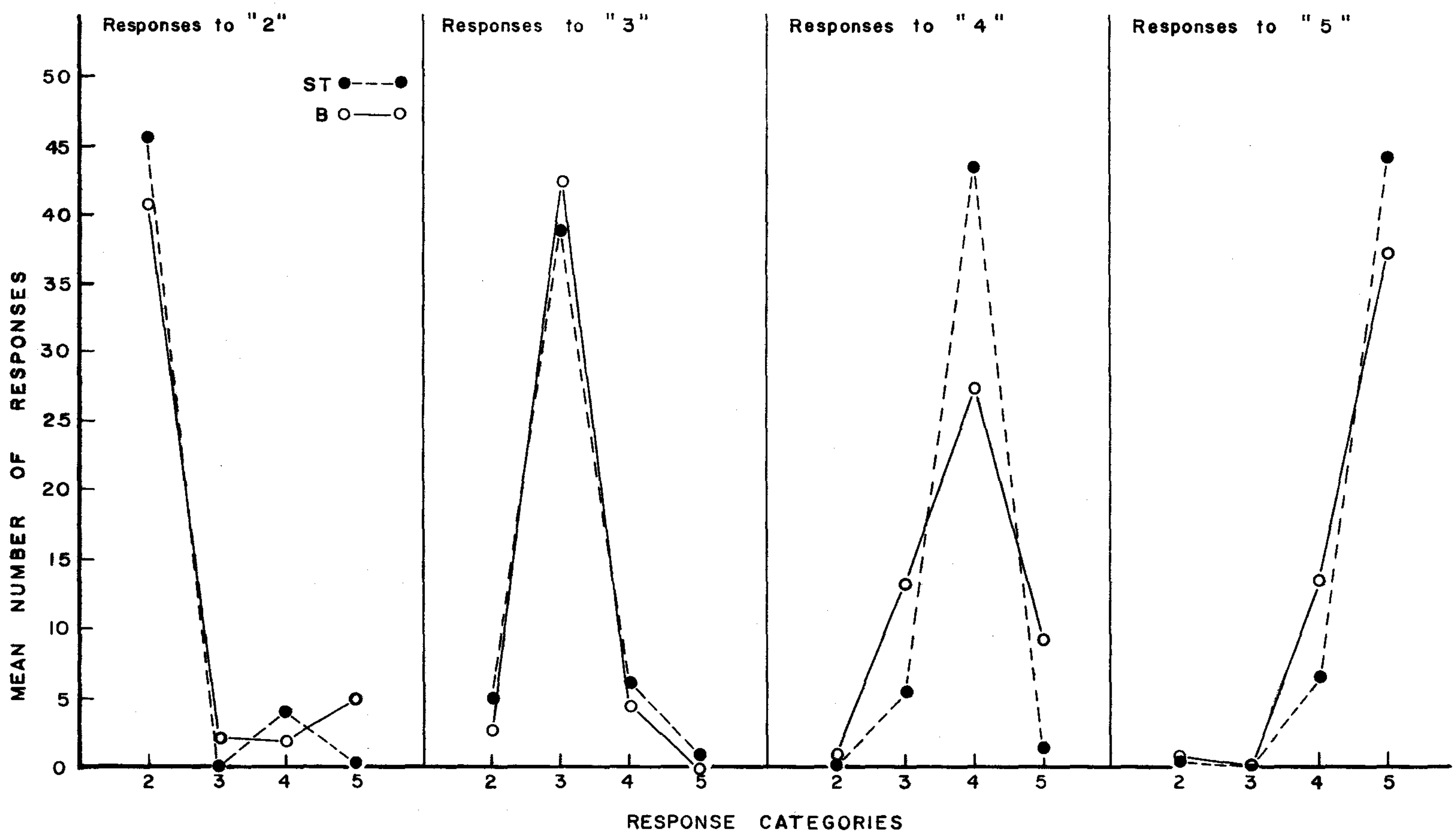


FIGURE 2

DISTRIBUTIONS OF MEAN NUMBER OF RESPONSES FOR THE FINAL 3 DAYS OF PRACTICE



that at a presentation rate of 10/sec. the response category used most frequently, that is, modal number reported, corresponds to the number of stimuli presented.

The probabilities associated with each response category, given a particular stimulus condition, are presented for the two Ss in Table 2. For subject ST the values are based on data obtained during six sessions. For subject B the values presented are based only on data obtained during the final three sessions, since probabilities associated with different response categories did not appear to reach a consistent level until the fourth session (see Appendix A, Table 2). Inspection of these probabilities indicates that for trains containing 3, 4 and 5 pulses both Ss tend to distribute their erroneous responses in the category representing number of units, one smaller than the modal number.

B. Test Sessions

Data points relating modal numbers of stimuli reported to modal numbers predicted ($\overline{R}$) are presented for the two Ss in Figures 3 and 4 respectively. For each assumed value of q, i.e. q equal to 40, 50 and 60 msec., grids are presented for stimulus trains containing different numbers of pulses (n equal to 2, 3, 4 and 5), each train varying only in the number of quanta assumed to be occupied during presentation of the train.

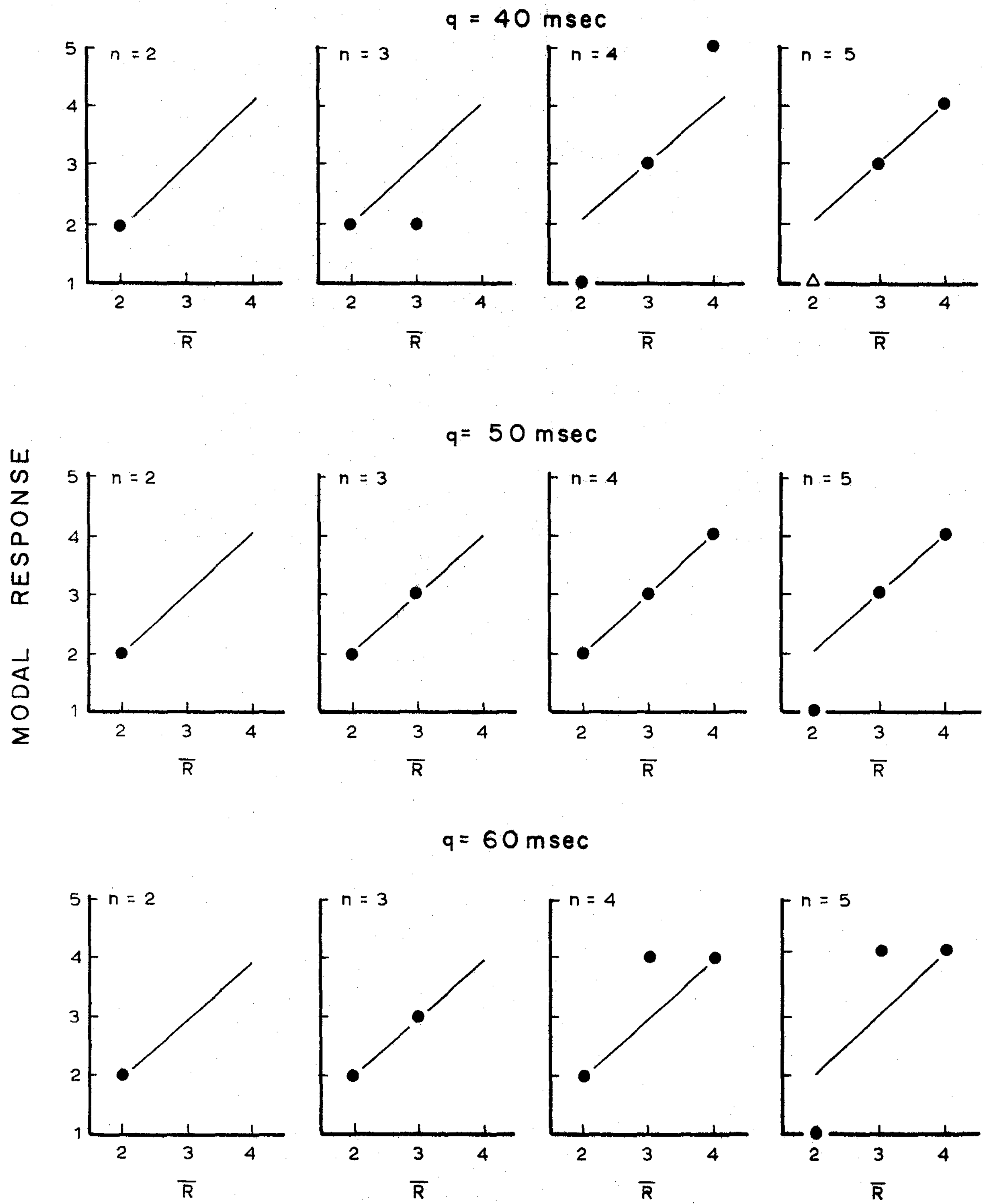
According to the assumptions outlined, modal number reported should equal the number of quanta assumed to fall between the onsets of the first and final pulses of the train. This assumption implies that given a constant number of internal units of duration, that is, a constant duration for presentation, variation in the number of pulses should in no way influence S's report. However, if the value of q on which pre-

Table 2

Probabilities of Each Response Conditional on Stimulus Events During the Practice Trials in Experiment 1

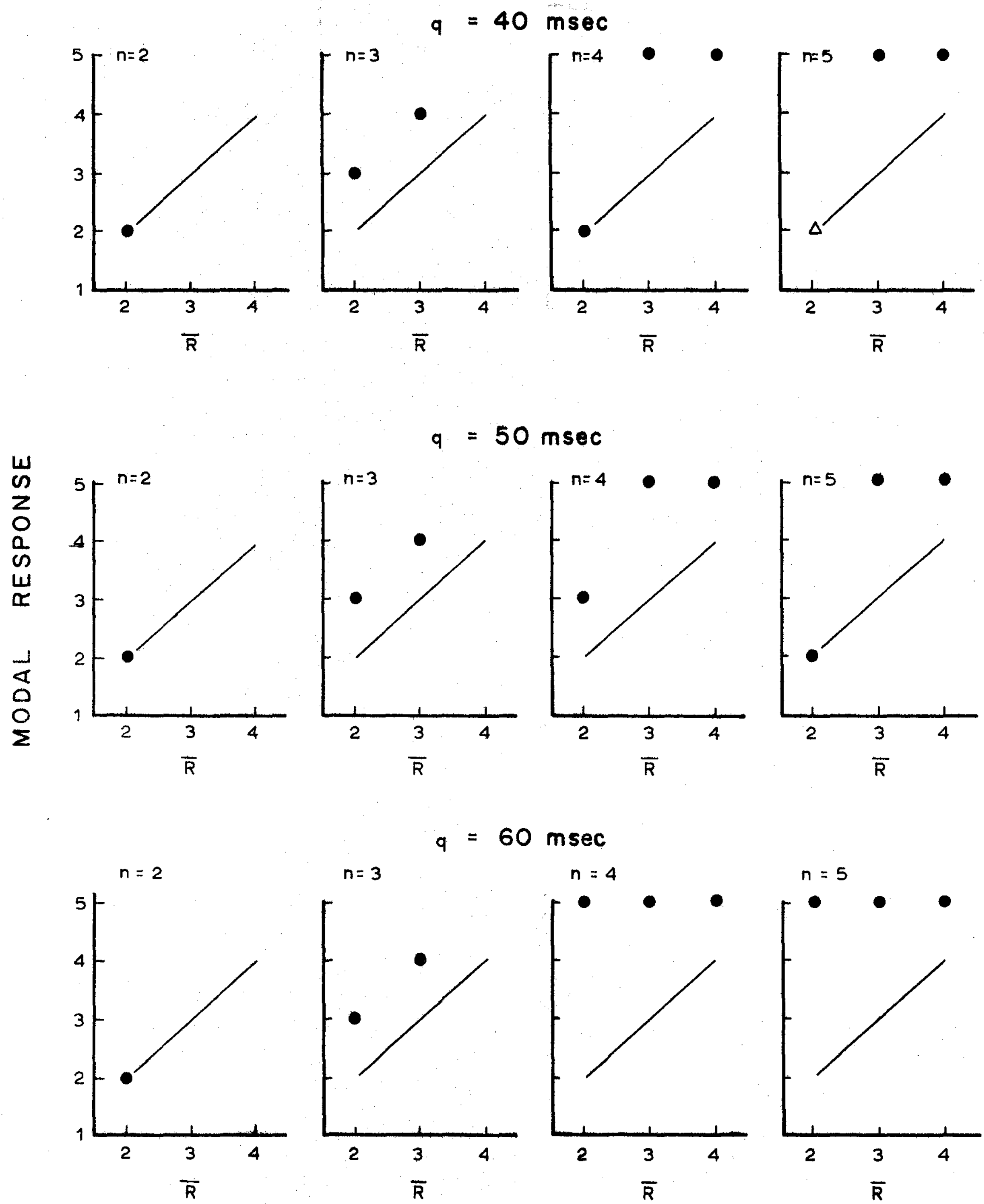
Subject	No. of Pulses	Response Categories			
		2	3	4	5
ST	2	.897	.000	.100	.003
	3	.103	.784	.113	.000
	4	.003	.107	.857	.033
	5	.003	.000	.150	.847
B	2	.813	.040	.040	.107
	3	.053	.847	.087	.013
	4	.013	.260	.547	.180
	5	.007	.000	.260	.733

FIGURE 3 MODAL RESPONSE COMPARED WITH PREDICTED RESPONSE ($\bar{R}$) FOR DIFFERENT ASSUMED VALUES OF q (SUBJECT ST)



Δ See note Table I

FIGURE 4 MODAL RESPONSE COMPARED WITH PREDICTED RESPONSE ($\bar{R}$) FOR DIFFERENT ASSUMED VALUES OF q (SUBJECT B)



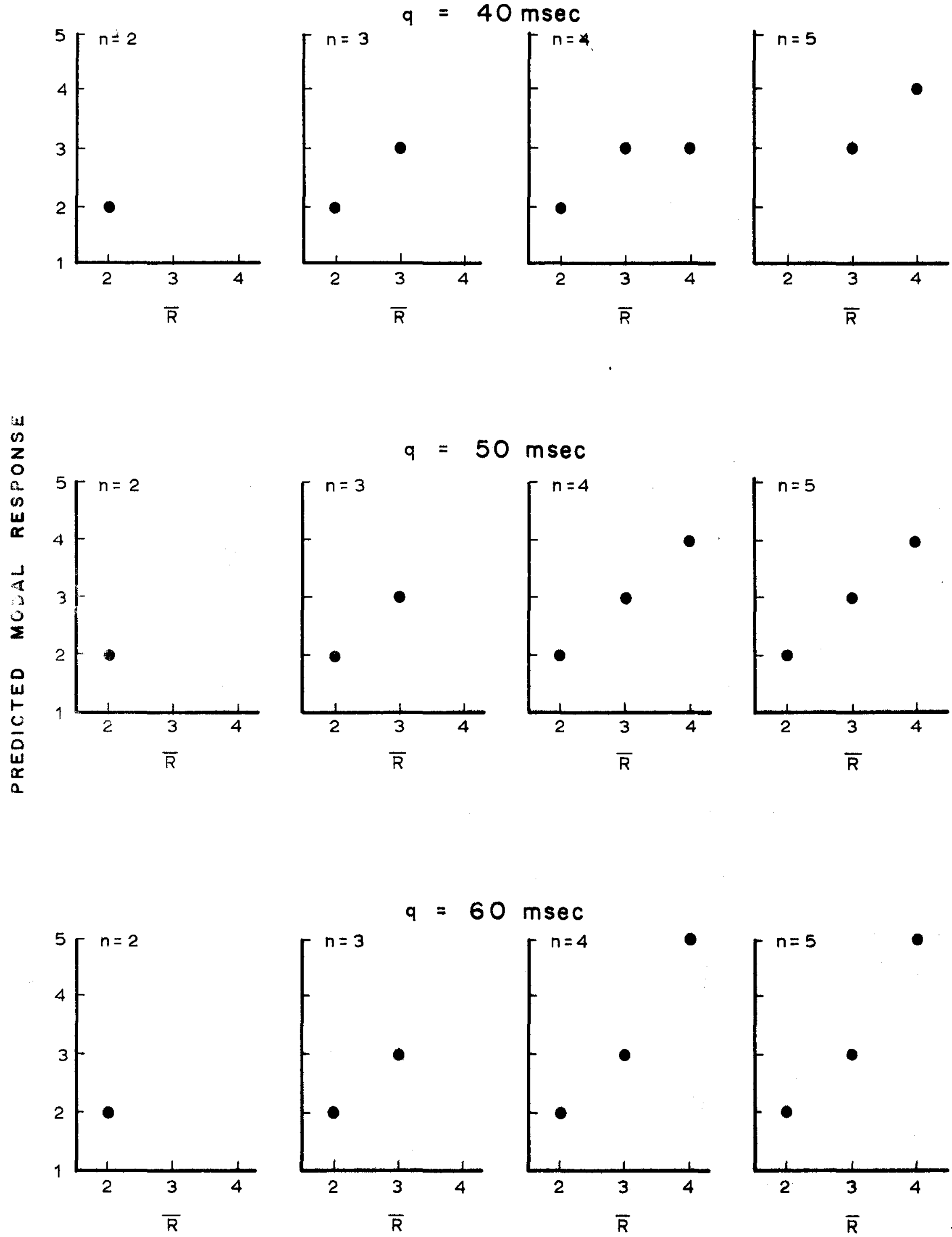
Δ See note Table I

dictions are based exceeds the true value of the internal unit of duration, then the number of quanta really involved should be greater than the predicted number and hence, modal number reported should exceed ($\overline{R}$) the number predicted. Further given a constant rate of presentation the discrepancy between predicted and obtained modal reports should increase as the total presentation time increases (i.e. as n increases). **For example,** if the assumed value of q on which predictions are based is 100 msec. but the true value of the quantum is 50 msec., then for a train duration of 300 msec. the discrepancy between predicted number and actual number of quanta spanned is three quanta. For a train duration of 600 msec. this discrepancy is six quanta.

If the assumed value of q is less than the true value fewer units should be involved than predicted and modal number obtained should be less than $\overline{R}$, the predicted number.

The results obtained imply, that for subject ST, of the three assumed values of q, q equal to 50 msec. is the "best" predictor of performance. The expected modal reports given this value are shown graphically for the 27 cells of the design in Figure 5. A comparison of predicted values plotted in Figure 5 for durations based on q assumed equal to 40 and 60 msec. with obtained values shown in Figure 3 does not provide complete support for the arguments presented above. For example, in Figure 3 for the condition: q assumed equal to 40 msec., n equal to 3, and $\overline{R}$ equal to 3, the modal number reported is "2". Yet if we assume that the true value of q is 50 msec., presentation of 3 pulses at the rate specified by the particular condition, i.e. 25/sec., would lead us still to predict a report of "3". An underestimation is obtained where

FIGURE 5 PREDICTED MODAL RESPONSE FOR q EQUAL TO 50 MSEC. COMPARED WITH $\bar{R}$ FOR DIFFERENT ASSUMED VALUES OF q



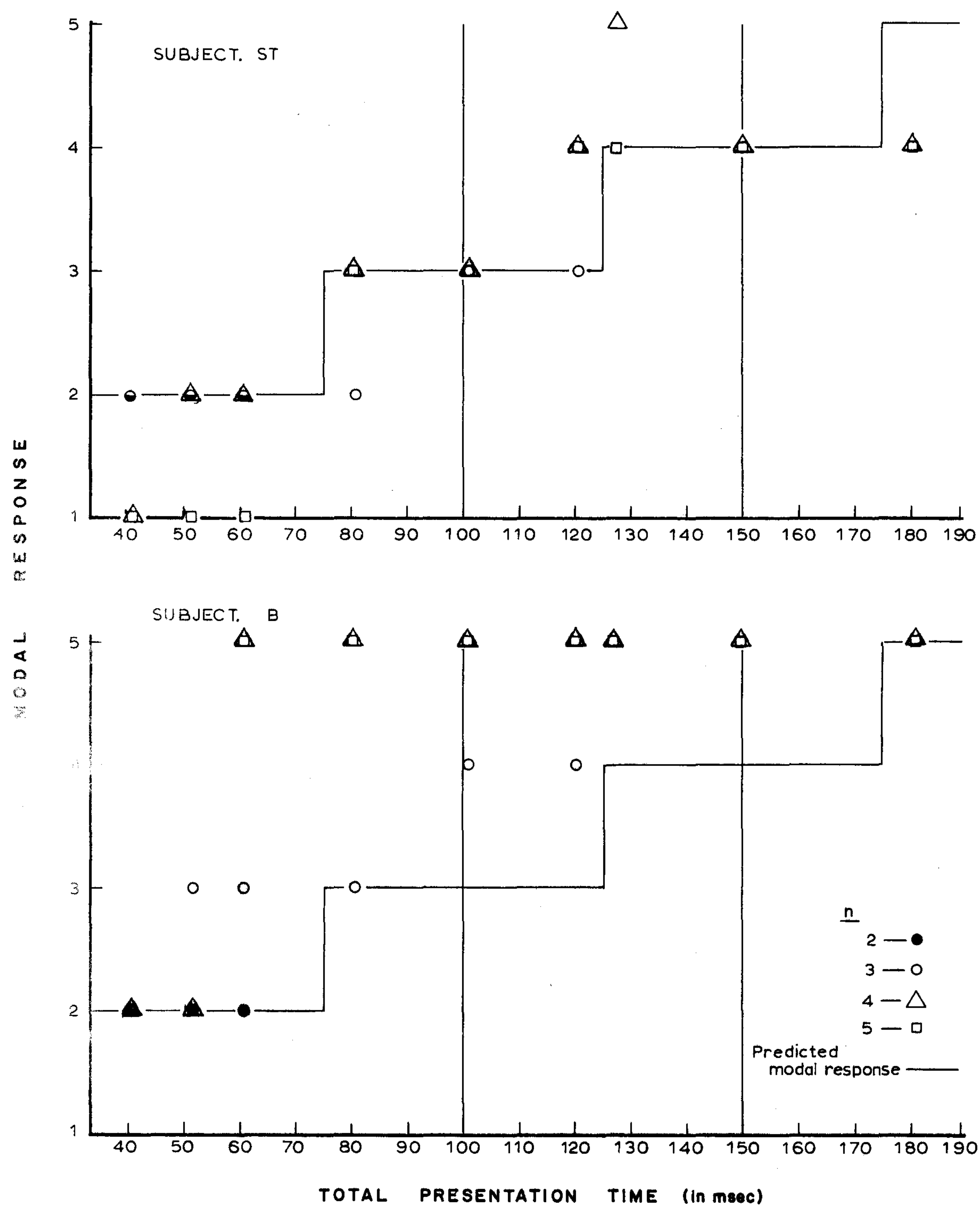
none is expected. For the condition: q assumed equal to 40 msec., n equal to 4 and $\overline{R}$ equal to 4, if the true value of q is 50 msec., an underestimation (as compared to $\overline{R}$) is expected but modal number reported is "5". Analogously, for q assumed equal to 60 msec., reports are greater than expected for n equal to 4 or 5 and $\overline{R}$ equal to 3, and less than expected for n equal to 4 or 5 and $\overline{R}$ equal to 4.

For subject B, none of the assumed values of q appears to be an adequate predictor of performance.

The extent to which modal response increases as a function of total duration is shown more directly for the two Ss in Figure 6. The predicted modal response based on q equal to 50 msec. is presented for each duration used. These predictions take into consideration the asynchrony of the first pulse in the train with the first quantum. For example, although a train 80 msec. in duration is less than three quanta (if q equals 50 msecs.) predicted modal response must be three since onset of the first pulse at any point beyond the fourth msec. (of the 50 msec.) of the ongoing quantum will result in coincidence of the final pulse in the train with the third quantum.

A comparison of predicted modal response in Figure 6 with the modal reports of subject ST support the assumption that changes in modal number reported are correlated with the succession of units of duration. More explicitly, for trains of 4 and 5 pulses modal response changes from "1" to "3" between 50 and 100 msec., and from "3" to "4" between 100 and 150 msec. Subject B appears to use two categories of response, reporting "2" or "3" for pulse trains, 40-50 msec. in duration, and "5" for those longer than 60 msec. The increasing trend evident in subject ST's data is found for subject B only for trains consisting of 3 pulses and in this case modal report is not consistently equal to number of quanta assumed

FIGURE 6 MODAL RESPONSE AS A FUNCTION OF PRESENTATION TIME



to be spanned.

In order to examine the effects of rate of presentation the frequencies of response obtained for stimulus trains presented under various rates were compiled. Six intervals of rates were studied: 17/sec., 20-22/sec., 25-27/sec., 30-33/sec., 37-40/sec. and 50/sec. The distributions of the Ss' responses conditional on presentation of trains containing different numbers of pulses are shown in Tables 3 and 4. Frequencies, that is, numbers of responses falling into particular response categories for each condition, have been converted to probabilities. Ss' probability of a correct response P(C) are plotted as a function of rate of presentation for trains containing different numbers of pulses in Figure 7. Subject ST's data indicate that for the mostpart for each rate of presentation, P(C) decreases as the number of pulses presented increases, and for each train of pulses P(C) decreases as rate increases. These relationships are not, however, apparent in subject B's data. Rate of presentation does not appear to affect systematically the P(C) for trains differing in numbers of pulses. The finding that P(C) is consistently highest across rates for trains containing 5 pulses together with an increase in P(C) for 4 pulses as rate increases is suggestive of a bias to report larger numbers for this subject. Statistical tests were not applied to these results as the interest at this stage of the research was primarily in comparing the ordering of response categories in terms of probability, contingent on the changes in rate of presentation and on number of pulses.

The probabilities associated with particular response categories for various rates of presentation, given different numbers of pulses, are shown graphically for the Ss in Figures 8 and 9 respectively.

Table 3

Probabilities of Each Response Category Conditional on Stimulus Events During Test Trials in Experiment 1 (Subject ST)

Rate (pulses/ sec.)	No. of Pulses	Response Categories				
		1	2	3	4	5
17	2	.000	.863	.050	.087	.000
	3	.000	.137	.800	.063	.000
	4	.000	.000	.200	.800	.000
	5	----	----	----	----	----
20-22	2	.000	.850	.113	.037	.000
	3	.000	.187	.788	.025	.000
	4	.000	.013	.250	.737	.000
	5	.000	.000	.100	.900	.000
25-27	2	.025	.813	.100	.062	.000
	3	.000	.550	.450	.000	.000
	4	.000	.075	.456	.469	.000
	5	.000	.000	.050	.950	.000
30-33	2	----	----	----	----	----
	3	.013	.675	.312	.000	.000
	4	.000	.100	.688	.212	.000
	5	.000	.000	.331	.669	.000
37-40	2	----	----	----	----	----
	3	.025	.863	.112	.000	.000
	4	.000	.137	.725	.138	.000
	5	.012	.063	.625	.300	.000
50	2	----	----	----	----	----
	3	.125	.838	.037	.000	.000
	4	.139	.519	.329	.013	.000
	5	.163	.150	.650	.037	.000

Table 4

Probabilities of Each Response Category Conditional on Stimulus Events During Test Trials in Experiment 1 (Subject B)

Rate (pulses/ sec.)	No. of Pulses	Response Categories				
		1	2	3	4	5
17	2	.000	.813	.125	.012	.050
	3	.000	.037	.425	.450	.088
	4	.000	.025	.087	.300	.588
	5	----	----	----	----	----
20-22	2	.000	.813	.100	.012	.075
	3	.000	.050	.287	.588	.075
	4	.000	.037	.063	.325	.575
	5	.000	.013	.012	.125	.850
25-27	2	.000	.763	.125	.025	.087
	3	.000	.087	.413	.425	.075
	4	.000	.037	.063	.306	.594
	5	.000	.025	.013	.125	.837
30-33	2	----	----	----	----	----
	3	.000	.150	.488	.187	.175
	4	.000	.038	.012	.308	.642
	5	.000	.012	.000	.100	.888
37-40	2	----	----	----	----	----
	3	.000	.138	.638	.137	.087
	4	.000	.025	.062	.338	.575
	5	.000	.038	.000	.162	.800
50	2	----	----	----	----	----
	3	.000	.312	.538	.050	.100
	4	.013	.126	.139	.190	.532
	5	.000	.138	.088	.062	.712

FIGURE 7 PROBABILITY OF A CORRECT RESPONSE AS A FUNCTION OF RATE OF PRESENTATION

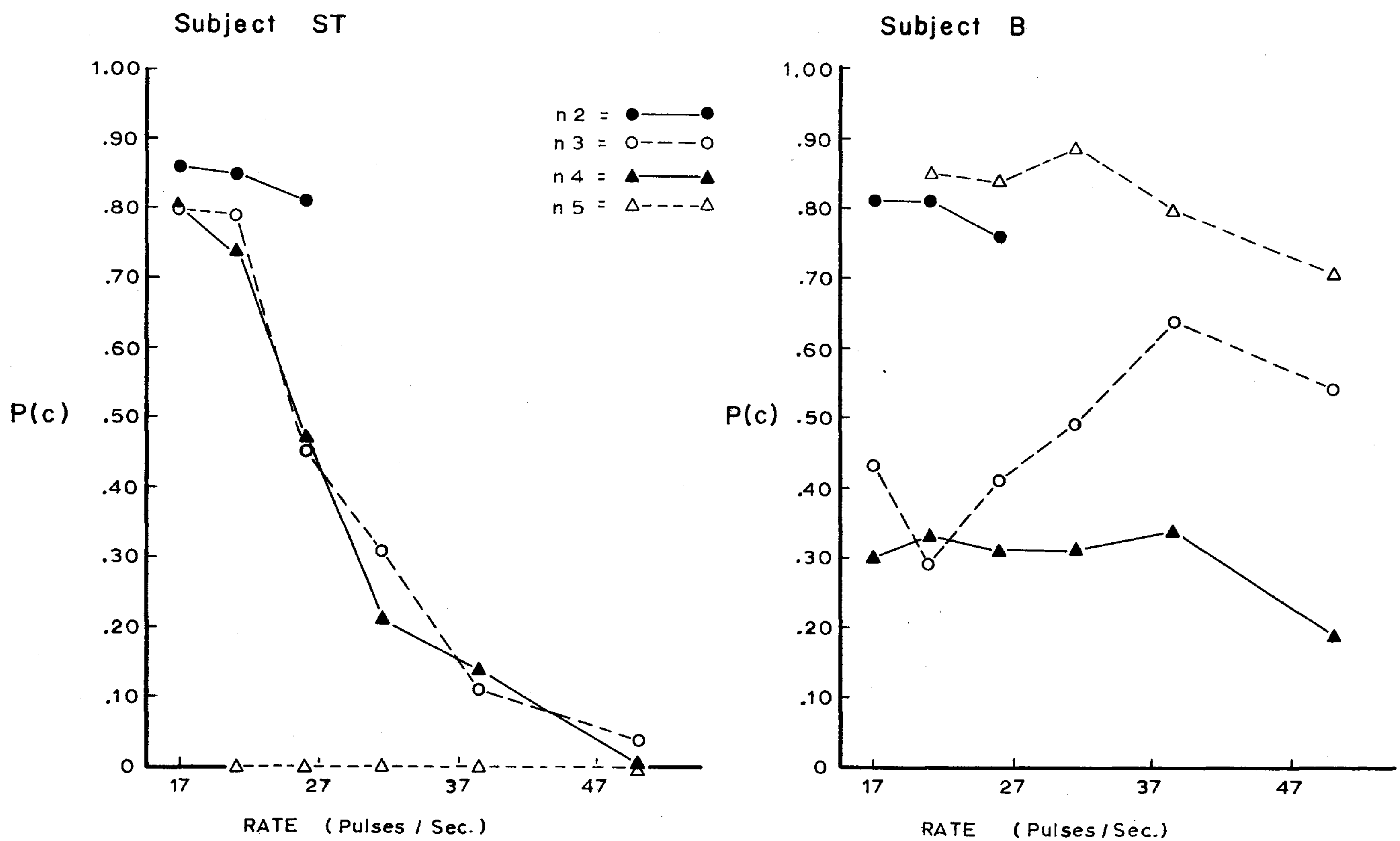


FIGURE 8

PROBABILITY OF RESPONSE AS A FUNCTION OF RATE OF PRESENTATION

Subject ST

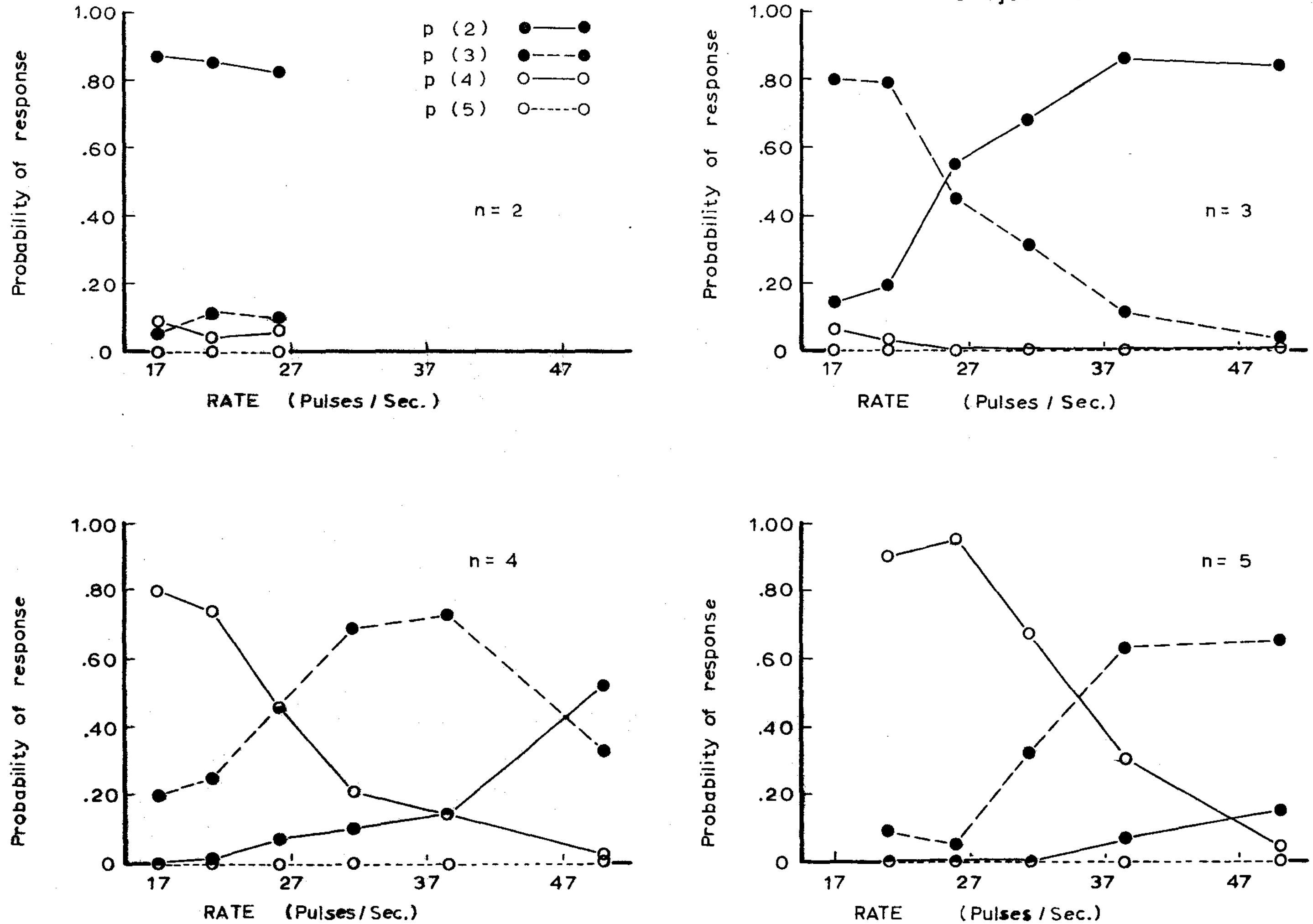
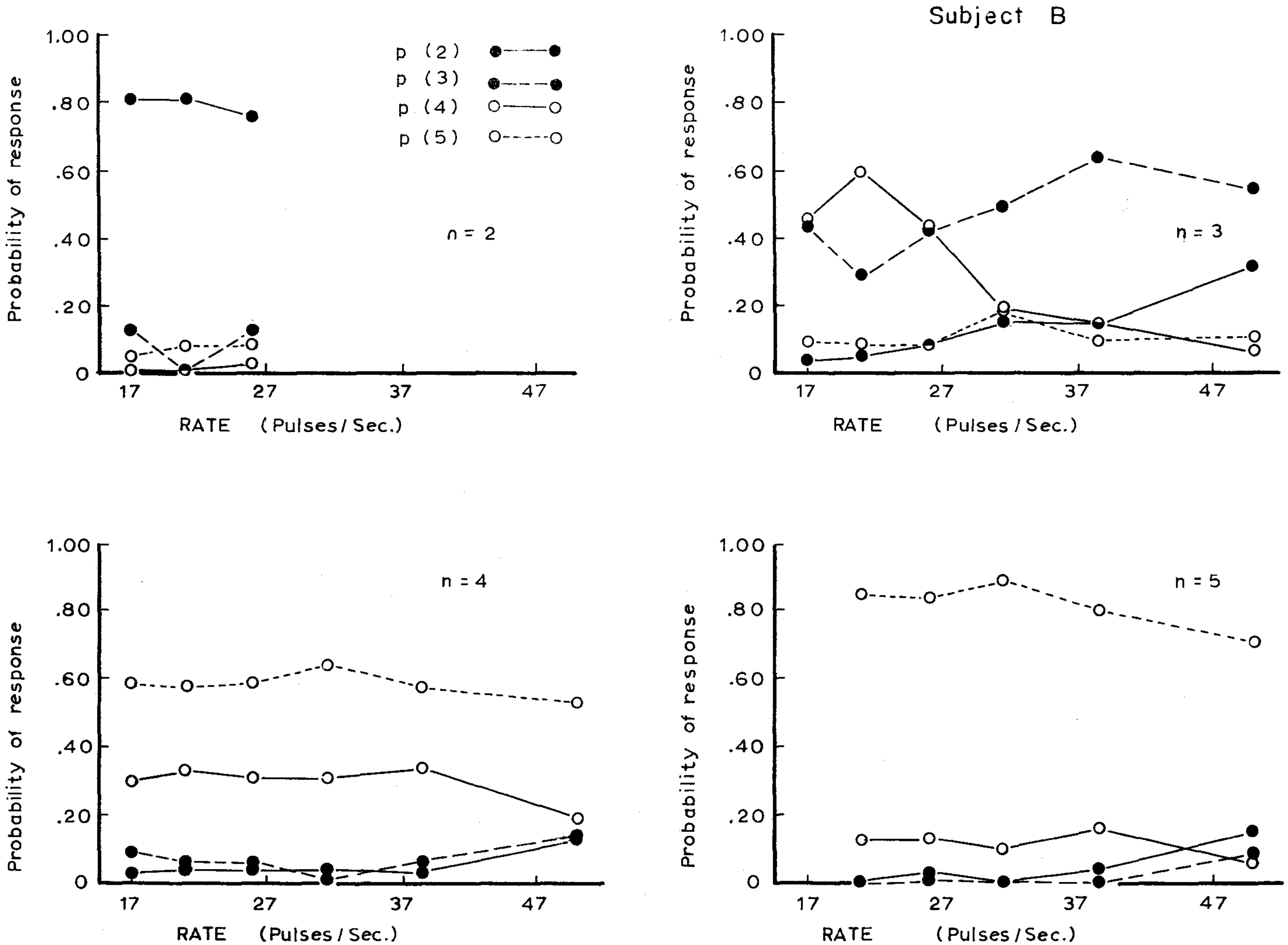


FIGURE 9

PROBABILITY OF RESPONSE AS A FUNCTION OF RATE OF PRESENTATION

Subject B



(i) Subject ST

Inspection of the functions in Figure 8 shows that for each pulse train, there is a tendency for increase in rate of presentation to be correlated with increase in the probabilities associated with the lowest response category. For example, given a train of four pulses, if the rate of presentation is in the range 25-27/ sec., then the probabilities associated with responding 2, 3, and 4 are respectively .08, .46 and .47. When the rate changes to 50/sec., p(2)=.52, p(3)=.33 and p(4)=.01.

(ii) Subject B

Subject B also shows a tendency to report a lesser number as the rate of presentation increases for a constant stimulus input, although the effect is barely discernable in his data. The pattern of response appears to interact with the *S*'s tendency to overestimate, shown in the *modal* response data (see Figure 4). Thus, for example, given a train of four pulses, presented at the rate of 25-27/sec., p(2)=.04, p(3)=.06, p(4)=.31 and p(5)=.59. At the rate of 50/sec., p(2)=.13, p(3)=.14, p(4)=.19 and p(5)=.53.

DISCUSSION

The practice data indicate that for both subjects *modal number* reported corresponds with number of stimuli presented, when the rate of presentation is 10 pulses per second. The finding implies that the limiting rate for temporal acuity is in the neighbourhood of one pulse every 100 msec. But even at this rate of presentation performance is not totally free of errors in reporting. Data collected from experiments using slower rates of presentation, i.e. 12/sec., 10/sec., 8/sec., 6/sec., and 4/sec.

have been published by Garner (1951) who found non-error free performance. Data obtained under four conditions, that is, for 1000 Hz tones of two intensities, 55 and 95 db. and two durations, 5 and 40 msec. indicated that some errors were made even for the easiest condition, a train of five stimuli, presented at the slowest available rate. The systematic distribution of erroneous responses found for practice trials in the present experiment are in a direction predictable from the model. That is, given a rate of presentation of events faster than the rate necessary for perfect correlation of successive events with successive internal units of duration, it is expected that number reported will fall short of number presented.

The data obtained during test sessions of experiment 1, a preliminary attempt to investigate the possibility of invoking a hypothetical internal "clock", are indicative of a fixed value of q for subject ST, one of two Ss employed. For this S's data both a comparison of modal number reported with predicted number ($\overline{R}$) and with total presentation time suggest that a unit of about 50 msec. in duration is not an unreasonable assumption.

Acceptance of the counting model as a predictor of temporal numerosity functions relating number of stimuli reported to number presented is, however precluded by several findings.

(i) Subject ST's data show an increase in modal number reported as number of pulses increases given a constant duration, which does not agree with prediction. For example, where q is assumed to equal 60 msec. and $\overline{R}$ (the number of quanta assumed to be spanned) is three, the expected modal report, given a true value of q of 50 msec., is "3" for trains containing 3, 4 and 5 pulses. Subject ST's data indicate that reports of "4" are actually obtained for the two longer sequences. If, indeed, units containing pulses are counted rather than number of pulses, then, an additional pulse falling within a quantum already partially filled should not, according to the counting model proposed, affect S's judgment.

(ii) Given an assumed value of q less than the "best" predictor value, i.e. 50 msec., there are instances in subject ST's data where addition of a pulse without a concomitant change in total presentation time results in report of a fewer number perceived. For example, where q is assumed to equal 40 msec. presentation of 2 or 3 pulses at the rates 25/sec. and 50/sec. result in reports of "2" pulses. Presented 4 pulses at the rate of 75/sec., S reports "1". The finding cannot be explained in terms of the mechanism described.

(iii) The consistent overestimations of subject B show that judgments are influenced by factors other than those provided for by the counting model. If the train duration is short, a small number perceived is reported. The longer duration for presentation of trains of 4 and 5 pulses results in the use of the category implying the largest perceived number. This finding points to the necessity of analyzing the data for each subject taken individually. Where averaging responses for a group of Ss, reacting differentially to the same information would tend to obscure a phenomenon common in the responses of all, comparison of the results of individuals might reveal the significant trend.

Some support for the proposed quantal processing is obtained from the changes both in probabilities associated with the use of response categories and in P(C) for trains differing in number of pulses, as a function of rate of presentation. The functions plotted in Figures 8 and 9 appear to indicate that for both Ss for a constant stimulus input, faster rates of presentation, that is, decreases in interpulse time hence, decreases in total time or number of occupied units of time increase the likelihood of report of progressively smaller numbers of stimuli.

The finding in subject ST's data presented in Figure 7 that P(C) for 2 pulses exceeds that for 3 and 4 pulses for the three rates at which all of these trains were presented suggests that discrimination may be more difficult as number of pulses increases even though the inter-stimulus interval remains constant. A similar observation was made by Hall and Jastrow in 1886. They reported,

> ..."in order that their discontinuity may be clearly perceived, four or even three clicks or beats must be farther apart than two need to be. When two are easily distinguished, three or four separated by the same interval... are often confidently pronounced to be two or three respectively."(p. 58-59).

Intervals used by these investigators were 52.3 and 89.5 msec. The finding was corroborated in 1950 by R. E. Taubman, who observed, in presenting trains of 1 to 10 auditory pulses with interstimulus intervals of 62, 71, 83, and 100 msec., that per cent correct decreased as number of pulses increased for each of the four rates of presentation. The effect became more pronounced as rate increased. These findings can be deduced from the postulates of the counting model. That is, for any rate of presentation faster than the rate of temporal processing, it is expected that constant increases in the number of pulses presented will be correlated with increasingly discrepant reports. These results were in fact obtained by Cheatham and White in presenting trains containing 1 to 15 pulses at the rate of 30/sec.

Taken together, the results of experiment 1 offer some support for White's hypothesis of perceptual simultaneity, and more concretely for the existence of a unit of duration, within which successive events are not likely to be discriminated as multiple rather than single. For one subject a value of 50 msec. for the hypothetical unit appears to be the "best" predictor of performance. The value is the same as that suggested by Kristofferson but is almost one-half as great as that suggested by the slopes of White's temporal numerosity functions.

Although the data do not negate the three basic assumptions of the model described, the discrepancies between predicted and observed responses which are revealed when a more detailed analysis is done make obvious the inadequacy of the model, as it is described, and point to the necessity of examining the basic assumptions.

EXPERIMENT 2

In order to examine the feasibility of the second of the two tentative assumptions, that both units containing events and empty units occurring between events would be counted, a second simplified study was designed, requiring S to report number of pulses perceived given trains consisting of a variable number of pulses, each presented at three different rates. In accordance with the model described, it was predicted that if the selected rate matched or was less than the periodicity of the internal clock proposed, report would vary as a function of the number of pulses in the train. Where the rate selected was faster than that required for processing successive events, it was expected that modal reported number would fall short of number presented. Trains of odd numbered pulses presented at each rate were matched with trains similar in all respects except that the central pulse was omitted during presentation. Given the validity of the second tentative assumption, it was predicted that Ss would respond similarly to matched sequences.

METHOD

Subjects:

The subjects used for Experiment 2 were those who had participated in Experiment 1.

Apparatus:

The apparatus is described in Experiment 1 (see page 8).

Design:

The independent variables manipulated in the study were (a) number of pulses (2, 3, 4 or 5) appearing in the sequence and (b) rate of presentation, i.e. 33/sec., 20/sec., and 14/sec. (i.e., one pulse every

30, 50, and 70 msec.). Combinations of the two variables produced the 3 x 4 factorial design composed of 12 experimental cells shown in Table 5. Total time for presentation of a train of a given length varied directly with rate of presentation.

Six additional cells, in which the central pulse in the sequence was omitted during presentation were inserted in the matrix to match the six design cells for which sequences contained an odd number of pulses.

Procedure:

Five sessions, each one hour in duration, were given on separate days over a period of one week. Each session consisted of the presentation of two randomized blocks of 90 trials. In each block 18 possible combinations of rate, number of stimuli and omission appeared five times. Thus 50 responses per cell were obtained.

On a given trial, completion of the presentation was followed by S's report of the number of pulses he had perceived. No feedback was given to S regarding the accuracy of his judgments.

At the start of the experimental period Ss were told that judgments should consist in counting discrete pulses perceived, as in Experiment 1.

RESULTS

The modal numbers of pulses reported are plotted for the two Ss as a function of number of stimuli presented in Figure 10. Figure 10 indicates that for subject ST a presentation rate of one pulse every 70 msec. (1/70 msec.) resulted in relatively "best" performance. That is, for the five sessions taken together, modal reported number of stimuli matched the number of pulses presented for trains of 2 to 5 pulses.

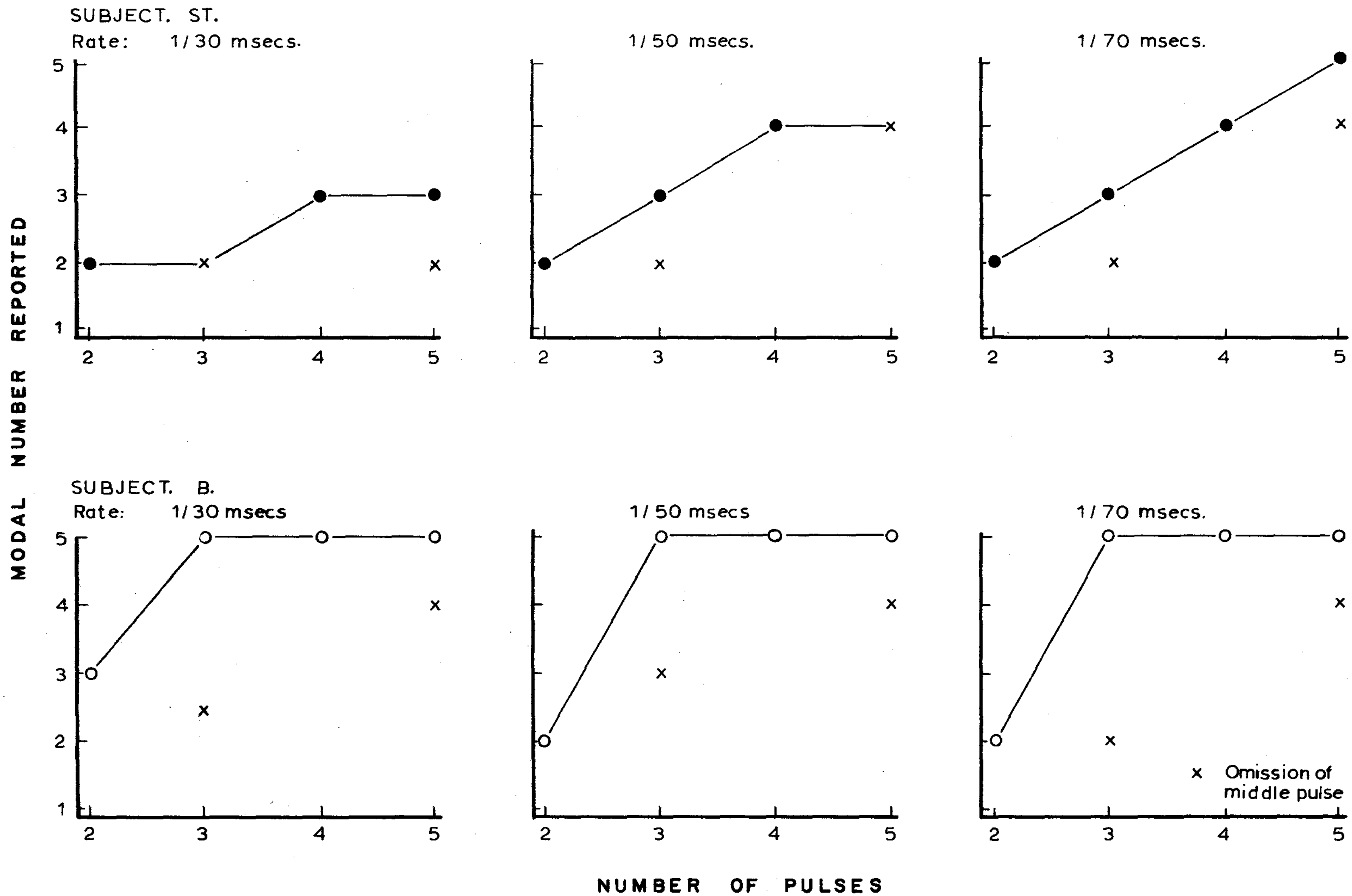
Table 5

Design for Experiment 2

No. of Pulses Presented	Rates of Presentation		
	33/sec.	20/sec.	14/sec.
2	40+	60	80
3	70	110	150
4	100	160	220
5	130	210	290

+ Total time for presentation of train measured from onset of first pulse to offset of the final pulse (in msec.).

FIGURE 10 MODAL RESPONSE AS A FUNCTION OF NUMBER OF PULSES PRESENTED



As rate of signal presentation changed from 1/70 msec. to 1/30 msec., subject ST's ability to discriminate progressively decreased. At the rate of 1/50 msec. modal response was equal to number presented for trains of 2, 3 and 4 pulses. But at 1/30 msec. trains consisting of more than two pulses resulted in modal reports smaller than the number presented. Inspection of modal reported numbers for sessions taken individually (see Appendix B, Figures 1 and 2) indicated that for the fastest rate (1/30 msec.) practice resulted in improved discrimination. By the fifth session of testing modal reports for trains of 2, 3, 4 and 5 pulses were respectively 2, 3, 3 and 3 instead of 2, 2, 2 and 3 as obtained during the first session.

Predicted modal reports (based on the initial assumptions) for trains of 2, 3, 4 and 5 pulses presented at the rates of 1/30 and 1/50 msec. were calculated for units of duration assumed equal to 70, 65, and 60 msec. respectively. The results of this analysis are presented in Table 6. The table indicates that when q is assumed to be 60 msec. predicted and obtained modal numbers correspond for all three rates of presentation. It should be noted that when the probabilities associated with two response categories are each .50, that category representing the higher number has been arbitrarily chosen as the predicted modal report.

If the true value of q is 60 msec., then at a presentation rate of 1/70 msec. when the central pulse is omitted in trains containing 3 and 5 pulses, an empty quantum will necessarily fall between filled quanta. The total duration for presentation of the train does not change. According to the model the empty units of duration will be "counted". More explicitly, report will be based on the number of total and partial units contained

Table 6

Predicted Modal Reports for Different Assumed Values of q

Rate of Presentation	Assumed Value of q	No. of Pulses	Predicted Modal Report	Calculated Prob. of Modal Report	Obtained Modal Report (Subject ST)
1/50 msec.	70 msec.	2	2	.71	2
		3	2	.57	3
		4	3	.86	4
		5	4	.86	4
	65 msec.	2	2	.77	2
		3	3	.54	3
		4	3	.69	4
		5	4	.92	4
	60 msec.	2	2	.83	2
		3	3	.67	3
		4	4	.50	4
		5	4	.67	4
1/30 msec.	70 msec.	2	1	.57	2
		3	2	.86	2
		4	2	.71	3
		5	3	.71	3
	65 msec.	2	1	.54	2
		3	2	.92	2
		4	2	.62	3
		5	3	.85	3
	60 msec.	2	2	.50	2
		3	2	1.00	2
		4	3	.50	3
		5	3	1.00	3

within the total occupied duration. Subject ST's data for trains of 3 and 5 pulses containing omissions lend weight to the alternative assumption. Modal reports were "2" and "4" respectively, indicating detection of the omission.

Additional evidence to support the alternative assumption that only filled quanta can influence S's report is obtained when predicted modal reports based on this assumption are compared with data obtained for trains with omissions presented at the rates of 1/30 and 1/50 msec. Predictions are based on a value of q equal to 60 msec. and for the most-part agree with the findings. To take one example, 3 pulses presented at the rate of 1/50 msec. occupy three units of duration (i.e. 3C) with a probability of .67 and two units with a probability of .33. Given three occupied units omission of the central pulse will always result in the occurrence of an empty quantum. Both predicted and obtained modal reports are "2". Trains of 5 pulses presented at the rate of 1/50 msec. will occupy four units with a probability of .67 and five units with a probability of .33. If five units are occupied omission of the central pulse in the train will always result in an empty unit between filled units. If four quanta are spanned, the probability of occurrence of an empty quantum contingent on omission of the middle pulse is .16. Thus predicted modal number is "4". And the obtained modal report is "4". Analogously, given central omissions and q assumed equal to 60 msec., predicted and obtained modal reports correspond for a train of 3 but not for a train of 5 pulses presented at the rate of 1/30 msec.

Subject B's modal responses fell into two categories for each of the three rates of presentation: "2" or "3" and "5". Omission in trains of 3 presented at the two faster rates resulted in modal reports more closely approximating number presented, that is to modal report of "3" as opposed to "5", and to a correct modal judgment at the slowest rate. Omissions in trains of five pulses resulted in correct modal counts for all rates.

Figure 11 shows each S's average per cent accuracy in discriminating the number of pulses presented for the three rates of presentation. For subject ST a rate of 1/30 msec. results in a precipitous drop in accuracy from 64 per cent to 0 per cent as number of pulses in the train increases from 2 to 5. At 1/50 msec. judgments are noticably affected (P(C) changes from 64 per cent to 6 per cent) only as n increases from 4 to 5. A comparable change is evident but to a lesser degree, that is P(C) is 80 per cent and 50 per cent for n equal to 4 and 5 when the rate is 1/70 msec. Comparison of the three functions in the figure suggests that as number of pulses increases, increases in rate of presentation differentially affects accuracy. It is clear that a change in rate is more effective for 4 and 5 pulses than for 2 pulses.

Subject B shows equally poor performance across combinations of rate and train length. His perfect performance given a sequence of five pulses will be interpreted as the result of response bias.

The probabilities associated with response categories 1, 2, 3, 4 and 5 for trains varying in number of pulses are shown for the three rates of presentation in **Table 7.** Data tabulated for subject ST in Table 7 show a tendency to report progressively smaller numbers as rate of presentation increases for a constant stimulus input. Thus, for example, for an input of four auditory pulses, an increase in rate from 1/70 msec.

FIGURE II PER CENT CORRECT RESPONSES AS A FUNCTION OF NUMBER OF PULSES PRESENTED

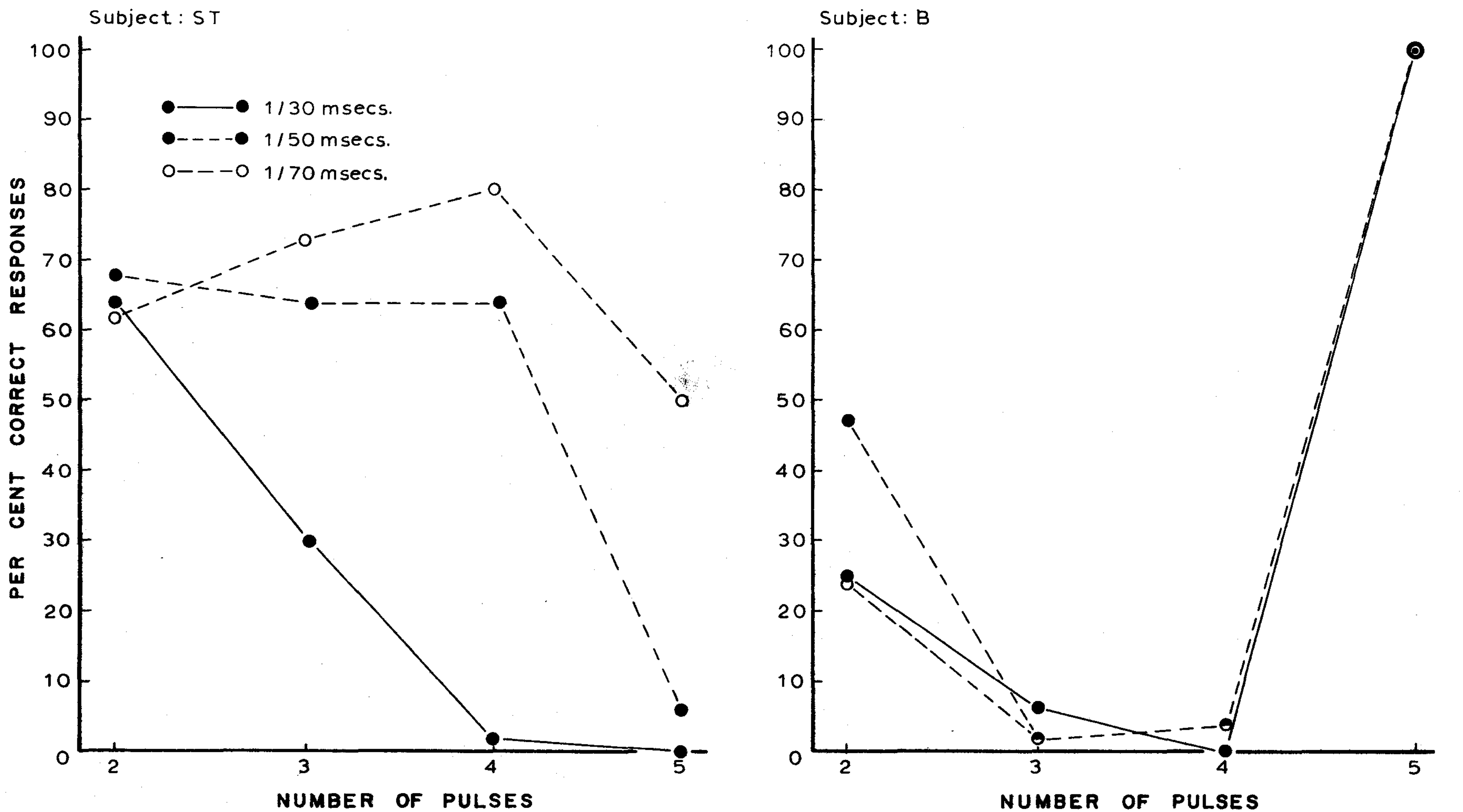


Table 7

Probabilities Associated with Response Categories for Stimulus Events in Experiment 2

Rate	No. of Pulses	Response Categories					
		1	2	3	4	5	6
Subject ST - Experiment 2							
1/30 msec.	2	.340	.640	.020	.000	.000	.000
	3	.292	.396	.312	.000	.000	.000
	4	.300	.100	.580	.020	.000	.000
	5	.240	.060	.560	.140	.000	.000
1/50 msec.	2	.280	.680	.020	.020	.000	.000
	3	.040	.300	.640	.020	.000	.000
	4	.060	.140	.140	.640	.020	.000
	5	.000	.060	.160	.720	.060	.000
1/70 msec.	2	.360	.620	.000	.020	.000	.000
	3	.039	.115	.731	.115	.000	.000
	4	.020	.020	.140	.800	.020	.000
	5	.000	.000	.000	.462	.500	.038
Subject B - Experiment 2							
1/30 msec.	2	.000	.255	.471	.176	.098	.000
	3	.000	.020	.060	.060	.860	.000
	4	.000	.020	.000	.000	.980	.000
	5	.000	.000	.000	.000	1.000	.000
1/50 msec.	2	.000	.469	.327	.163	.041	.000
	3	.000	.000	.020	.180	.800	.000
	4	.000	.000	.020	.000	.980	.000
	5	.000	.000	.000	.000	1.000	.000
1/70 msec.	2	.000	.240	.620	.140	.000	.000
	3	.000	.040	.020	.380	.560	.000
	4	.000	.000	.000	.040	.960	.000
	5	.000	.000	.000	.000	1.000	.000

to 1/30 msec. results in an increase in the probability of reporting "1" (P(1)) from .02 to .30 and a decrease in P(4) from .80 to .02.

Comparable data presented for subject B in Table 7 show almost no change in probability of a given response contingent on changes in rate of presentation. The probability of reporting "5" is relatively high for all stimulus inputs and for a given stimulus input increases with increases in rate.

DISCUSSION

The results of experiment 2 indicate that a unit of duration equal to approximately 60 msec. "best" predicts subject ST's modal reported numbers for trains of 2, 3, 4 and 5 stimuli, presented at the rates of 1/30, 1/50 and 1/70 msec. The value is similar to that obtained for the same subject in experiment 1 and is still considerably less than that posited by White.

Subject ST's data for trains of pulses containing omissions lends weight to the hypothesis that empty units occurring between successive events are not included in the "count". The finding supports modification of the model and in particular of tentative assumption (b). The original statement of the assumption implied that modal report would equal the number of quanta occurring between the onsets of the first and final pulses in the train presented.

The results obtained for subject ST when the data for each condition are analyzed in terms of probabilities associated with different response categories essentially replicate the findings of Experiment 1. That is, as rate of presentation increases for a constant stimulus input, there is a tendency to report smaller numbers. Further, the per cent correct data imply that a constant change in the interpulse interval differentially affects the discriminability of trains containing different numbers of pulses.

Once again error-free performance is not evident at a rate of presentation (1/70 msec.) slower than the periodicity of the hypothesized internal clock "best" predicting modal report, a finding not consistent with the model. Inspection of Table 7 indicates that for subject ST most errors consist of reporting numbers smaller than modal report. This result would be in a direction consistent with the counting model, but only if the value of the quantal unit were greater than 70 msec. It indicates that the counting model is inadequate for use with the current method of data collection, at least when detailed predictions are considered. Both the presence of response bias in subject B's results and the impossibility of determining the extent to which response bias is present in subject ST's results, however, suggest that factors not controlled for by the methodology, might be contributing to the discrepancy between predicted and obtained results.

EXPERIMENT 3

Taken together the temporal numerosity data of experiments 1 and 2 support the usefulness of the counting model, given the modification in the second tentative assumption as suggested by the results of experiment 2. Experiment 3 represents an attempt at modification of the methodology to allow a clearer evaluation of the model. Specifically, the subject was presented with a train containing either n or (n+1) pulses on each trial and was forced to decide which of the two had occurred. No other response was permitted. For each session rate of presentation remained constant but was varied systematically between sessions.

In accordance with the counting model, it was predicted that for a constant value of n, accuracy, as measured, for example in terms of probability of a correct response would increase as a function of decreases in rate of presentation to a value of 1.00 for a critical inter-pulse interval (IPI). The sum of the durations of the pulse and the critical IPI would then define the period of the "clock". For rates of presentation exceeding internal periodicity it was hypothesized that errors would be unidirectional with S reporting perception of n more often than (n+1) pulses.

It was predicted that for any value of n, the value of q derived from the data would be a constant. This estimate of q will hereafter be referred to as D.

METHOD

Subjects:

The subjects, 2 males and 1 female, different from those used in experiments 1 and 2, were students of McMaster University. Their ages ranged from 19 to 27 years. The male Ss were participating in visual signal detection experiments during the course of the study. The female S had had no previous laboratory experience.

Apparatus:

The apparatus used is described in Experiment 1 (see page 8). Two response keys, labelled A and B respectively, were placed in the S's cubicle to allow communication of judgments. The circuitry was arranged so that depression of a key activated a corresponding A or B light on the panel of E's Timing and Stimulus Intensity Control Unit.

Design:

The variables manipulated in the study were (a) duration of the interpulse interval (IPI) and (b) lengths n and (n+1) of a pair of pulse trains. Ten values chosen for the IPI ranged from 0 to 135 msec. in steps of 15 msec. Two values, 105 and 135 msec., were changed to 106 and 136 msec. respectively to facilitate programming of the Control Unit. The number of pulses presented in the pair of trains depended on the experimental condition. For Condition A three and four pulses comprised the trains and for Condition B, four and five pulses.

Procedure:

Ss participated in 4 sets of experimental sessions given over a period of 46 days. A set was defined as a group of 10 sessions for which the condition, A or B, remained constant. For the 4 sets, conditions appeared in the order ABBA so that effects of practice if any would be equal. Each of the 10 IPI's appeared once within a set, their order determined randomly. Thus, a different IPI was used for each session.

A session consisted of presentation of 2 blocks of 100 trials separated by a rest period of 5 to 10 minutes. On a given trial, presentation of the stimulus train was followed by S's depression of response key A or B to signify his perception of n or (n+1) pulses respectively. Feedback regarding the accuracy of judgment was immediate and in the form of an auditory signal qualitatively different from that used as the experimental stimulus.

On each trial the probability of presenting n pulses was .5.

The instructions given to the subject were:

> This is an experiment in auditory perception. On each of 100 trials, after a warning signal, you will be given a train of 3 or 4 (4 or 5) auditory pulses. If you perceive 3, (4), push button A; if you perceive 4, (5), push button B. When you are correct I will sound a buzzer.
>
> The probability of a 3 (4) appearing is .5 on each trial. After the block of 100 trials you will be given a short rest before proceeding to the second block.

Prior to presentation of the two blocks, the subject was given two samples of each of the trains to be discriminated.

RESULTS

A direct comparison of discrimination situations A and B was achieved through comparison of d' (sensitivity) values for each of the 10 interpulse intervals. The hit and false alarm probabilities used to enter a table of d' values (Swets, 1964) were respectively (i) p (3/3), p (3/4), (where p(3/4) represented the probability of responding "3" when 4 pulses were presented) and (ii) p(4/4), p(4/5) for the two conditions. The probabilities appear for each subject in Appendix D, Tables 1 and 2. Use of d' in this way as a response measure necessitates the assumptions (as yet untested) that inputs of 3, 4 and 5 pulses result in overlapping discrete response distributions, binomial in form and of equal variance. The standardized value of the distance between the means of any pair of distributions is then the value of d'.

Figure 12, showing the mean of d' values obtained for 3 Ss as a function of interpulse interval, appears to indicate that 4 and 5 pulses were less discriminable than were 3 and 4 pulses for IPIs ranging from 0 to 75 msec. That is, within this range of IPIs d' is always greater for Condition A than B. It should be noted that the highest tabled value of d', 4.64 obtains for a P(C)=.99. For error-free data (P(C)=1.00) of individual Ss in the present experiment use of this value signifies imposition of an artificial ceiling for the growth of sensitivity. Within each condition inspection of the figure suggests that sensitivity may increase linearly until some critical value of IPI is reached. For A and B these values appear to be in the neighbourhood of 75 and 106 msec. respectively. Measures of d' for greater values of PIP are neither consistently increasing nor constant. But for IPI's beyond 90 msec. the mean value of mean d's is about the same for conditions A and B, that is approximately 3.4 and 3.2 respectively. Data for individual Ss presented in Table 8 show similar trends.

While suggesting that discrimination of the trains may be easier as IPI increases, the sensitivity data do not indicate whether S judges each train of pulses in an absolute fashion (i.e. by reporting the "count" produced by each train) or relative to the only possible alternative in the situation. Evidence in favour of absolute judgment comes from an analysis of hit probabilities.

Figure 13 shows the probabilities of correct response P(C) for

FIGURE 12. SENSITIVITY AS A FUNCTION OF INTERPULSE INTERVAL FOR TWO EXPERIMENTAL CONDITIONS

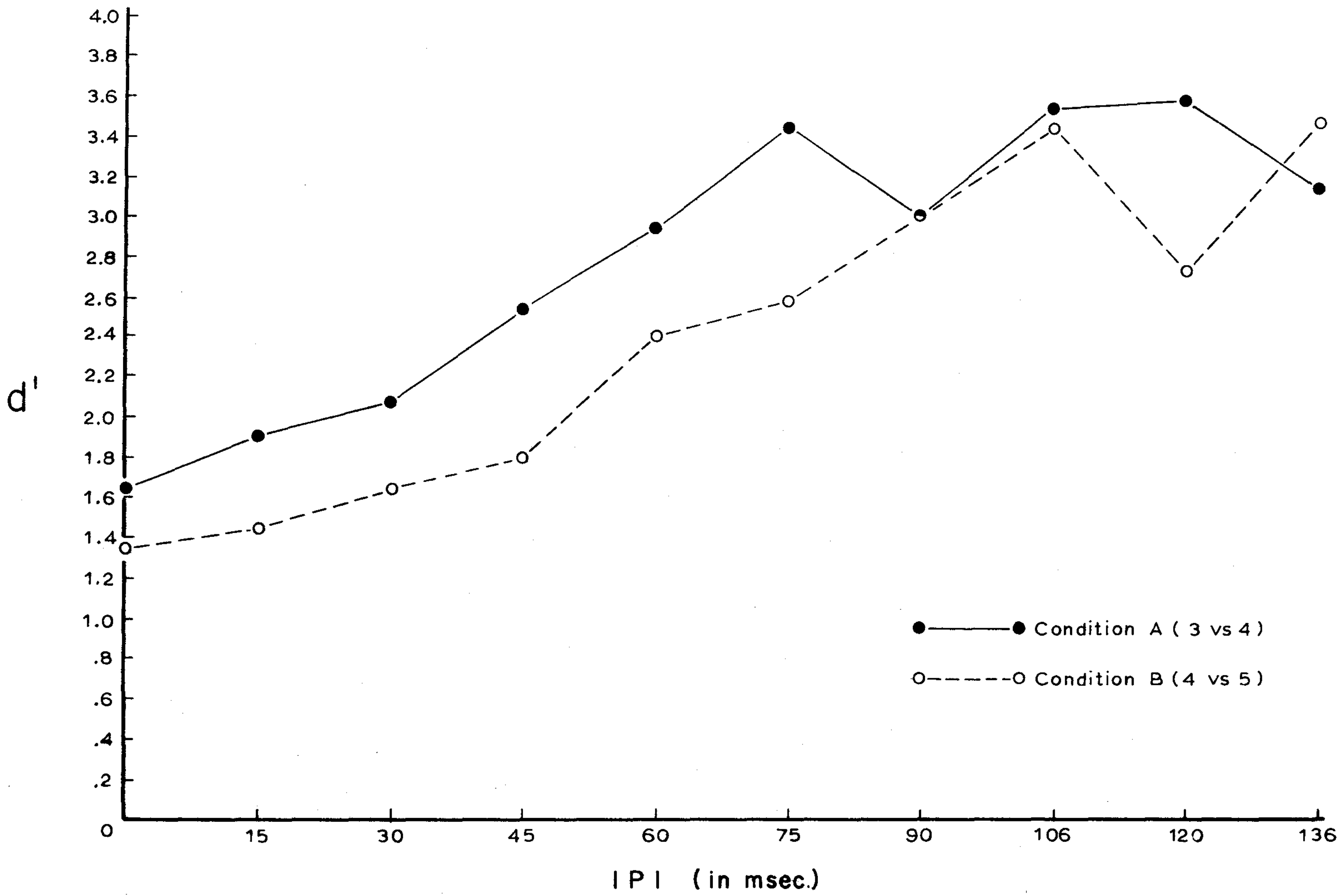


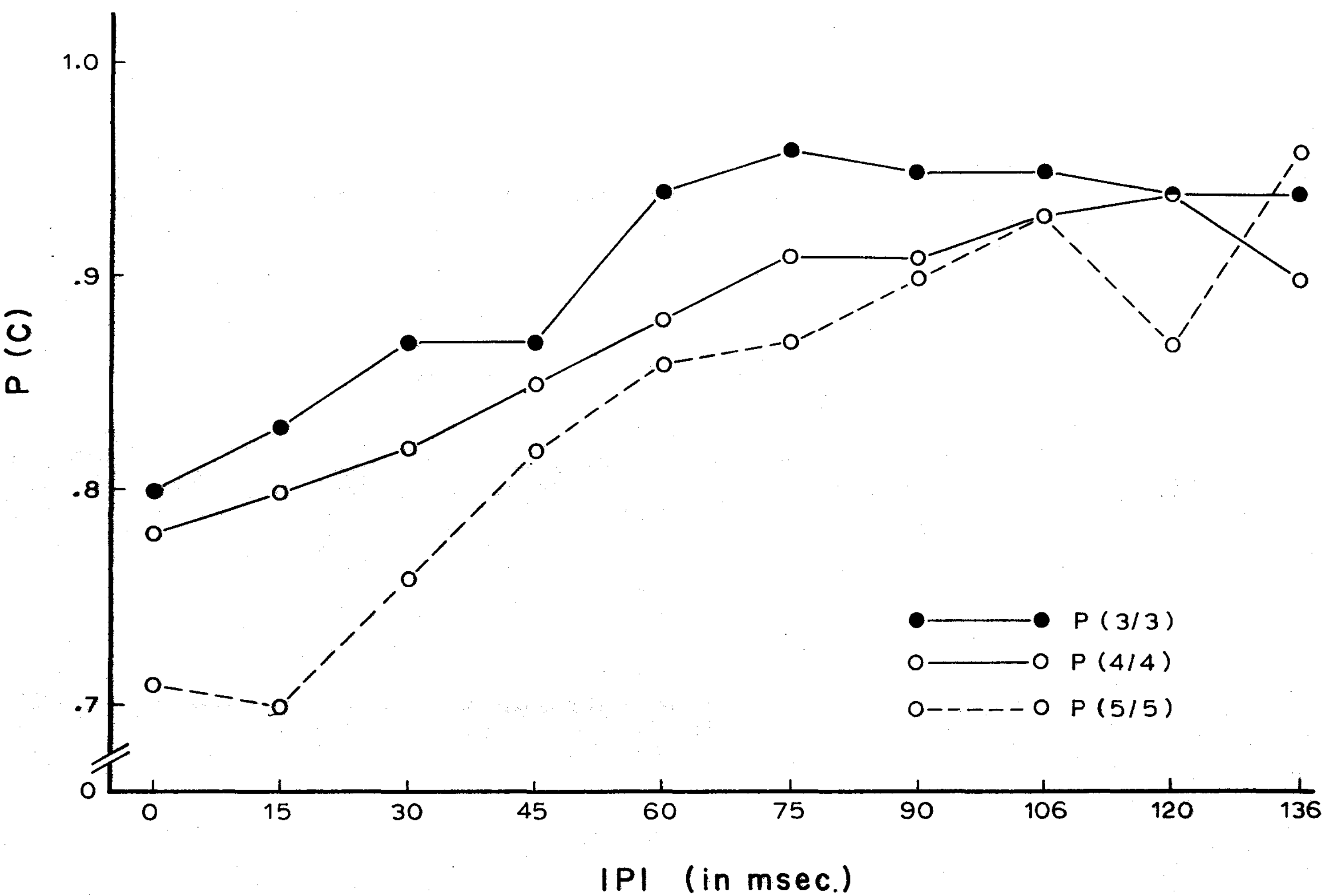
Table 8

Sensitivity (d') Values as a Function of IPI
for the 3 Ss in Experiment 3

	Interpulse Interval (in msec.)									
	0	15	30	45	60	75	90	106	120	136
Condition A										
D.S.	1.50*	.97	1.72	1.62	2.04	2.12	3.11	2.16	2.92	1.88
A.S.	1.48	2.22	2.26	2.63	3.39	3.93	2.41	3.87	3.22	2.92
C.C.	1.94	2.59	2.26	3.35	3.39	4.37	3.50	4.64	4.64	4.64
Mean d'	1.64	1.92	2.08	2.53	2.94	3.47	3.01	3.56	3.59	3.15
Condition B										
D.S.	1.12	.74	1.35	1.18	1.48	1.83	1.69	1.83	1.81	2.46
A.S.	1.38	1.66	1.76	1.68	2.52	2.26	3.11	3.93	3.04	3.43
C.C.	1.54	1.92	1.82	2.57	3.30	3.69	4.20	4.64	3.30	4.64
Mean d'	1.35	1.44	1.64	1.81	2.43	2.59	3.00	3.47	2.72	3.51

* Each value is based on 400 judgments.

FIGURE 13 MEAN PROBABILITY OF A CORRECT RESPONSE AS A FUNCTION OF INTERPULSE INTERVAL



trains differing in number of pulses. Since the shape of the corresponding curves obtained for the three Ss individually and for blocks 1 and 2 within sessions within Ss appeared to show similar trends, (for tabulated values see Appendix C, Tables 1 and 2), the data were averaged across these three variables. Data points for p(3/3) and p(5/5) are each based on 600 trials. Points comprising the p(4/4) function are averages of data obtained in the two discrimination conditions and thus are based on 1200 trials. Inspection of the curves presented suggests that P(C) is increasing as a function of both increases in IPI and decreases in number of stimulus pulses. Comparison of the slopes of the three functions suggests an interaction of the effects of these variables. Whereas p(3/3) and p(4/4) have reached asymptote at an IPI of 75 msec., p(5/5) continues to change beyond this value.

The per cent correct as a function of IPI given 4 pulses is shown independently for the two situations in Figure 14. It can be seen that p(4/4) values across the IPI range are approximately the same regardless of the particular discrimination S is required to make. The mean of the ten values plotted for conditions A and B are .88 and .87 respectively. Number reported, after presentation of 4 pulses in either condition then appears not to be solely a function of S's comparison of that train with the only possible alternative.

A graphical analysis of the kinds of errors made in each of the two conditions is shown in Figure 15. Data points are means of probabilities of error for three Ss. The group data indicate that the probability of error is rather consistently higher across the range of interpulse intervals for trains containing the larger number of pulses

FIGURE 14 MEAN PROBABILITY OF A CORRECT RESPONSE AS A FUNCTION OF INTERPULSE INTERVAL FOR TRAINS OF FOUR PULSES

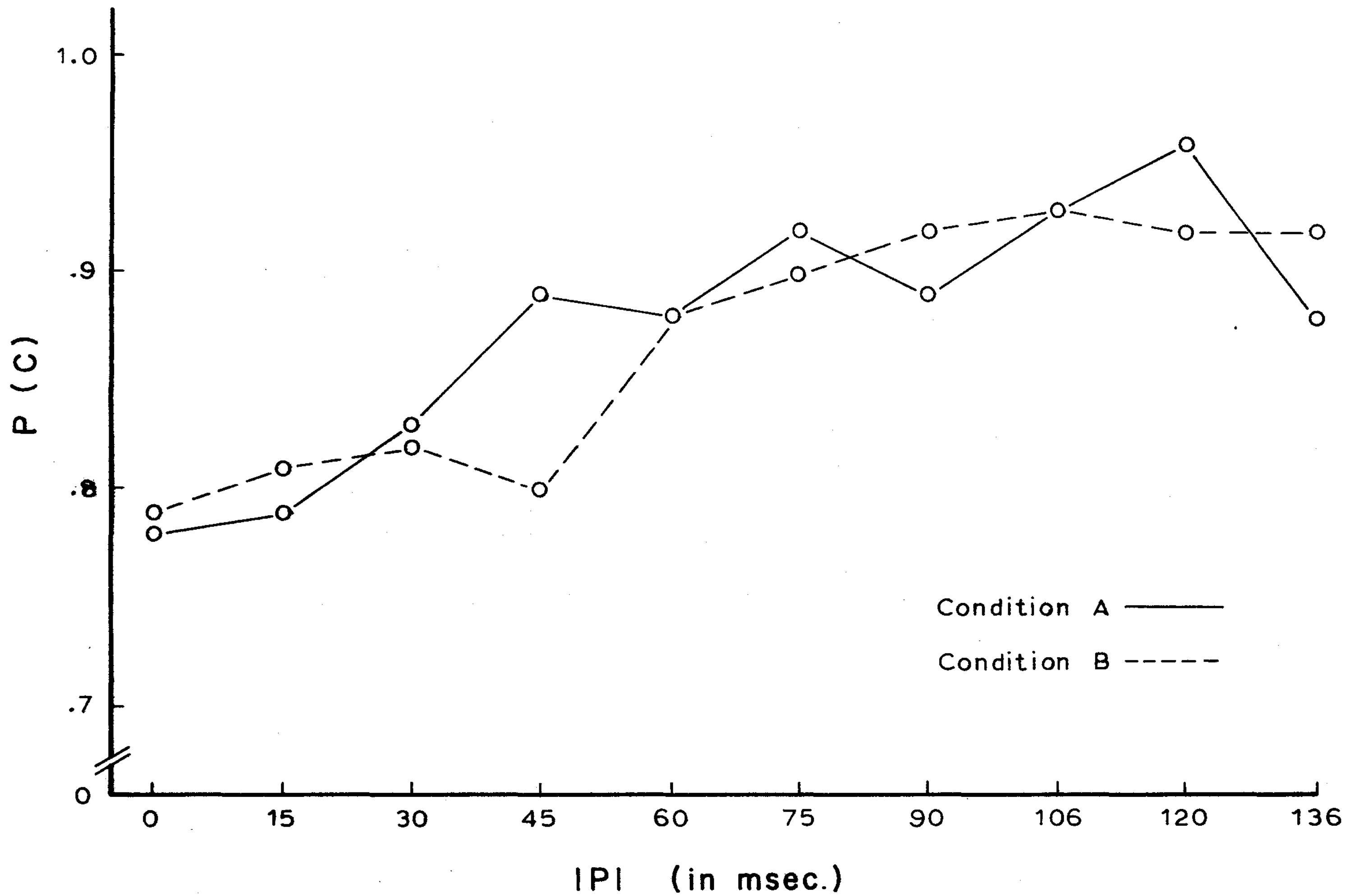
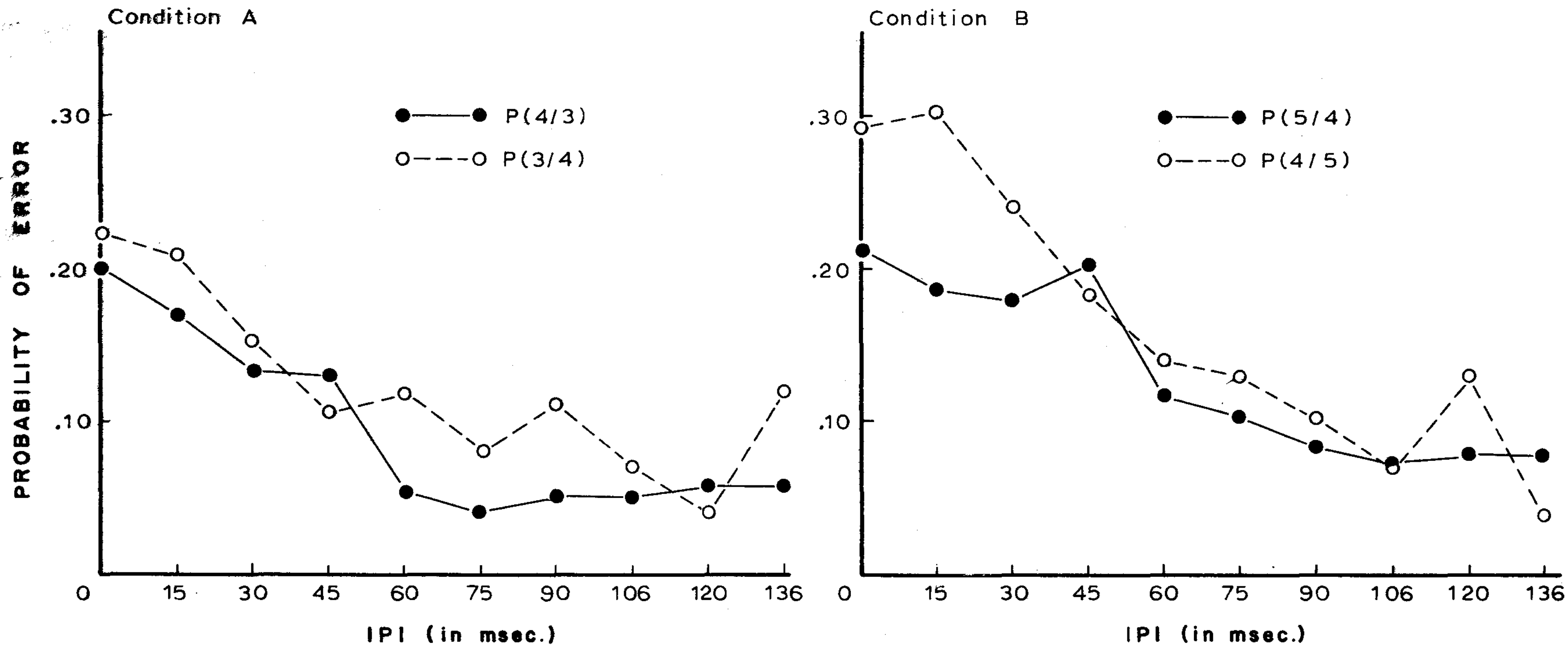


FIGURE 15 MEAN PROBABILITY OF ERROR AS A FUNCTION OF INTERPULSE INTERVAL



in each condition. A reversal is apparent in two and three instances respectively for conditions A and B. Data for individual Ss presented in Table 9 appear to show similar trends.

DISCUSSION

Values of d' plotted as a function of IPI for conditions A and B suggest that S may be sensitive to successive increments in interpulse interval up to a critical value. The sum of this duration plus the duration of the pulse will be interpreted as D the estimate of q. Increases beyond this value do not appear to facilitate the differentiation between trains of n and (n+1) pulses in a systematic fashion. The finding lends weight to the assumption of an internal and independent time base because it validates the deduction that the "count" will not be systematically affected by interstimulus intervals equal to or greater than the period of the "clock". In terms of d' sensitivity to a difference between the two trains presented in either condition should be and appears to be at a maximum when the value of IPI is in the immediate neighbourhood of the value of the unit of duration inferred from the data. The findings (i) that the critical IPI differs for the two conditions and (ii) that discrimination is not perfect for values of IPI equal to and greater than D are not congruent with theoretical predictions.

The estimates of q, that is, the value D inferred from these data are in the regions of 75 and 106 msec. for conditions A and B respectively. Both estimates are greater than the values obtained from the data of experiments 1 and 2 but are closer to that suggested by White. The estimates of q for the three designs used appear to be increasing as a function of a decrease in the difficulty of the subject's task or more explicitly as a function of the number of alternative conditions he is required to

Table 9

The Probability of Error for Individual Ss in Conditions A and B of Experiment 3

Error	S	0	15	30	45	60	75	90	106	120	136
		Interpulse Interval (in msec.)									
Condition A											
4/3	C.C.	.16	.05	.09	.07	.02	.00	.00	.00	.01	.00
	A.S.	.15	.19	.14	.08	.02	.02	.10	.01	.04	.05
	D.S.	.29	.27	.17	.24	.13	.10	.05	.14	.12	.12
Mean P(4/3)		.20	.17	.13	.13	.06	.04	.05	.05	.06	.06
3/4	C.C.	.17	.17	.18	.03	.09	.02	.12	.01	.01	.01
	A.S.	.33	.09	.12	.11	.09	.03	.13	.06	.07	.10
	D.S.	.17	.36	.22	.18	.18	.20	.07	.14	.04	.24
Mean p(3/4)		.22	.21	.17	.11	.12	.08	.11	.07	.04	.12
Condition B											
5/4	C.C.	.20	.14	.12	.09	.04	.02	.01	.01	.04	.01
	A.S.	.24	.16	.20	.20	.09	.09	.07	.03	.08	.06
	D.S.	.20	.26	.22	.32	.22	.20	.17	.18	.11	.16
Mean p(5/4)		.21	.19	.18	.20	.12	.10	.08	.07	.08	.08
4/5	C.C.	.24	.20	.26	.11	.06	.05	.03	.01	.06	.01
	A.S.	.25	.25	.18	.20	.12	.18	.05	.02	.05	.03
	D.S.	.39	.46	.28	.24	.24	.16	.23	.18	.28	.07
Mean p(4/5)		.29	.30	.24	.18	.14	.13	.10	.07	.13	.04

consider. Experimental data recently obtained by Kristofferson (1967b), specifically designed to investigate the effect of task difficulty, defined by the length of the interval between offsets of a pair of qualitatively different stimuli, indicate an increase in the value of M (the estimate of q provided by data for successiveness discrimination) as the task becomes easier. The relationship might be interpreted in terms of a decrease in level of concentration necessary to perform the easier task with a concomitant increase in S's ability to attend simultaneously either (i) to other tasks or (ii) to an increasing number of dimensions of the stimuli presented. A higher-order mechanism might then be functioning to process sensory data. This interpretation requiring extensive experimental support does not account directly for the apparent increase in the value of D within experiment 3 where S is presented with the same number of alternatives but the number of pulses comprising the trains to be judged is increased. The different estimates of q may simply reflect the inadequacy of the particular method of obtaining the value.

The apparently larger error scores in either condition for the trains containing the larger number of pulses supports the idea of central temporal processing. The non-zero error probabilities for the shorter of the two trains in either condition and for the longer trains for values of IPI equal to and greater than the suggested critical value are as indicated above not consistent with the model, and imply that Ss are not making their judgments solely on the basis of the "count".

One cue used by Ss for discrimination may be the difference in the total duration of the trains presented for comparison. More generally, duration discrimination may provide an alternative explanation for data obtained in all three experiments. The stimuli presented in experiment 3 will be examined with a view to evaluating the feasibility of this alternative.

The trains of pulses presented in experiment 3 can be divided into two categories:

(i) those having an interpulse interval of 0 msec. and hence equivalent to continuous tones of fixed duration

and (ii) those with 0 msec. $<$IPI $\leq$136 msec. In condition A an IPI of 0 msec. signifies that S must distinguish continuous tones, 30 and 40 msec. in duration, and in condition B continuous tones, 40 and 50 msec. in duration. For IPI's greater than 0 msec. for either condition, discrimination will consist of comparing two durations differing by an approximately constant Weber fraction ($\Delta T/T$), where T represents the duration (from onset of the first to offset of the final pulse) of the shorter of the two trains presented for evaluation. For condition A, the value of the Weber fraction is between the limits of .42 and .48 and for condition B, between the limits of .29 and .33. For the two conditions total durations of the shorter stimulus trains vary from 30 to approximately 400 msec.

Small and Campbell (1962) have attempted to measure the differential threshold for duration by having subjects compare a standard and a variable duration 0.25 to 2.5 times the standard. On each trial the standard was presented first and S was instructed to judge whether the second stimulus was longer or shorter than the first. Tones were 1000 Hz and 81 to 87 db referred to .0002 ubar. The probability of a longer judgment for each stimulus condition was plotted on probability paper and a straight line fitted visually. The DL was defined as one-half the difference between the stimulus value yielding 25 per cent longer judgments and the one yielding 75 per cent longer judgments. It was found that $\Delta T/T$ for the range of durations used in the present experiment, that is 30 to 400 msec. remained constant at approximately .2. This value compared with the almost constant values obtaining in the present experiment implies that S's sensitivity to a difference in the trains presented should be equivalent across the range of IPI's used in either condition. In the present study, however, d' appeared to increase in both conditions with increases in IPI up to a critical level. This increase cannot be explained solely in terms of the use of duration differences as a cue for discrimination. The present experimental design does not, however, allow a precise evaluation of its significance.

Comparison of the $\Delta T/T$ value obtaining in the Small and Campbell study with those of the present study also implies that in conditions A and B for any IPI the trains differ by a duration greater than that necessary for differentiation 50 per cent of the time. Further, the Weber fraction in Condition A is larger than that obtaining in Condition B. If Ss' d' values are greater in Condition A than in B for the range of IPI values suggested by the data, then this difference could be the result of Ss' having used duration as a cue, at least in part.

The difference between the tones used in the Small and Campbell study and in the present study, in terms of frequency and intensity have been shown by Henry (1948) not to influence $\Delta T/T$ by an amount relevant for the present discussion. Specifically, mean Weber ratios decreased from .166 to .157 as intensity increased from 60 to 80 db.

The durations of trains and the values of IPI's used in the present experiment are according to Zwislocki (1960) within the limits of durations providing for some temporal summation. More explicitly for any IPI trains differing in number of pulses and concomitantly in total duration will not be of equal loudness. Loudness discrimination must then be seriously considered as a third alternative for explaining the data.

The preceding discussion regarding the possibility that cues other than those provided for in the counting model may be at least partially responsible for the temporal numerosity functions points to the need for a series of studies, utilizing a methodology similar to experiment 3 but controlling for intensity differences and allowing for evaluation of the significance of differences in duration. The latter objective might possibly be achieved through (i) observation of the effect on discrimination of prior practice sessions where the most reasonable basis for discrimination is that of duration and the use of that cue is specifically encouraged for practice and test sessions, or (ii) requiring judgment of pairs of trains differing in number of pulses but equal in duration.

The methodology used in experiment 3 appears to be adequate in view of the finding that the relationships studied were similar for all three of the three Ss employed.

SUMMARY AND CONCLUSIONS

Three preliminary experiments were conducted to investigate the feasibility of positing a central unit of duration to explain temporal numerosity data. Carroll T. White (1963) had suggested that the notion of a central duration unit (or quantum of time) had two related implications for perception. First, "temporally discrete events occurring during any one unit of duration should be perceived as simultaneous". Second, "there should be a definite limit to the perceived rate of stimulation". White's experimental results provided some support for the latter prediction and suggested that the value of the quantum was approximately 75 milliseconds (msec.). Experiment 1 of the present study was an attempt to validate the former of the two implications.

Prior to the designing of the experiment a theoretical model was developed to allow prediction of reports of number of auditory pulses perceived contingent on presentation of trains of ten-millisecond pulses. The model consisted of a description of the proposed central gating of sequences differing in number of pulses and rate of presentation. Given the hypothesis of an internal time base, that is, of a succession of internal units of duration, it was assumed that (i) where two or more signals occurred within one unit of duration these would be "counted" as one event, (ii) number of pulses reported by S would equal the number of quanta "counted" and (iii) that the first event in the sequence (or train) of external events might arrive with equi-probability at any point during the ongoing (first) quantum.

Two assumptions tentatively stated were: (a) that the total "count" would equal the number of quanta, total or partial, falling between the onsets of the first and final pulses in the sequence, and (b) that both quanta containing events and empty quanta occurring between events would be "counted".

Experiment 1

The independent variables manipulated in Experiment 1 were

(i) number of auditory pulses presented (i.e. 2, 3, 4 and 5) and (ii) the total time for presentation of the sequence. The total durations chosen were multiples of (i.e. 2, 3 and 4 times) three different assumed values of the hypothesized quantum. The assumed values were 40, 50 and 60 msec. Combination of these three variables resulted in a 4 x 3 x 3 factorial design composed of 36 cells. Within each cell rate of presentation was completely determined by number of pulses and the duration within which they were to be presented. Nine cells of the design matrix in which the number of quanta assumed to be occupied (i.e. the multiple) exceeded the number of pulses presented were omitted. Following five practice sessions, two subjects were each given 10 test sessions during which a total of 80 responses were obtained for each of the 27 experimental conditions.

The modal "counts" predicted for each experimental condition were the number of quanta occurring during presentation of the train. The results showed that obtained and predicted modal numbers correspond for the most part for those conditions where duration was a multiple of 50 msec. Thus support was obtained for White's first prediction concerning simultaneity but not for the value of the unit which his results suggested. Additional evidence for the quantal processing described in the model was obtained when response distributions were compared. This comparison suggested that as rate increased for a given number of pulses, the probability of reporting a smaller number of pulses increased. However, a lack of support for detailed predictions suggested the inadequacy of the initial description of the model.

<u>Experiment 2</u>

Experiment 2 was an attempt to examine the validity of the second tentative assumption, that both units of duration containing events and empty units occurring between events would be "counted". The experimental conditions were combinations of (i) number of pulses presented in sequence (i.e. 2, 3, 4 and 5) and (ii) rate of presentation of pulses (i.e. one pulse every 30, 50 and 70 msec.). Sequences containing an odd number of pulses were matched with sequences in which the central pulse were not presented. Two Ss were used. Each was given six sessions during which a total of 50 responses were obtained for each of the 18 conditions.

Given the validity of the tentative assumption under consideration, it was predicted that modal reports would be the same for matched sequences. The results did not support the prediction. An examination of modal reported numbers contingent on presentation of trains containing no omissions suggested that a value of the quantum equal to 60 msec. was the "best" predictor of report. Given this value of the quantum and the alternative of the assumptions studied, that is that modal number reported would equal only the number of occupied units between the onsets of the first and final pulses in the sequence, modal reports were predicted for the six trains in the design containing omissions. Obtained and predicted modal reports were alike in five out of the six instances.

Although some support was obtained for the basic assumptions of the theoretical model in both Experiments 1 and 2, it was evident that the model did not control for such factors as response bias, and errors in reporting when rates of presentation were slower than derived rates of central processing. A change in methodology was suggested to allow a clearer evaluation of the model.

Experiment 3

In experiment 3 three Ss were presented on each trial with a train containing either n or (n+1) pulses and were required to report which of the two had occurred. The probability of occurrence of alternative trains on each trial was .5. There were two experimental conditions, A and B, in which trains contained 3 or 4 or 5 pulses respectively. The order of presentation of conditions was ABBA. Within a condition 10 sessions were given. For each of these 10 sessions one of 10 interpulse intervals (IPI), ranging from 0 to 136 msec., was used. The order of use was random. For each S 400 observations were obtained for each combination of discrimination condition and IPI.

It was predicted that accuracy in reporting would improve as the rate of presentation decreased. Further, errors in report would be unidirectional with S reporting n more often than (n+1) pulses. It was predicted that at some critical value of IPI the probability of a correct response would reach 1.00 and remain at this level for further increases in IPI. The rate of presentation corresponding to the critical IPI would then define the rate of central processing.

A graphical analysis of the data for each condition in terms of both probability of a correct response and sensitivity (d') suggested that both measures tended to increase to some asymptotic value as a function of increases in IPI. However, the critical level at which asymptote was reached appeared to differ for the two conditions. Further, for IPI's equal to and larger than the critical value discrimination was not perfect. This latter finding corroborated the results of experiments 1 and 2. For the mostpart the number of errors was greater when the train containing the larger number of pulses for each condition was presented.

Estimates of the unit of duration in Experiment 3, approximately 75 and 106 msec. for conditions A and B respectively, were larger than the estimates obtained in Experiments 1 and 2. The possibility that the difference was a function of task difficulty (as defined by the number of alternative conditions that S was required to consider) was discussed.

The conditions of Experiment 3 were examined with a view to evaluating such alternative explanations of the data as duration and intensity discrimination. Control procedures to eliminate the use of these cues were considered.

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APPENDIX A

Raw Data for Experiment 1

Table 1

Response Distributions Contingent on Trains of Different Length for Five Practice Sessons in Experiment 1

Subject	No. of Pulses	Response Categories					
		2	3	4	5	6	N*
ST	2	269	0	30	1	0	300
	3	31	235	34	0	0	300
	4	1	32	256	10	0	299
	5	1	0	46	253	0	300
B	2	250	7	15	27	0	299
	3	30	237	30	4	0	301
	4	2	96	160	42	0	300
	5	2	7	96	194	1	300

* A value of N unequal to 300 signifies that the particular condition was inadvertently presented on fewer or more trials than specified in the procedure.

Table 2

Response Distributions Contingent on Stimulus Events Occurring During Daily Practice Trials in Experiment 1

Subject	Day	No. of Pulses	Response Categories 2	3	4	5
ST	1	2	46	0	4	0
		3	6	41	3	0
		4	0	6	44	0
		5	0	0	7	43
	2	2	44	0	6	0
		3	2	42	6	0
		4	1	5	39	5
		5	1	0	11	38
	3	2	42	0	8	0
		3	8	36	6	0
		4	0	5	43	2
		5	0	0	9	41
	4	2	46	0	3	1
		3	7	39	4	0
		4	0	5	45	0
		5	0	0	8	42
	5	2	43	0	7	0
		3	2	40	8	0
		4	0	5	45	0
		5	0	0	6	44
	6	2	48	0	2	0
		3	6	37	7	0
		4	0	6	40	3
		5	0	0	5	45

Table 2 (continued)

Subject	Day	No. of Pulses	Response Categories			
			2	3	4	5
B	1	2	44	1	3	2
		3	5	38	7	0
		4	0	10	32	8
		5	0	4	22	23
	2	2	39	0	3	7
		3	12	30	7	2
		4	0	22	22	6
		5	1	2	14	33
	3	2	45	0	3	2
		3	5	42	3	0
		4	0	25	24	1
		5	0	1	21	28
	4	2	40	1	2	7
		3	2	41	6	1
		4	0	16	27	7
		5	0	0	14	36
	5	2	40	4	1	5
		3	3	43	3	1
		4	0	16	24	10
		5	1	0	13	36
	6	2	42	1	3	4
		3	3	43	4	0
		4	2	7	31	10
		5	0	0	12	38

Table 3

Frequency Distributions for 10 Test Sessions in Experiment 1
for Subject ST

No. of Units (C)	Assumed Value of q	No. of Pulses	Response Categories 1	2	3	4	5	N*
2	40 msec.	2	2	65	8	5	0	80
		3	10	67	3	0	0	80
		4	78	1	0	0	0	79
		5	See note Experiment 1, Table 1					
	50 msec.	2	0	68	9	3	0	80
		3	2	69	9	0	0	80
		4	12	61	7	0	0	80
		5	78	2	0	0	0	
	60 msec.	2	0	69	4	7	0	80
		3	1	54	25	0	0	80
		4	11	41	26	1	0	79
		5	69	11	0	0	0	80
3	40 msec.	3	0	44	36	0	0	80
		4	0	11	58	11	0	80
		5	13	12	52	3	0	80
	50 msec.	3	0	15	63	2	0	80
		4	0	8	55	17	0	80
		5	1	5	50	24	0	80
	60 msec.	3	0	11	64	5	0	80
		4	0	12	73	75	0	160+
		5	0	0	35	45	0	80
4	40 msec.	4	0	12	73	75	0	160+
		5	0	0	18	62	0	80
	50 msec.	4	0	1	20	59	0	80
		5	0	0	4	76	0	80
	60 msec.	4	0	0	16	64	0	80
		5	0	0	8	72	0	80

* A value of N unequal to 80 signifies that the particular condition was inadvertently presented on fewer or more trials than specified in the procedure.

+ Number of pulses and rate of presentation are the same for these two conditions. Therefore, they have been treated as one condition for which 160 responses were obtained.

Table 4

Frequency Distributions for 10 Test Sessons in Experiment 1 for Subject B

No. of Units (C)	Assumed Value of q	No. of Pulses	Response Categories 1	2	3	4	5	N*
2	40 msec.	2	0	61	10	2	7	80
		3	0	25	43	4	8	80
		4	0	60	12	0	7	79
		5	See note, Experiment 1, Table 1					
	50 msec.	2	0	65	8	1	6	80
		3	0	11	51	11	7	80
		4	0	18	27	10	25	80
		5	2	42	16	2	18	80
	60 msec.	2	0	65	10	1	4	80
		3	0	12	39	15	14	80
		4	1	10	11	15	42	79
		5	1	29	12	5	33	80
3	40 msec.	3	0	7	33	34	6	80
		4	0	2	5	27	46	80
		5	0	11	7	5	57	80
	50 msec.	3	0	4	23	47	6	80
		4	0	3	1	25	52	81
		5	0	3	0	13	64	80
	60 msec.	3	0	3	34	36	7	80
		4	0	6	10	49	95	160+
		5	0	1	0	9	70	80
4	40 msec.	4	0	6	10	49	95	160+
		5	0	1	0	7	72	80
	50 msec.	4	0	3	5	26	46	80
		5	0	2	1	10	67	80
	60 msec.	4	0	2	7	24	47	80
		5	0	1	1	10	68	80

* A value of N unequal to 80 signifies that the particular condition was inadvertently presented on fewer or more trials than specified in the procedure.

\+ Number of pulses and rate of presentation are the same for these two conditions. Therefore, they have been treated as one condition for which 160 responses were obtained.

APPENDIX B

Raw Data for Experiment 2

Table 1

Frequency Distributions of Responses Contingent on Trains Containing No Omissions in Experiment 2

Subject	Rate of Presentation	No. of Pulses	Response Categories 1	2	3	4	5	6	N*
ST	1/30 msec.	2	17	32	1	0	0	0	50
		3	14	19	15	0	0	0	48
		4	15	5	29	1	0	0	50
		5	12	3	28	7	0	0	50
	1/50 msec.	2	14	34	1	1	0	0	50
		3	2	15	32	1	0	0	50
		4	3	7	7	32	1	0	50
		5	0	3	8	36	3	0	50
	1/70 msec.	2	18	31	0	1	0	0	50
		3	2	6	38	6	0	0	52
		4	1	1	7	40	1	0	50
		5	0	0	0	24	26	2	52
B	1/30 msec.	2	0	13	24	9	5	0	51
		3	0	1	3	3	43	0	50
		4	0	1	0	0	49	0	50
		5	0	0	0	0	50	0	50
	1/50 msec.	2	0	23	16	8	2	0	49
		3	0	0	1	9	40	0	50
		4	0	0	1	0	49	0	50
		5	0	0	0	0	50	0	50
	1/70 msec.	2	0	12	31	7	0	0	50
		3	0	2	1	19	28	0	50
		4	0	0	0	2	48	0	50
		5	0	0	0	0	50	0	50

* A value of N unequal to 50 signifies that the particular condition was inadvertently presented on fewer or more trials than specified in the procedure.

Table 2

Frequency Distributions of Responses Contingent on Trains Containing Omissions in Experiment 2

Subject	Rate of Presentation	No. of Pulses	Response Categories 1	2	3	4	5	6	N*
ST	1/30 msec.	3	13	37	0	0	0	0	50
		5	7	26	2	14	0	0	49
	1/50 msec.	3	1	49	0	0	0	0	50
		5	0	19	7	24	0	0	50
	1/70 msec.	3	0	51	0	0	0	0	51
		5	0	10	12	26	0	0	48
B	1/30 msec.	3	0	21	21	8	0	0	50
		5	0	5	2	36	7	0	50
	1/50 msec.	3	0	20	25	4	1	0	50
		5	0	0	2	47	1	0	50
	1/70 msec.	3	0	26	20	4	0	0	50
		5	0	2	2	46	0	0	50

* A value of N unequal to 50 signifies that the particular condition was inadvertently presented on fewer or more trials than specified in the procedure.

FIGURE I MODAL RESPONSES CONTINGENT ON STIMULUS EVENTS IN EXPERIMENT 2

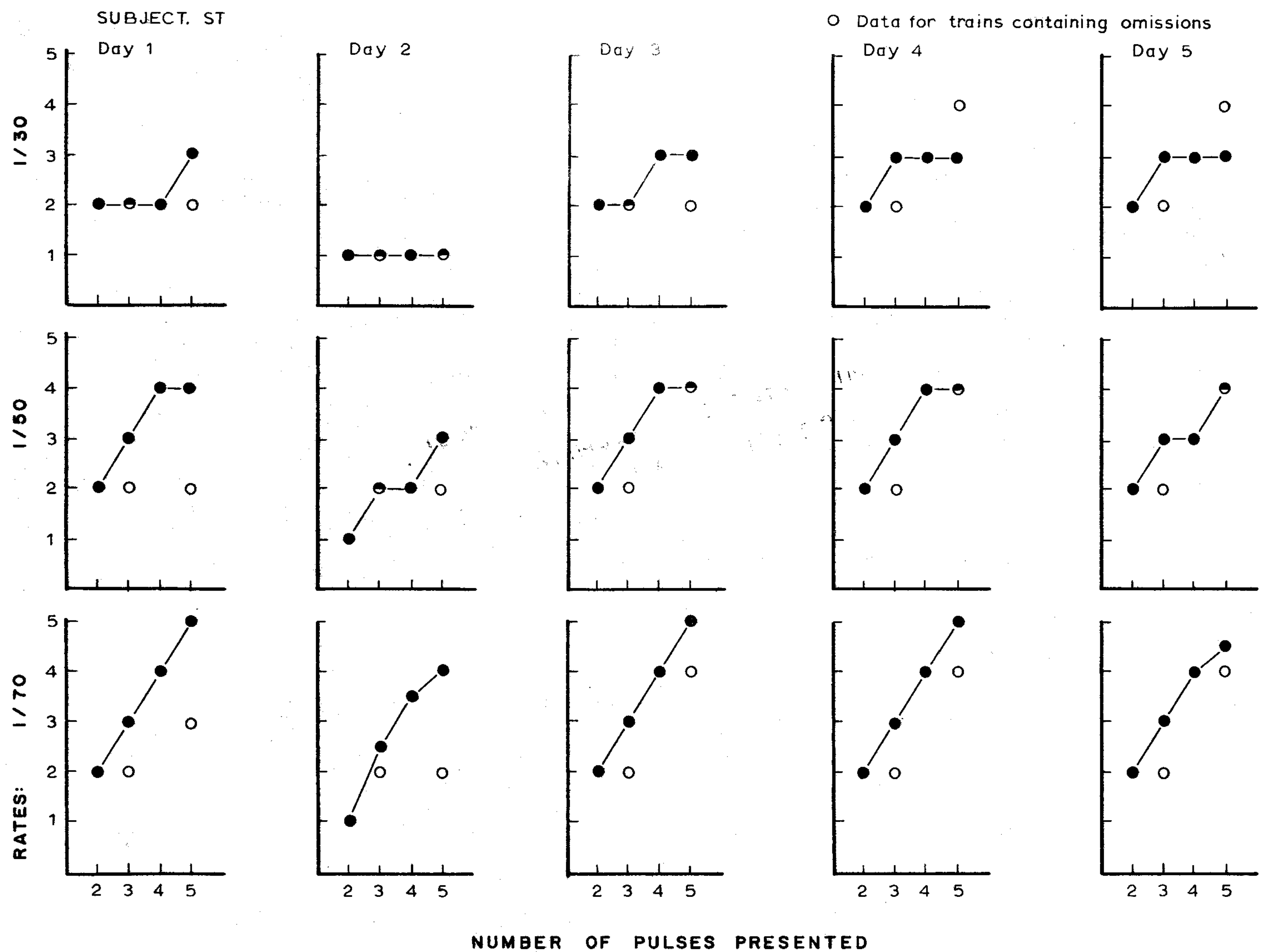
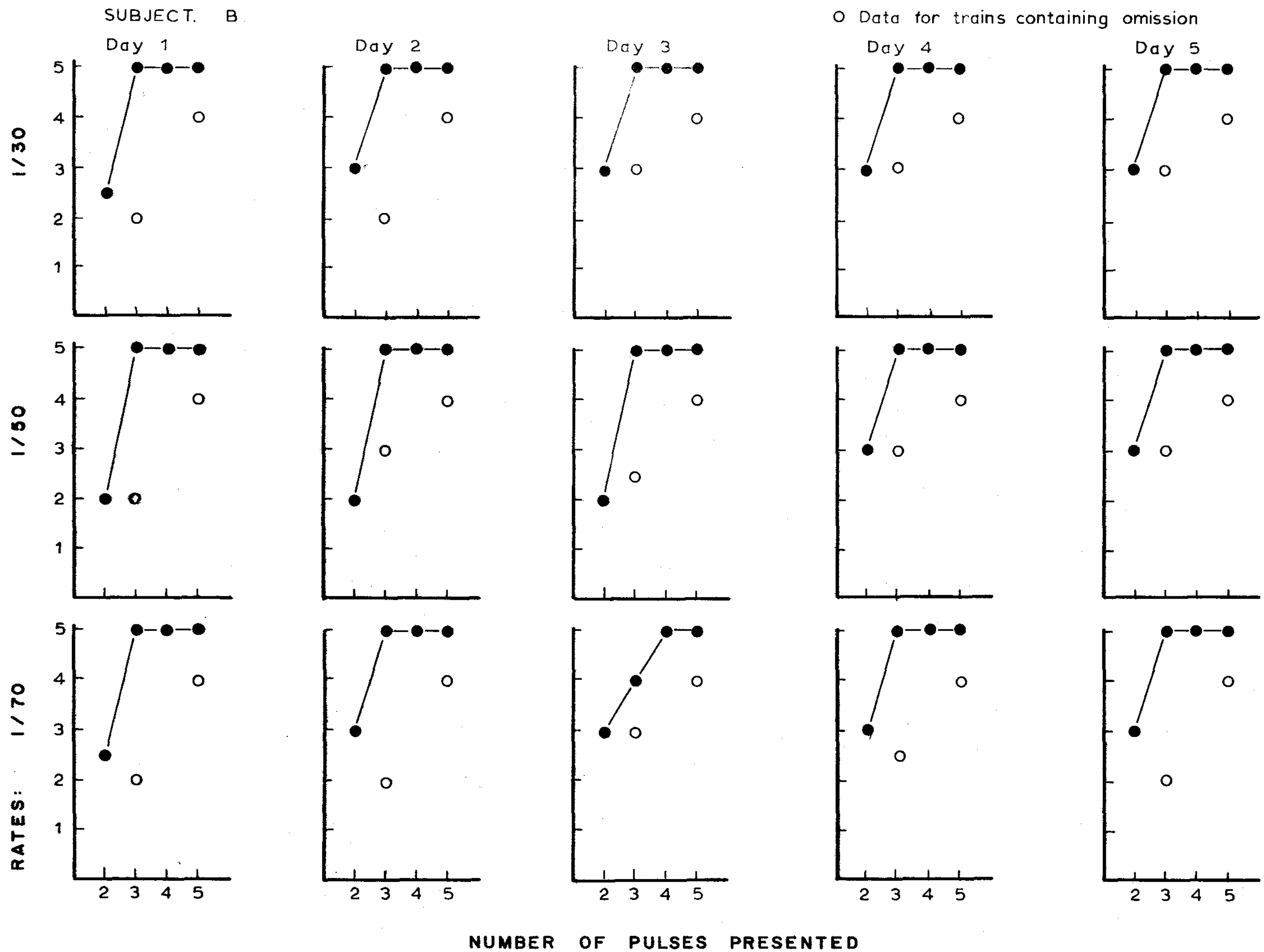


FIGURE 2 MODAL RESPONSES CONTINGENT ON STIMULUS EVENTS IN EXPERIMENT 2



APPENDIX C

Raw Data for Experiment 3

Table 1

Per Cent Correct Averaged Over Blocks Within Sessions
for Condition A in Experiment 3

		First Presentation of Condition				Second Presentation of Condition			
Subject	IPI	P(3/3)	P(4/3)	P(4/4)	P(3/4)	P(3/3)	P(4/3)	P(4/4)	P(3/4)
CC	0	84	16	82	18	84	16	84	16
	15	91	9	75	25	99	1	92	8
	30	89	11	69	31	94	6	95	5
	45	98	2	100	0	89	11	93	7
	60	96	4	81	19	100	0	100	0
	75	100	0	100	0	100	0	97	3
	90	100	0	77	23	100	0	100	0
	106	100	0	99	1	100	0	100	0
	120	99	1	100	0	99	1	99	1
	136	100	0	100	0	100	0	98	2
AS	0	79	21	45	55	91	9	88	12
	15	77	23	99	1	85	15	83	17
	30	93	7	85	15	79	21	91	9
	45	87	13	78	22	97	3	99	1
	60	97	3	82	18	98	2	100	0
	75	97	3	95	5	99	1	99	1
	90	83	17	75	25	98	2	99	1
	106	98	2	93	7	99	1	96	4
	120	95	5	87	13	98	2	99	1
	136	94	6	83	17	97	3	97	3
DS	0	80	20	89	11	63	37	78	22
	15	61	39	76	24	84	16	52	48
	30	87	13	66	34	79	21	91	9
	45	72	28	84	16	79	21	80	20
	60	89	11	88	12	86	14	77	23
	75	94	6	78	22	86	14	82	18
	90	94	6	91	9	95	5	96	4
	106	83	17	88	12	89	11	84	16
	120	84	16	95	5	93	7	96	4
	136	87	13	74	26	89	11	77	23

Table 2

Per Cent Correct Averaged Over Blocks Within Sessions for Condition B in Experiment 3

		First Presentation of Condition				Second Presentation of Condition			
Subject	IPI	P(4/4)	P(5/4)	P(5/5)	P(4/5)	P(4/4)	P(5/4)	P(5/5)	P(4/5)
CC	0	79	21	69	31	80	20	83	17
	15	82	18	74	26	90	10	86	14
	30	96	4	67	33	80	20	81	19
	45	93	7	90	10	90	10	89	11
	60	97	3	97	3	94	6	91	9
	75	95	5	90	10	100	0	99	1
	90	99	1	95	5	100	0	99	1
	106	99	1	100	0	0	98	99	1
	120	98	2	96	4	93	7	92	8
	136	99	1	98	2	100	0	100	0
AS	0	69	31	75	25	82	18	75	25
	15	78	22	71	29	91	9	80	20
	30	81	19	85	15	80	20	79	21
	45	83	17	74	26	77	23	86	14
	60	92	8	87	13	90	10	90	10
	75	93	7	82	18	90	10	83	17
	90	93	7	92	8	94	6	97	3
	106	97	3	100	0	96	4	96	4
	120	90	10	93	7	94	6	97	3
	136	93	7	97	3	95	5	97	3
DS	0	69	31	63	37	93	7	60	40
	15	79	21	46	54	70	30	61	39
	30	70	30	71	29	86	14	73	27
	45	62	38	81	19	73	27	72	28
	60	74	26	73	27	81	19	79	21
	75	80	20	82	18	80	20	85	15
	90	82	18	94	6	84	16	60	40
	106	79	21	83	17	85	15	82	18
	120	90	10	71	29	88	12	73	27
	136	86	14	88	12	81	19	97	3

Table 3

Per Cent Correct Averaged Over Length of Train Within Sessions for Condition A in Experiment 3

		First Presentation of Condition		Second Presentation of Condition	
Subject	IPI	Block 1	Block 2	Block 1	Block 2
CC	0	83	83	82	86
	15	85	81	95	96
	30	75	83	95	94
	45	99	99	91	91
	60	91	87	100	100
	75	100	100	99	98
	90	86	92	100	100
	106	100	99	100	100
	120	99	100	99	99
	136	100	100	100	98
AS	0	65	64	88	91
	15	88	88	83	85
	30	89	89	85	84
	45	85	80	98	98
	60	90	89	99	99
	75	95	97	98	100
	90	80	78	98	99
	106	94	97	98	97
	120	94	87	99	98
	136	85	92	98	96
DS	0	83	85	70	70
	15	71	67	66	69
	30	78	75	91	78
	45	80	76	78	81
	60	86	91	81	81
	75	85	86	85	83
	90	93	92	95	96
	106	89	82	89	84
	120	85	94	97	93
	136	76	85	86	81

Table 4

Per Cent Correct Averaged Over Length of Train Within Sessions for Condition B in Experiment 3

		First Presentation of Condition		Second Presentation of Condition	
Subject	IPI	Block 1	Block 2	Block 1	Block 2
CC	0	71	78	82	81
	15	74	82	88	87
	30	75	87	83	78
	45	89	93	89	90
	60	97	97	93	92
	75	96	89	99	100
	90	98	96	100	99
	106	100	99	100	97
	120	98	96	89	96
	136	98	99	100	100
AS	0	67	77	77	80
	15	76	73	85	86
	30	81	85	83	76
	45	75	81	80	83
	60	83	96	89	91
	75	87	88	79	93
	90	93	92	96	95
	106	97	100	96	96
	120	92	92	96	95
	136	95	95	95	97
DS	0	70	62	74	78
	15	66	59	69	62
	30	71	70	76	83
	45	73	70	71	74
	60	73	74	77	83
	75	86	76	82	83
	90	87	89	82	63
	106	82	80	85	82
	120	82	80	78	83
	136	89	85	94	84