A STUDY OF FACILITATION AND INHIBITION IN REACTION TO HETEROMODAL STIMULATION

by

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TABLE OF CONTENTS

While measuring reaction time (RT) in an attempt to condition sensory responses in 1925, Helson (personal communication), found that a second stimulus introduced 75 msec. after the primary stimulus resulted in lengthening RT to a significant degree. Although this phenomenon bears a resemblance to external inhibition in Pavlovian conditioning and "retroactive masking" (Raab, Fehrer, & Hershenson, 1961), previous studies, have not, to my knowledge, shown the inhibitory effect on RT of a second stimulus that follows the primary signal in a simple reaction time[1] experiment. The closest finding, until recently (Helson & Steger, in press), to this inhibitory effect was that of Todd in 1912, who found that RTs were longer to the second or third of successive stimuli in different sense modalities than RTs to stimuli in one modality.

The serial or choice RT studies (Davis, 1956; Elithorn & Lawrence, 1955; Klemmer, 1958; Mowbray & Gebhard, 1956; Welford, 1959) have shown that RT to the second of two signals is lengthened when these signals are presented within 500 msec. of each other. The findings reported here are unique in that: (a) RT to the signal for action (S_1) was influenced when followed by a second appearing stimulus (S_2) presented in a different sense modality; (b) the second appearing stimulus (S_2) was not to be reacted to as in the case of serial RT studies or with Todd's successive stimuli, and (c) the intervals after the onset of S_1 during which S_2 still exerts a significant influence on RT are comparatively long.

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[1]Simple reaction time (RT) defined as the time interval between the onset of the stimulus and the response under the condition that the subject has been instructed to react as quickly as possible. To be distinguished from serial or choice RT situations.

A previous study by Helson & Steger (in press) on the inhibitory effect of a second stimulus in the same sense modality as the action stimulus (visual) provided the basis for the present study. Using a simple RT experimental procedure we found that RT to S_1 was significantly increased when S_2 followed S_1 at intervals ranging from 20 to 170 msec. with maximum effect occurring from 40 to 140 msec. The following parabola was computed for the data shown in Figure 1: $Y = (-17/6400)(x - 90)^2 + 241$, where Y is RT and x is the interval between S_1 and S_2. As Helson & Steger (in press) point out, the parabolic type function is most reasonable since little or no effect is expected from S_2 if it follows S_1 after too short or too long an interval. A finding of interest is that even after 360 repetitions the inhibiting effect of S_2 was still present as seen from Figure 2 wherein RT is plotted as a function of trials with intervals confounded.

Individual differences in susceptibility to the influence of S_2 were present in that four of the ten experimental _S_s failed to give significantly longer RTs over all 18 intervals, although they did have significantly longer RTs at some of the intervals than under single stimulus conditions.

In the previous study unimodal presentation was employed and the stimuli were equal in intensity. In the present study visual and auditory stimuli were employed in all combinations of three levels of intensity and each stimulus served as S_1 or S_2. The 3 x 3 factorial design shown in Table 1 was for the purpose of testing the following hypotheses:

1. S_2 when presented over a limited time range will

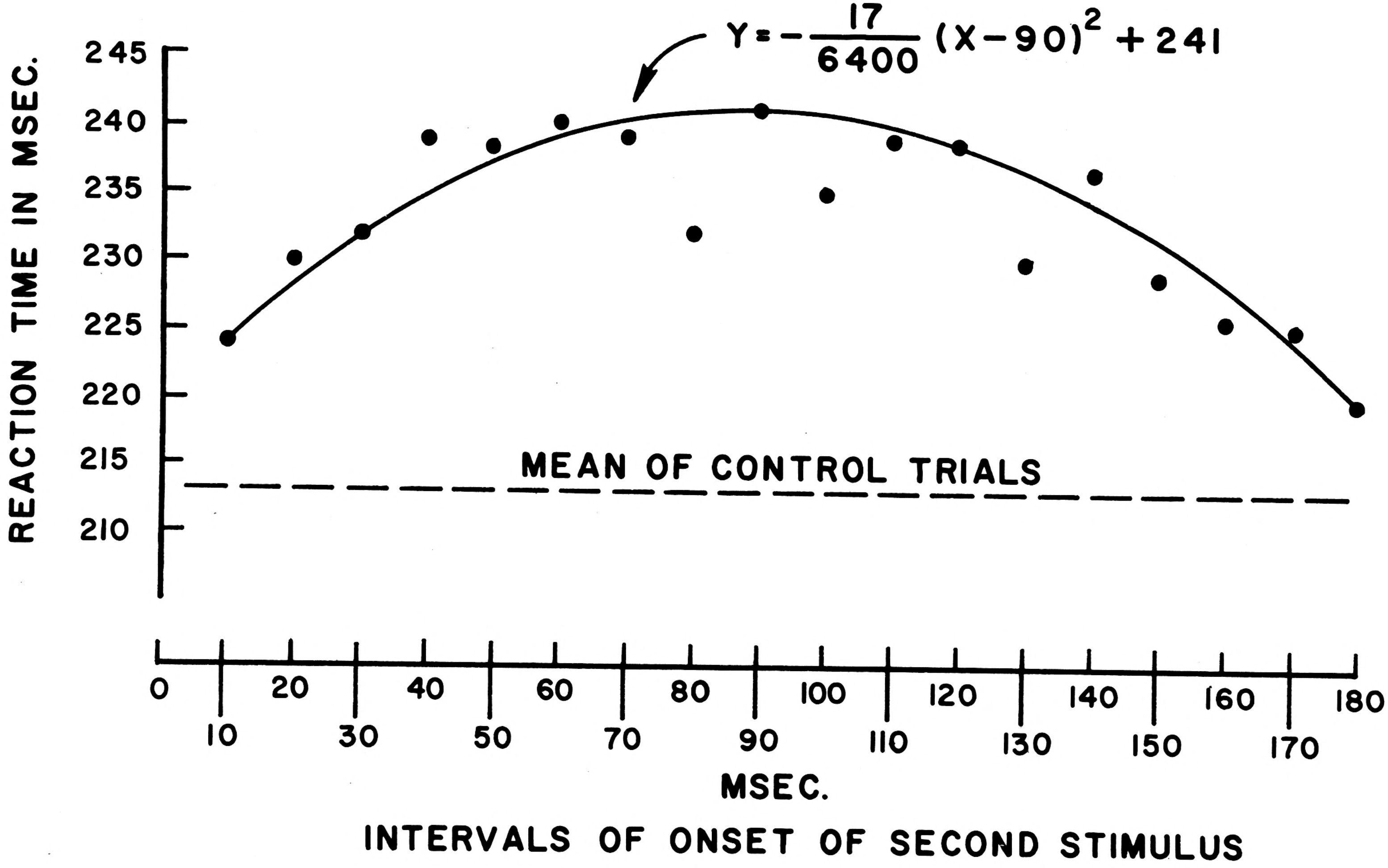

Fig. 1. Parabola fitted to RT at $S_1 - S_2$ intervals. Taken from Helson & Steger (in press).

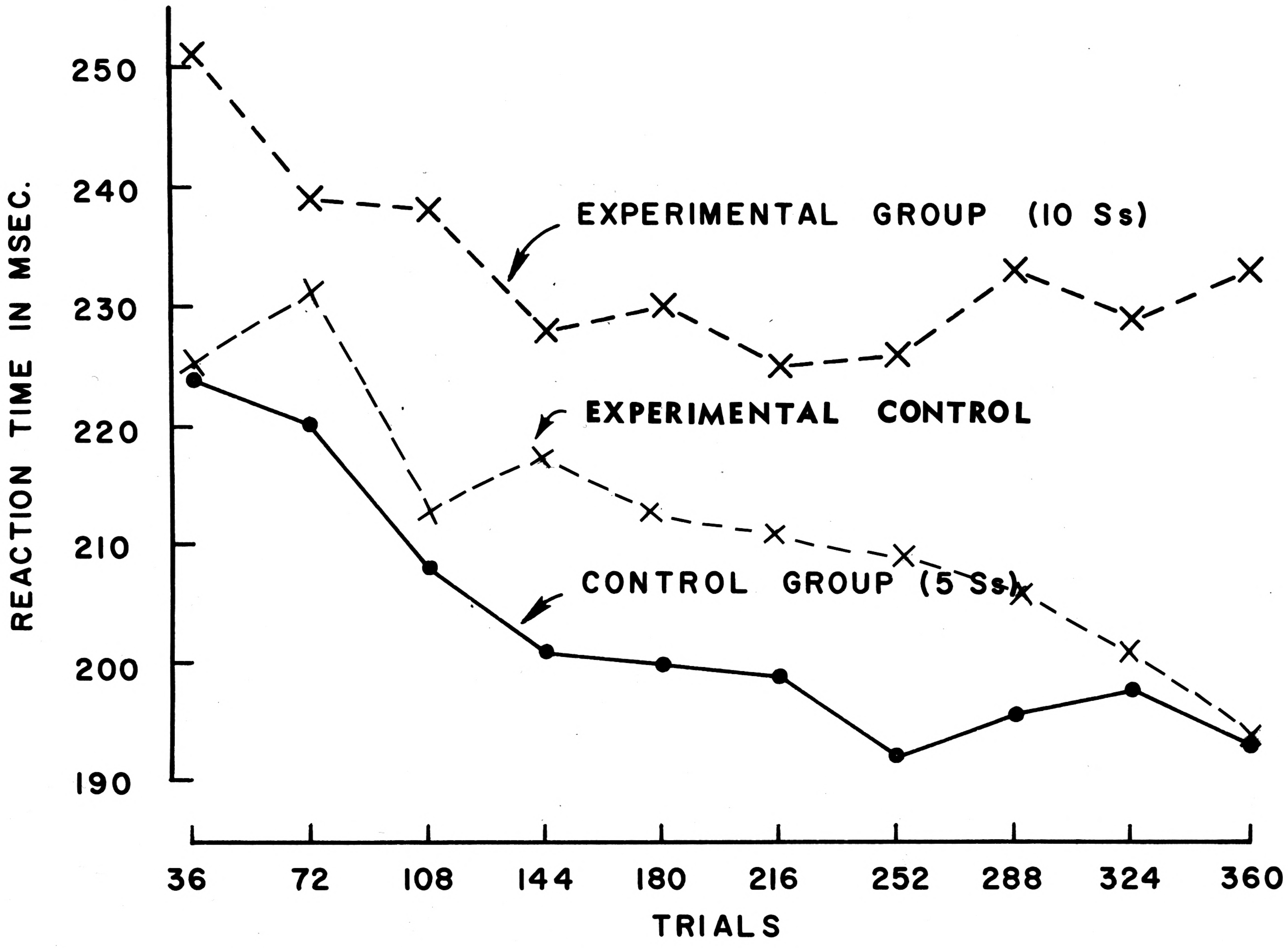

Fig. 2. Practice curves from Helson & Steger (in press).

significantly increase RT to S_1.

2. The inhibiting effect of S_2 will depend on its intensity relative to S_1; the greater the relative difference the greater the inhibiting effect.
3. A stimulus in one modality, at some delay interval, will be equivalent in inhibiting power to a stimulus in another modality.
4. Where there are differences in RT among sense modalities to a single stimulus, the inhibiting effect of S_2 will be greater for the sense modality stimulus that elicits a quicker initial RT than for the modality in which a stimulus elicits a slower initial RT.

METHOD

Subjects

The Ss were 90 men enrolled at Kansas State University ranging from 18 to 27 years of age. They were randomly divided into two primary groups. Group L which reacted to the light stimulus with tone as the second stimulus and Group T which reacted to the tone with the light as the second stimulus. The Ss were then randomly divided into 18 sub-groups, 9 groups of 5 subjects each, under each of the primary conditions, the total being the sum of conditions of a 3 x 3 matrix of stimulus intensities. (See Table 1 for designations of the sub-groups.)

Table 1

Design of the 3 x 3 Matrix of Intensities of the Light and Tone

Group L ---- Light Primary			
Tone secondary (in dbs)	Light (in Appt. Ft. C.)		
	2.5	75.6	183.6
20	LdTs	LmTs	LbTs
40	LdTm	LmTm	LbTm
60	LdTl	LmTl	LbTl

Group T ---- Tone Primary			
Light secondary (in Appt. Ft. C.)	Tone (in dbs)		
	20	40	60
2.5	TsLd	TmLd	TlLd
75.6	TsLm	TmLm	TlLm
183.6	TsLb	TmLb	TlLb

The designations of the sub-groups in the matrix follow this formula--the capital letter indicates the Light or Tone, the small letters indicate the intensity of light (b = bright, m = medium, d = dim) and tone (l = loud, m = medium, s = soft). The letters are presented in the order of presentation of the stimuli.

Apparatus and Procedure

The apparatus as seen schematically in Plate I was designed to control the interval between S_1 and S_2 and to record the reaction time of the Ss.

Ss sat facing a black panel board on which was mounted a one inch square frosted plastic window. Directly behind the window was a gas (argon and mercury) filled 3,000 volt light source with negligible lag and a Speed-O-Scope shutter which provided diaphram control over the white light source. By means of the diaphram control three levels of luminance were employed, 2.5, 75.6, and 183.6 apparent foot candles. The S sat facing the light source in a chair which provided an arm rest so that S's arm and hand could assume a convenient position in relation to the response key. The response key was very sensitive being tripped by a 41 gram pressure. The key when tripped, broke the circuit and shut off both stimuli. Ear phones were provided for the auditory stimulus.

The E sat behind the panel board at a control panel consisting of a reset button for a Standard Electric Clock which measured in .01 sec., a selector switch which allowed either the tone or light to be presented as the primary stimulus, an on-off switch for the power supply and a start button which actuated the primary stimulus, the Standard Electric Clock, the Hunter Interval Timer which operated the current on the second stimulus at intervals ranging from 0 to 200 msec. and the Hunter Klockounter which timed the interval timer and served as a check upon the accuracy of the interval timer. A Hewlett-Packard model 200 C.D. Wide Range oscillator with attenuator set (Model 350B) provided a 600 cps

EXPLANATION OF PLATE I

A schematic of the apparatus:

1 --- Start switch for the primary stimulus
2 --- Power supply off-on switch
3 --- Clock reset switch
4 --- Selector switch allowing either tone or light to be the S_1
5 --- Standard electric clock
6 --- Attenuator-model 350B
7 --- Hewlett Packard Model 200 C.D. Wide Range oscillator
8 --- Hunter Klockounter
9 --- Hunter Interval Timer
10 --- Hunter Interval Timer
11 --- Relays
12 --- 3,000 volt transformer
13 --- Neon light source
14 --- Light diaphram control
15 --- Earphones
16 --- Black shield board
17 --- Response key
18 --- Plastic diffusing screen

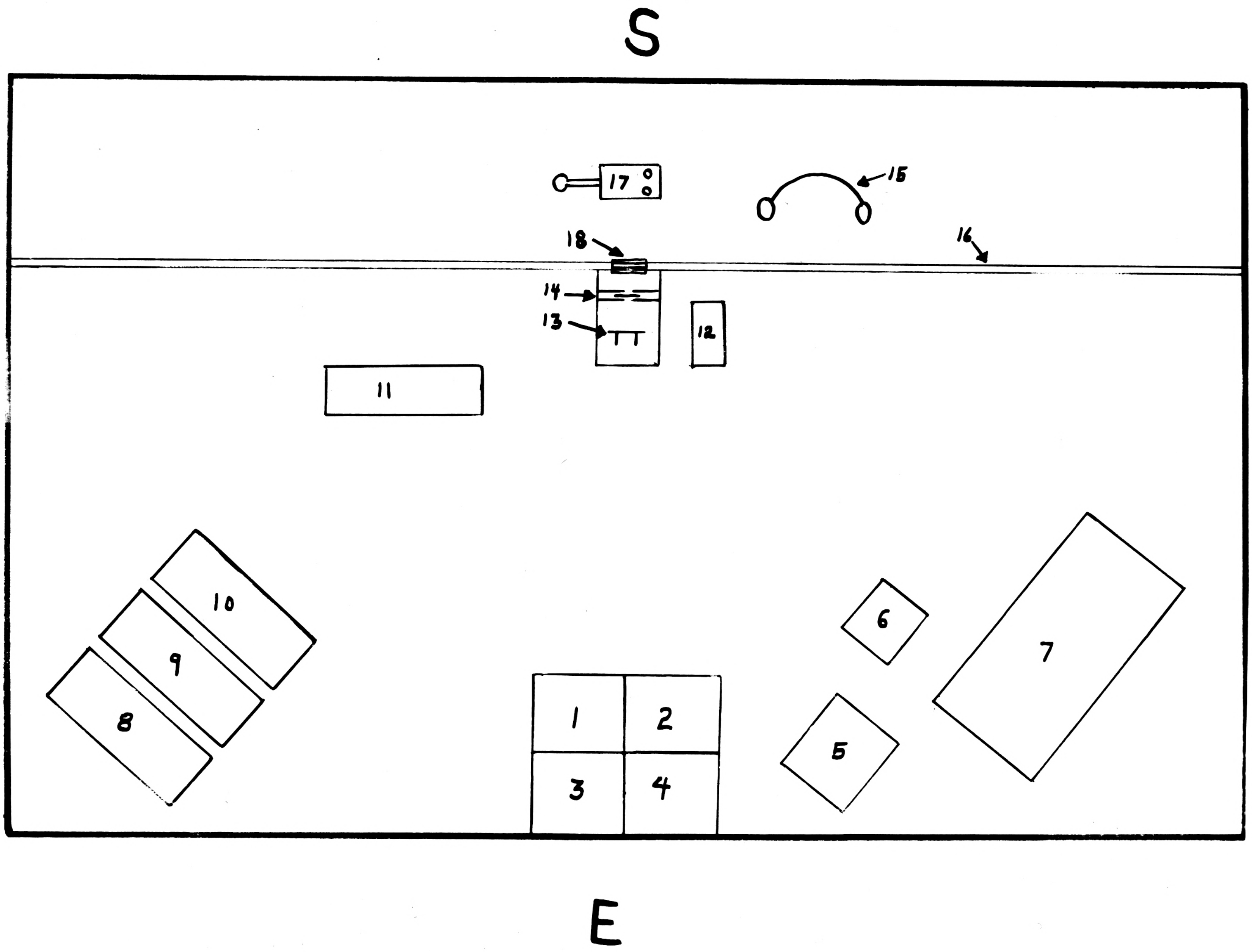

PLATE I

tone at levels of 20, 40, and 60 decibels, re .0002 dyne/cm^2.

The primary stimulus stayed on until S responded since it is known that duration of a stimulus affects reaction time. The room in which the experiment was conducted was dimly lighted (.026 appt. ft. candles) and shielded from external noise.

The actual procedure can best be understood from the instructions given S.

> This is an experiment in simple reaction time. You are to respond to the light (tone) as quickly as you possibly can by pressing the response key under your index finger. You may also hear a tone (see a light) occasionally. After each trial you will reset the response key like this (E demonstrated).
>
> The procedure will be as follows: I will say "ready" and a short time after I say ready the light (tone) will come on. You are to react as quickly as possible. After you react I will say "reset" and you will reset the response key.
>
> Are there any questions?

The E also had a standard answer to the often asked question, "Why does the tone (light) follow the light (tone) occasionally?". The answer given was,

> Because I am running another group of subjects to the light (tone) and I must keep the conditions of the experiment exactly the same in both cases. It would take too much electrical work to have separate systems so I ask everyone to serve under identical conditions.

The presentations of the primary stimulus were varied from .5 to 2 seconds after the "ready" signal. Each S reacted a total of 100 times, 10 times with each second stimulus presented at each of 9 intervals ranging from 0 to 200 msec. in steps of 25 msec., and 10 times when the second stimulus was omitted. The time intervals at which the second stimulus followed the first as well as the trials in which the second stimulus was omitted were chosen from a table of random numbers.

The Ss were given 10 trials with only the primary stimulus to familiarize them with the procedure. There were five seconds between trials and a five minute break after the 50th trial. All parts of the equipment were visually shielded from Ss.

RESULTS

The results leave no doubt that a stimulus (S_2) presented after the response stimulus (S_1) has an effect on RT to the response stimulus. The inhibiting and facilitating effect of S_2 on the RT to S_1 can be seen in Table 2 and Figure 3.

Figure 3 which represents a summing of all intensity subgroups of S_2 under the reaction to tone and the reaction to light, shows a parabolic trend very similar to that found by Helson & Steger (in press) which used two visual stimuli. The findings lend support to the expectation that the effect of S_2 as an inhibitor should be minimal at some very short interval following S_1, that it should increase to some maximal value or values at certain inter-stimulus intervals, and should then decline as the response is being consummated. The first hypothesis proposed in this study was that S_2 will significantly increase RT to S_1. Generally, this has been validated.

It can also be seen from Figure 3 that the RT to light (S_{1L}) was facilitated longer and to a greater degree by the tone (S_{2T}) than the RT to tone (S_{1T}) was by light (S_{2L}). Hypothesis 4, that there is a relation between the length of RT in different sense modalities and the inhibiting effect of S_2 in another modality is borne out since the slower initial

Table 2

The Group Mean Reaction Time As a Function of the $S_1 - S_2$ Intensity and Interval Relations (All Times in msec.)

Control		Group	$S_1 - S_2$ interval								
			0	25	50	75	100	125	150	175	200
Lb	205	LbTs	183	197	203	206	205	205	203	206	213
Lb	210	LbTm	201	214	223	230	220	221	228	222	228
Lb	211	LbTl	176	193	207	213	227	222	226	220	219
Lm	221	LmTs	190	210	228	219	230	219	233	228	229
Lm	212	LmTm	181	206	215	224	227	223	229	220	219
Lm	207	LmTl	180	204	216	217	223	215	219	213	210
Ld	232	LdTs	206	223	241	242	253	251	252	244	235
Ld	236	LdTm	185	201	227	226	236	242	232	236	235
Ld	221	LdTl	194	207	228	238	244	246	244	232	229
Tl	210	TlLd	197	197	210	213	205	199	206	202	207
Tl	186	TlLm	184	189	194	197	199	193	193	194	190
Tl	181	TlLb	178	190	195	197	200	194	197	189	189
Tm	205	TmLd	198	198	218	212	214	210	209	210	202
Tm	182	TmLm	180	188	185	194	185	187	182	182	179
Tm	204	TmLb	194	206	217	213	219	215	214	212	217
Ts	212	TsLd	201	209	214	206	209	221	222	219	223
Ts	180	TsLm	160	189	193	192	194	186	182	185	181
Ts	192	TsLb	182	200	212	211	216	210	206	205	194

Note.--The designations of the groups follow this formula: The capital letter indicates the Light or Tone, the small letter indicates the intensity of light (b = bright, m = medium, d = dim) and of tone (l = loud, m = medium, s = soft). The letters are shown in order of presentation of the stimuli. For example, LbTs would be reaction to a bright light followed by a soft tone as S_2.

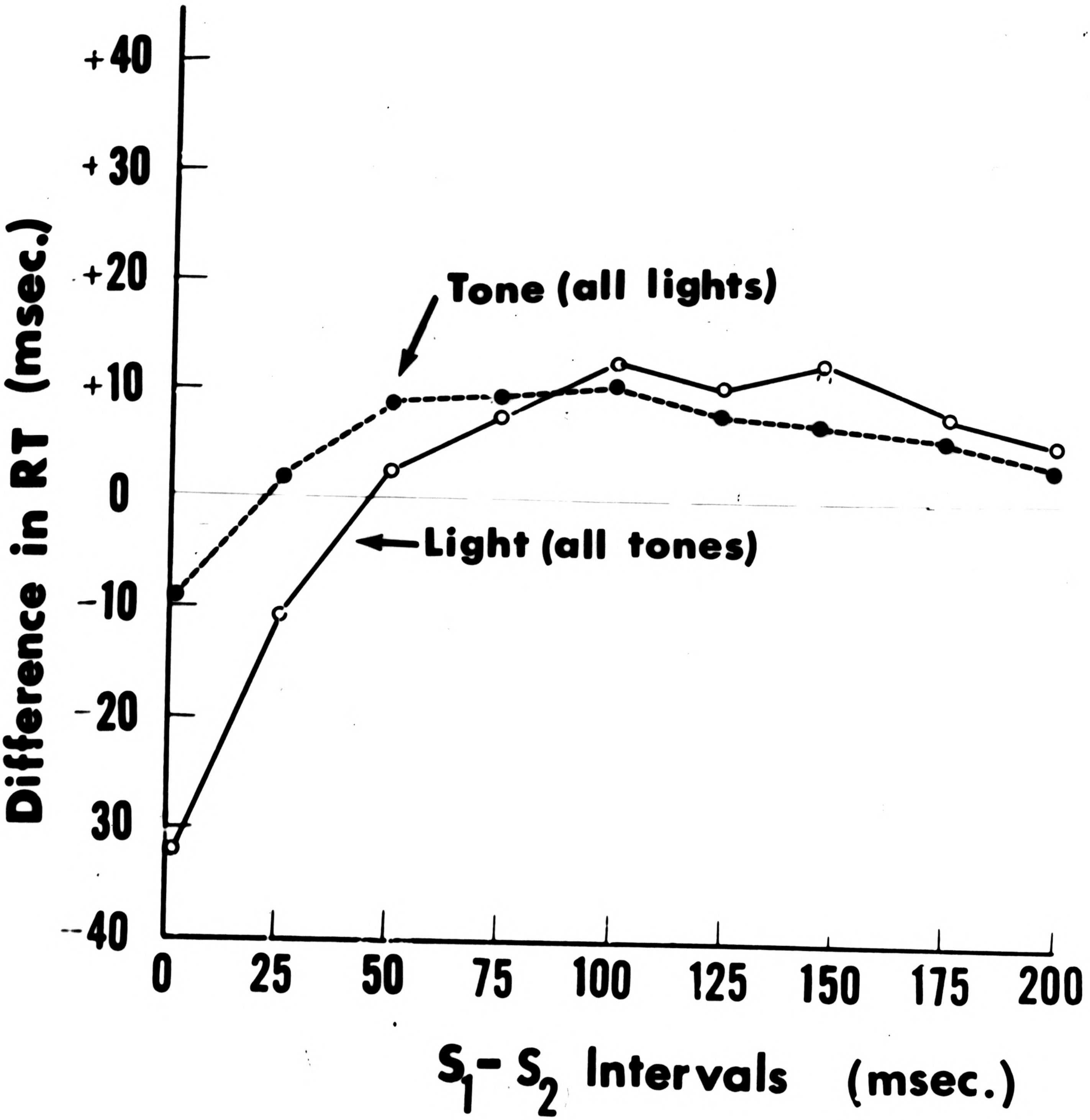

Fig. 3. The RT to Tone and the RT to Light under all S_1 - S_2 intensity relations as a function of the S_1 - S_2 interval. (Note in Figures 3 through 9 all RTs are shown in terms of difference from control RT, the minus being faster than the control RT and the plus being slower.)

reaction to S_{1L} is both inhibited and facilitated longer and to a greater degree than the RT to S_{1T}. A regression analysis (see Appendix C) of the curves in Figure 3 showed the range of the inhibiting effect of S_{2T} on S_{1L} to be greatest from 100 msec. to 175 msec. with the expected maximum at 116 msec. This shift of the range of inhibiting power of S_2 under the reaction to tone or light is relative to the control RT to these stimuli. The mean RT to light singly was 218 msec. and the mean RT to tone singly was 196 msec., a difference of 22 msec. which is approximately equal to the difference in the range of expected maximal inhibitory values under $S_{1L} - S_{2T}$ and $S_{1T} - S_{2L}$. The same difference in range of facilitation between $S_{1T} - S_{2L}$ and $S_{1L} - S_{2T}$ is also in evidence in Figure 3. The difference between S_{1L} and S_{2T} in length of facilitation was approximately 20 msec. with the S_{1L} being facilitated 20 msec. longer than S_{1T}, which is again in relation to the difference in RT to tone and light singly.

Hypothesis 3, that a stimulus in one modality at some $S_1 - S_2$ interval will be equivalent in inhibiting power to a stimulus in another modality, was in this study, found to be at the 90 msec. interval, as can be seen from Figure 3 where the curves for the RT to tone and the RT to light cross at the 90 msec. interval. Since the S_2 was not presented at this interval in the present study it is of interest to note that in the earlier study by Helson & Steger (in press) the most effective $S_1 - S_2$ interval in the inhibitory range was 90 msec.

An analysis of variance of the RT to light and to tone singly, at the 0 msec. interval, and the 100 msec. $S_1 - S_2$ interval, shown in Tables 3, 4, and 5 summarize the intensity and $S_{1T} - S_{2L}$ or $S_{1L} - S_{2T}$

order relations.

Table 3

Analysis of Variance for the Control Condition

Source of variation	df	SS	MS	F	P
Tone	2	52595	26298	.41	>.05
Light	2	822515	411258	6.49	<.01
T x L	4	49252	123313	.19	>.05
Order	1	1156000	1156000	18.24	<.001
O x T	2	5787	2894	.05	>.05
O x L	2	75920	37960	.60	>.05
O x T x L	4	164553	41138	.65	>.05
Sample O x T x L	72	4562960			
Total	89	6889582			

Table 4

Analysis of Variance for the 0 msec. $S_1 - S_2$ Condition

Source of variation	df	SS	MS	F	P
Tone	2	20420	15210	.29	>.05
Light	2	344027	172014	3.25	<.05
T x L	4	290893	72723	1.37	>.05
Order	1	7290	7290	.14	>.05
O x T	2	54420	27210	.51	>.05
O x L	2	20346	10173	.19	>.05
O x T x L	4	51694	12924	.24	>.05
Sample O x T x L	72	3819320			
Total	89	4609410			

The analysis of the control condition shows that the three light conditions yield significantly different RTs from one another ($P < .01$). The tone intensity effects on RT were not significantly different ($P > .05$). An LSD test of the differences in RT under the different light intensities showed the bright and medium intensities not to be significantly different (LSD = 130, D > 189, $p < .05$).

Table 5

Analysis of Variance for the 100 msec. $S_1 - S_2$ Condition

Source of variation	df	SS	MS	F	P
Tone	2	3563	1782	.03	>.05
Light	2	490016	245008	3.63	<.05
T x L	4	89697	22424	.33	>.05
Order	1	1411255	1411255	20.91	<.001
O x T	2	34495	17248	.26	>.05
O x L	2	425828	212914	3.15	<.05
O x T x L	4	268712	67178	1.00	>.05
Sample O x T x L	72	4859000			
Total	89	7582566			

Another thing in evidence in Table 3 is the difference in RT due to the order of presentation of stimuli. The order effects showed that RT to light is significantly slower than the RT to tone.

The analysis of the 0 msec. as simultaneous $S_1 - S_2$ interval (Table 4) showed the light intensities RTs to be significantly different from one another. The dim S_{1L} RT was significantly slower than the RTs to the medium or bright S_{1L}s (LSD = 167.7, D = 185, $p < .05$). As would be expected the greater the intensity difference between S_1 and S_2 the greater the facilitating effect of S_2 at the 0 msec. interval. The dim S_{1L} was significantly effected and yielded a larger decrease in RT when compared to its control RT than the medium or bright S_{1L} RTs compared to their control RTs. When the light serves as S_2 the differential facilitating effects of intensity on RT to tone are not present.

The RTs of $S_{1L} - S_{2T}$ and $S_{1T} - S_{2L}$ are significantly different at the 100 msec. interval as seen in the order effects in Table 5. The $S_{1L} - S_{2T}$ RTs are significantly slower than the RTs to $S_{1T} - S_{2L}$. This suggests that the tone S_2 had a greater inhibitory effect on RT than the light S_2. The tone S_2 also had a differential inhibiting effect upon the RTs to S_{1L} as is evidenced in the significant difference between light intensities in Table 5. The dim S_{1L} RTs were significantly slower ($LSD = 133.9$, $D = 182$, $p < .05$) than the RTs to the bright or medium S_{1L}s. Thus it would appear that the S_{2T} inhibits RT to the S_{1L} to a greater extent as the difference in their relative intensity becomes greater.

When the light serves as S_2 the inhibitory effects on the RT to tone are not significantly differential as is evidenced in the nonsignificant tone value in Table 5.

Evidence in support of hypothesis 2, that changes in the relative intensities of S_1 and S_2 will alter RT is present in the statistically significant difference found between the RTs to the three light intensities. The RTs to the tone intensities although not statistically significantly different show a trend toward differential facilitation and inhibition. The differential effects of relative intensity relations upon RT will be more clearly seen as the intensity subgroups are examined. We shall consider each subgroup separately.

RT to Tone Intensities

Tone Soft Groups

The RT to a soft tone shows a marked differentiation in relation to the intensity of S_2. Figure 4 leaves no doubt that the greater the intensity of the light the greater the facilitating and inhibiting effect produced upon RT to a soft tone. The expected order of the S_2 intensities is also very clearly shown in Figure 4. One would predict the bright S_2 would be more effective than the medium S_2 and the medium S_2 more effective than the dim S_2 in their inhibition of RT to a soft tone. A *t* test showed the statistically significant inhibitory effect of a bright S_2 was between 50 and 125 msec. ($p \leq .02$). The medium S_2 had its greatest inhibitory effect on RT to S_1 between 50 and 100 msec. ($p \leq .05$). The dim S_2 produced no significant inhibiting effect upon RT to S_1.

Tone Medium Groups

The tone medium groups did not show the marked differentiation in RT due to intensity differences of S_2 as that found in RT to a soft tone as is evidenced in Figure 5. This is what one would predict since the intensity relation between S_1 and S_2 in the tone medium condition are not as great as in the tone soft condition. However, the intensity relations among the different S_2s are as would be predicted. The bright S_2 is generally more effective than the medium or dim intensities. The medium and dim S_2 intensity groups show a very close correspondence and inversion. This is probably caused by the difference in susceptibility to the effect of S_2 of individuals within these groups. More will be said about the individual differences in susceptibility later.

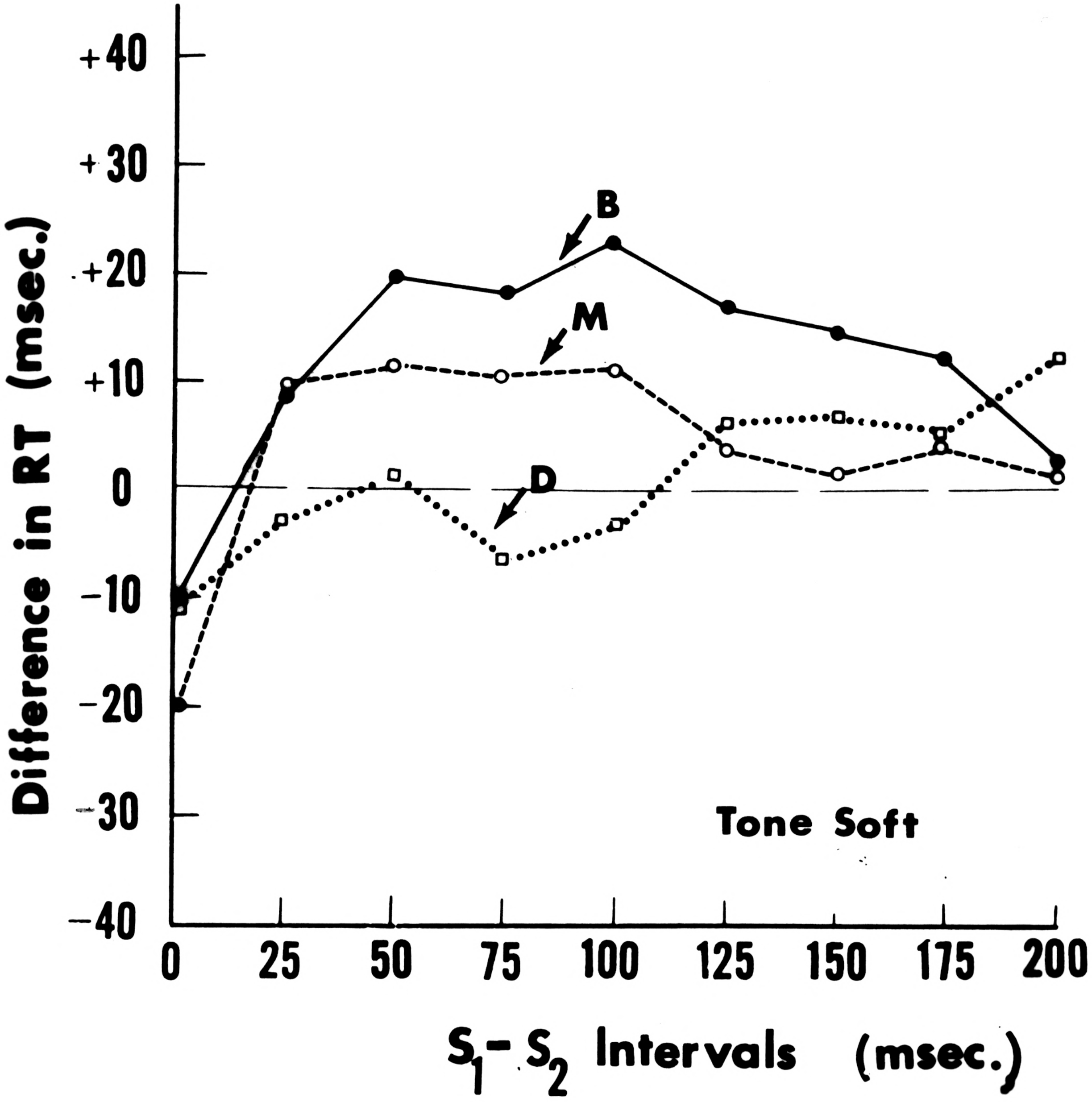

Fig. 4. Reaction time to a soft tone at three light intensities (S_2) as a function of the S_1 - S_2 interval where B = bright, M = medium, and D = dim light intensities.

Only the bright intensity of S_2 yielded a trend toward statistically significant inhibitory effects at intervals of 100, 125, and 150 msec. ($p \leq .10$).

Tone Loud Groups

Figure 6 shows the effect of the S_{2L} on RT to a loud tone. As would be predicted the order of S_2 intensity effectiveness is from bright to dim. The dim S_2 had no significant effect on RT to S_{1T} while the bright and medium S_2 produced a trend toward significant inhibitory effects at $S_1 - S_2$ intervals from 50 to 175 msec. ($p < .10$).

Although the relative intensity of S_{2L} between tone groups did not produce statistically significant differences in RT to S_{1T}, the relative intensity of S_{2L} within a given tone intensity did have significantly different effects. In other words, the differences between RTs to a loud, medium, or soft S_{1T} are not significant. But within each of these S_{1T} intensities the RTs are a function of the intensity of the S_{2L}. As is evidenced in Figures 4, 5, and 6 the bright S_2 is more effective than the medium S_2 and the medium more effective than the S_2 in producing inhibitory effects in RT to tone.

RT to Light Intensities

Light Dim Groups

The pronounced facilitating and inhibitory effects produced by tone upon RT to a dim light are evident in Figure 7. As appears from Figure 7, the intensity of S_{2T} made a difference in its effect on RT to S_{1L}. The intensity relation between S_{1T} and S_{2L} are not in the order one would

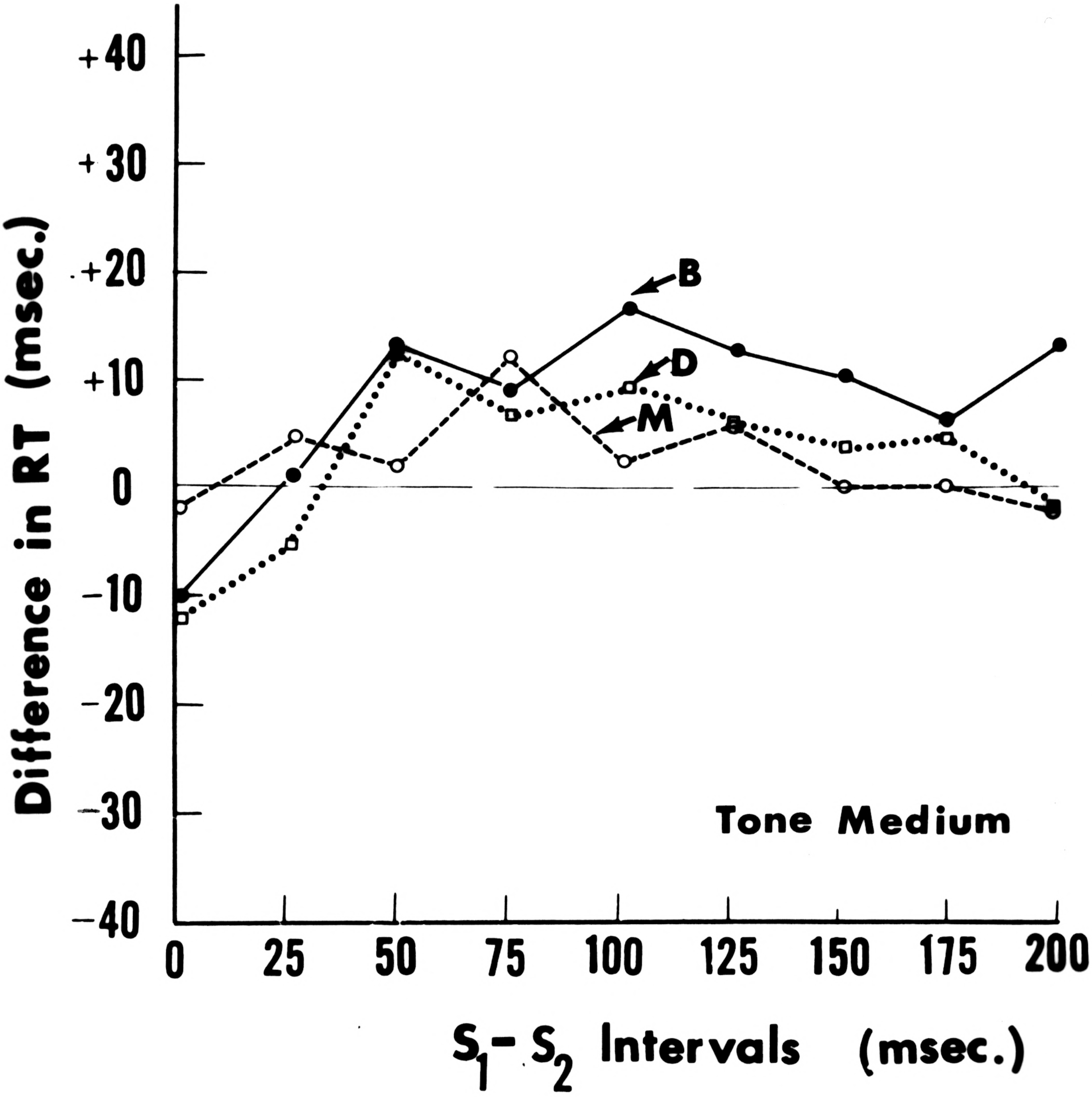

Fig. 5. Reaction time to a medium tone at three light intensities (S_2) as a function of the S_1 - S_2 interval where B = bright, M = medium, and D = dim light intensities.

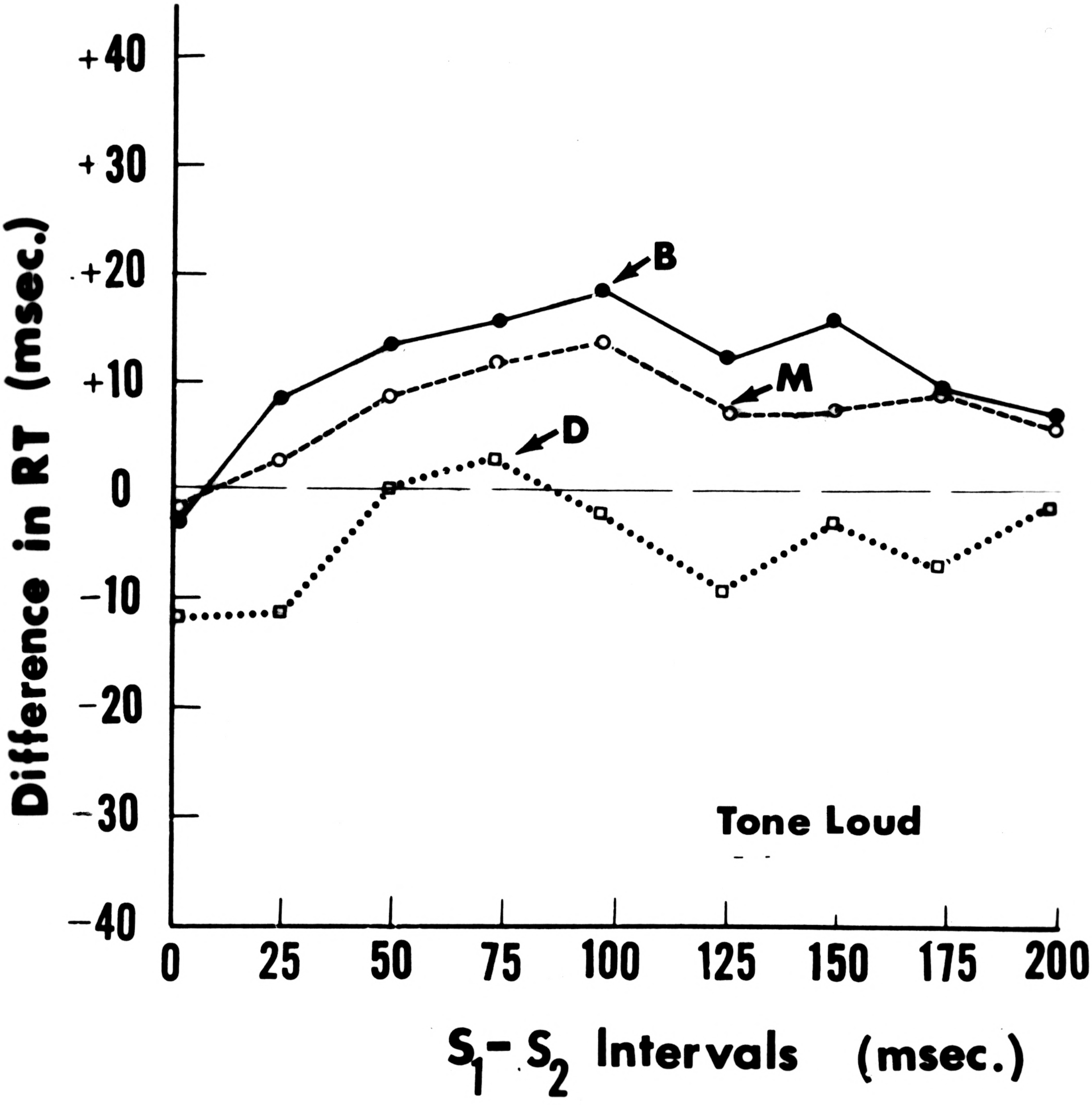

Fig. 6. Reaction time to a loud tone at three light intensities (S_2) as a function of the $S_1 - S_2$ interval where B = bright, M = medium, and D = dim light intensities.

predict. Although the loud S_{2T} has produced the greatest effects, the medium S_{2T} did not have as great an effect as the soft S_{2T}. This reversal of the medium S_{2T} and soft S_{2T} from the predicted order of effectiveness can be understood after examination of the variances of these groups. The standard deviation of the differences in RT from the control RT was 14.1 msec. for the soft S_{2T} group and 11.1 msec. for the medium S_{2T} group. It can be seen from Figure 7 that these S.D.s are, at most $S_1 - S_2$ intervals, larger than the mean difference in RT produced by S_2. For this reason the only RT interval differences from control RT that are significant for the medium S_{2T} group are the 0 and 25 msec. (p .01). The soft S_{2T} group had only one statistically significant $S_1 - S_2$ interval, the 0 msec. (p .01). This large variance exemplifies the individual differences in susceptibility to the influence of S_2 as an inhibitor of RT to S_1.

The loud S_{2T} group's RT was significantly affected by S_2. This is evidenced by the fact that the 0, 75, 100, 125, and 150 msec. $S_1 - S_2$ intervals produced significantly different RTs from the control RTs (p .05). The standard deviation of the differences in RT for this group was only 8 msec.

<u>Light Medium Groups</u>.

The light medium groups show the same trend found in the light dim groups over the $S_1 - S_2$ intervals. RT to the medium S_1 is facilitated in the simultaneous and early $S_1 - S_2$ intervals, inhibited in the intermediate intervals and returns to approximately the control RT at the later intervals. A comparison of Figures 7 and 8 shows that the general

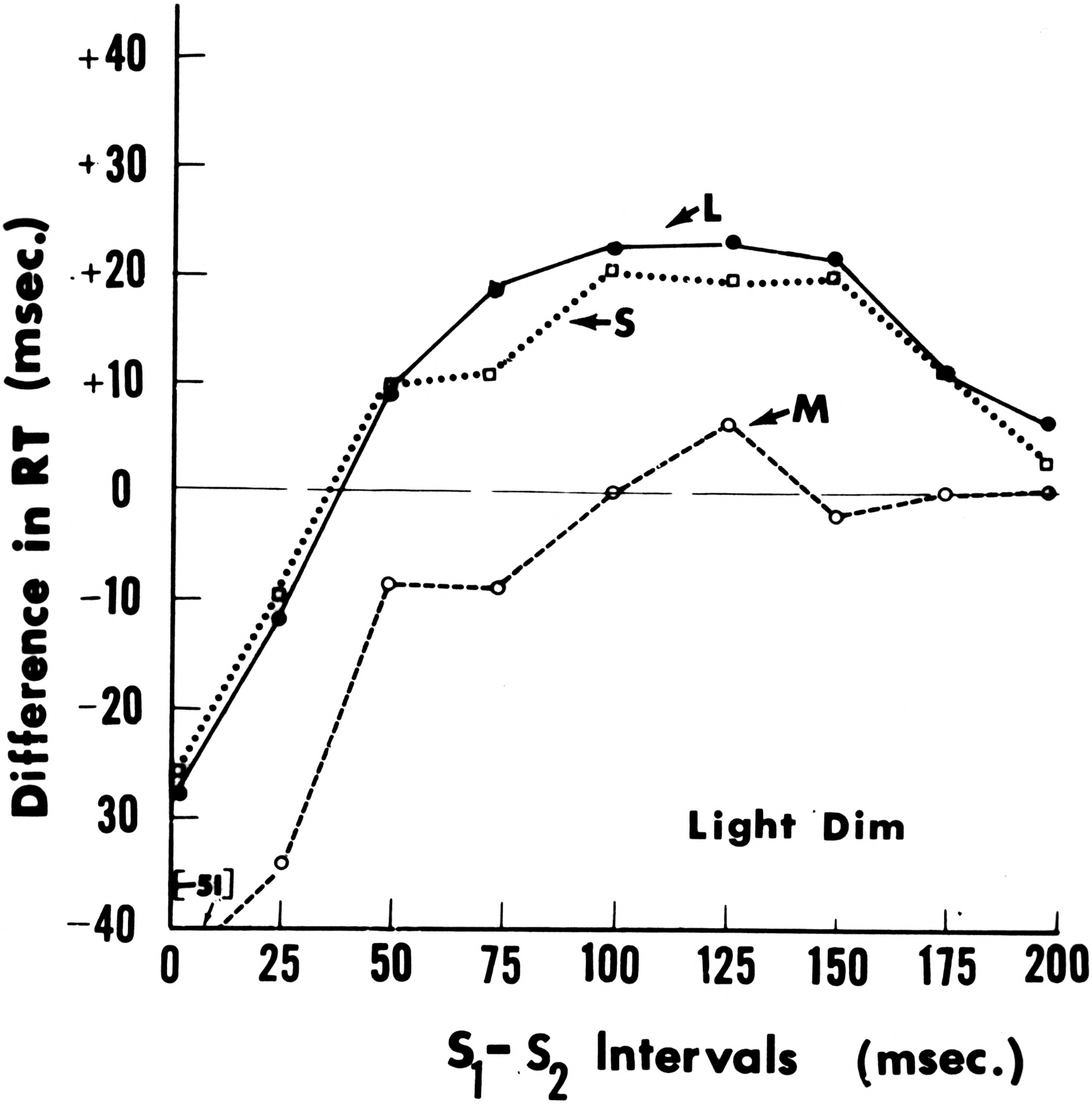

Fig. 7. Reaction time to a dim light at three tone intensities (S_2) as a function of the $S_1 - S_2$ interval where L = loud, M = medium, and S = soft tone intensities.

effect upon RT of S_{2T} is less for the medium S_{1L} condition than the dim S_{1L} condition. This is in the predicted direction since one would expect, as the relative intensities of S_{1L} and S_{2T} are decreased, that S_{2T} would have less effect upon RT to S_{1L}.

The predicted order of effectiveness of S_{2T} is also present in Figure 8. The loud S_{2T} had the greatest effect upon RT to S_{1L} yielding significantly different RTs from control RT at the 0, 75, 100, 125, 150 msec. intervals ($p < .05$). The medium S_{2T} was significantly effective at the 0, 75, and 100 msec. intervals ($p > .05$). The soft S_{2T} was only effective at the 0 msec. interval ($p > .05$).

<u>Light Bright Groups</u>

As seen in Figure 9 the RT to bright S_{1L} is also at first facilitated and later inhibited by S_{2T}. However, the effect of S_{2T} is less than for the dim or medium S_{1L} groups. This is in the predicted direction since the relative intensity is less than for the other S_{1L} groups. There are only two significant $S_1 - S_2$ RTs for each of the three bright S_{1L} groups. The loud S_{2T} RT was significantly different from control RT at the 0 and 25 msec. intervals ($p < .05$). The medium S_{2T} RTs were significantly affected at the 125 and 150 msec. $S_1 - S_2$ intervals ($p < .05$). The soft S_{2T} RTs were signifcantly faster than control RT at the 0 and 25 msec. intervals ($p < .05$).

Individual Differences

Individual differences should be mentioned since they appear both in initial RT and in the effects of S_2 upon RT. It was found by Helson

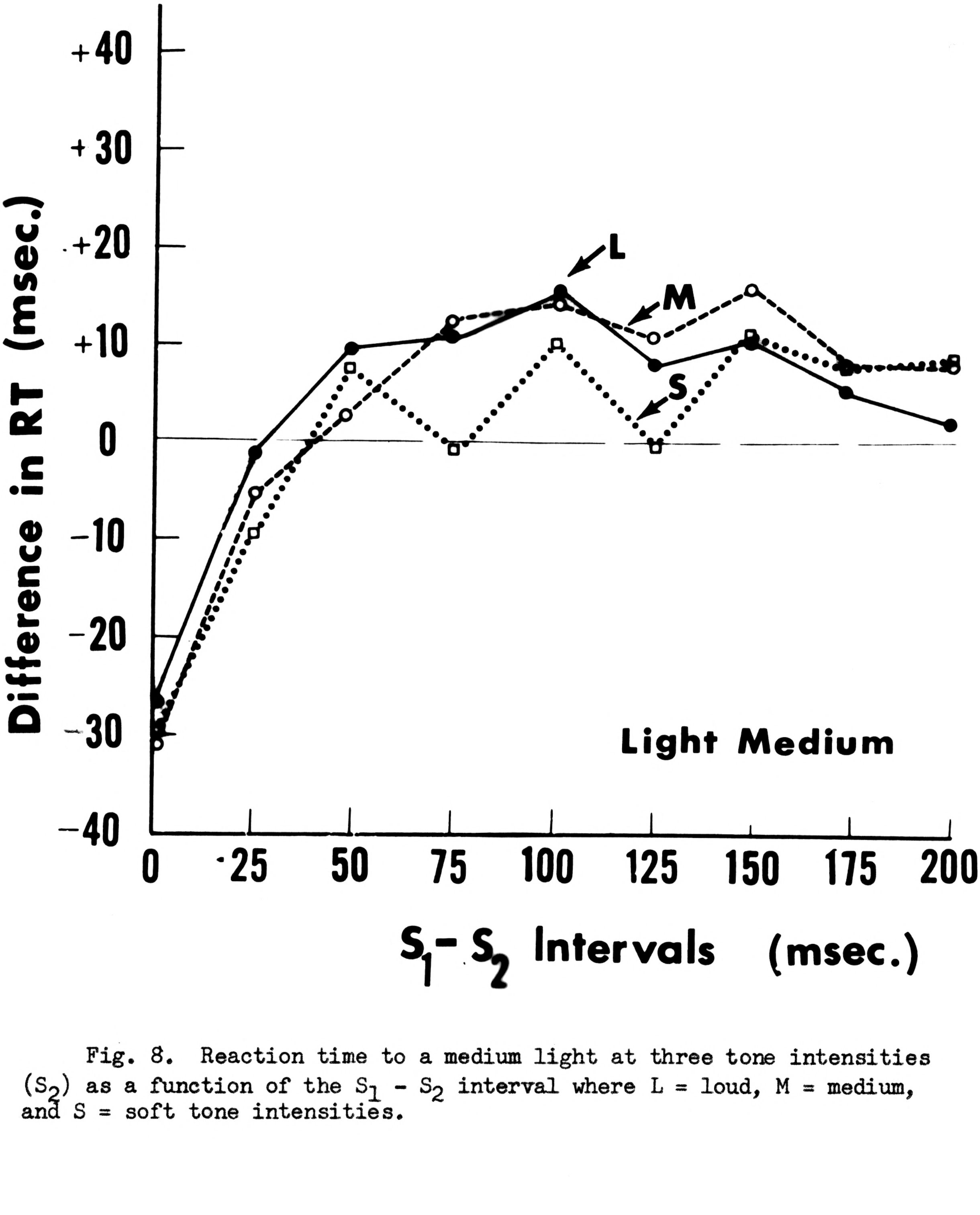

Fig. 8. Reaction time to a medium light at three tone intensities (S_2) as a function of the S_1 - S_2 interval where L = loud, M = medium, and S = soft tone intensities.

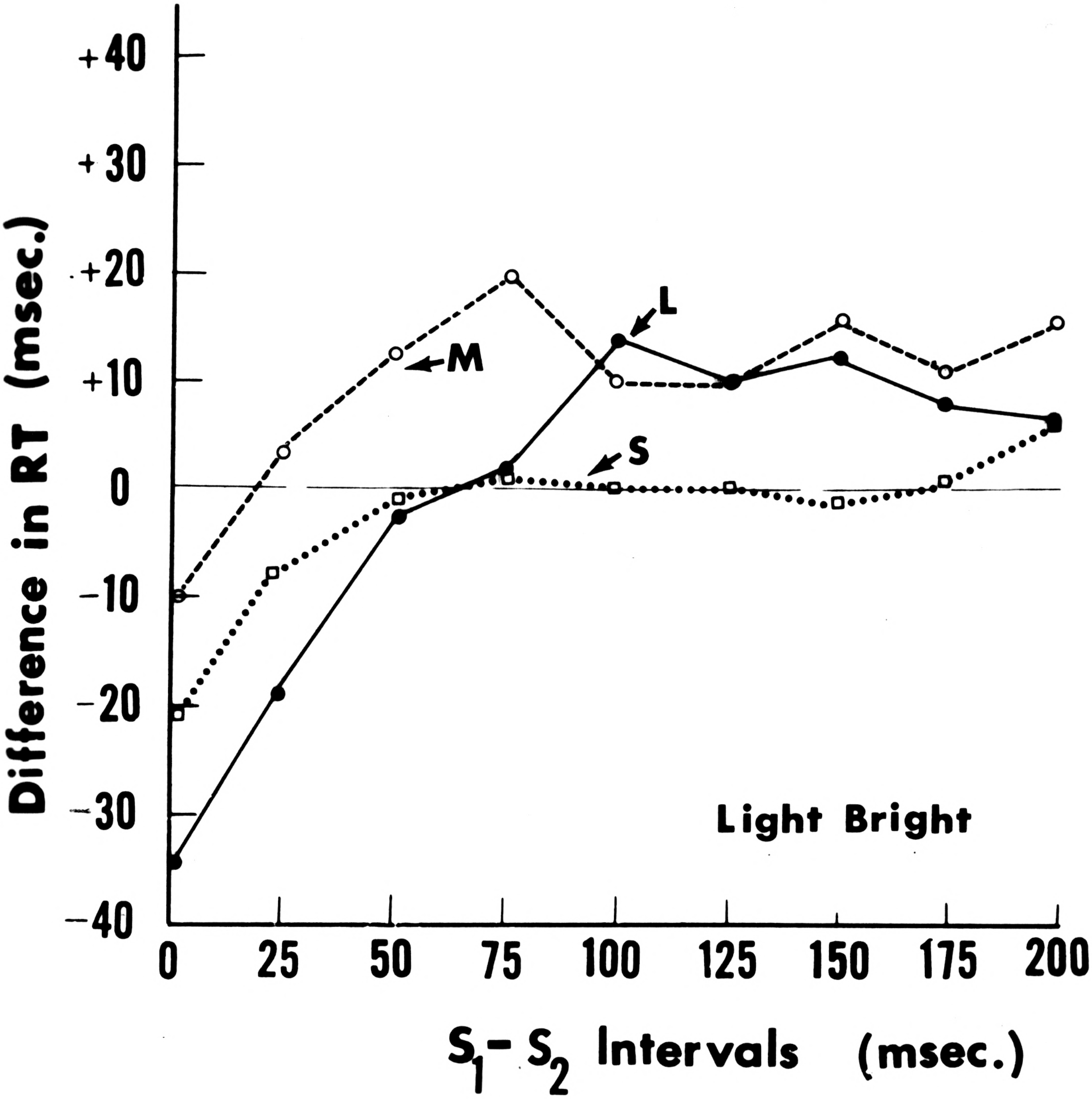

Fig. 9. Reaction time to a bright light at three tone intensities (S_2) as a function of the S_1 - S_2 interval where L = loud, M = medium, and S = soft tone intensities.

& Steger (in press) that four of the ten Ss of their experimental group showed no over-all significant effect of the S_2 on RT. Data from two Ss in the LdTs group and the differences in RT as a function of the $S_1 - S_2$ intervals, selected because their control RT was equal, are shown in Figure 10. Both Ss A and B show the same trend with facilitation and inhibition in RT as a function of S_2. However, A's RT is much more inhibited by the presentation of S_2 than B's RT. A is also less susceptible to the facilitating effect of S_2 than B. One suspects that these differences are due to differences in initial RT to S_1. One may hypothesize that A is initially faster than B and is inhibited by S_2 earlier. B is slower than A and hence his initial RT is facilitated by S_2 for a longer $S_1 - S_2$ period. This is clearly not the case since A's control RT is 208 msec. and B's control RT is 207 msec. These differences in susceptibility to the influence of S_2 may be a function of the S's set.

DISCUSSION

The findings of this study seem to establish for a heteromodal condition that a stimulus following a signal to react has an effect upon the initial reaction. This effect can be facilitating or inhibiting depending upon the intensity and temporal relations of S_2 to S_1. Why the tone groups did not significantly differ in their reaction to different intensities of tone is uncertain. It may have been due to the intensity levels of tone used or group differences that masked the differential effects of the tones.

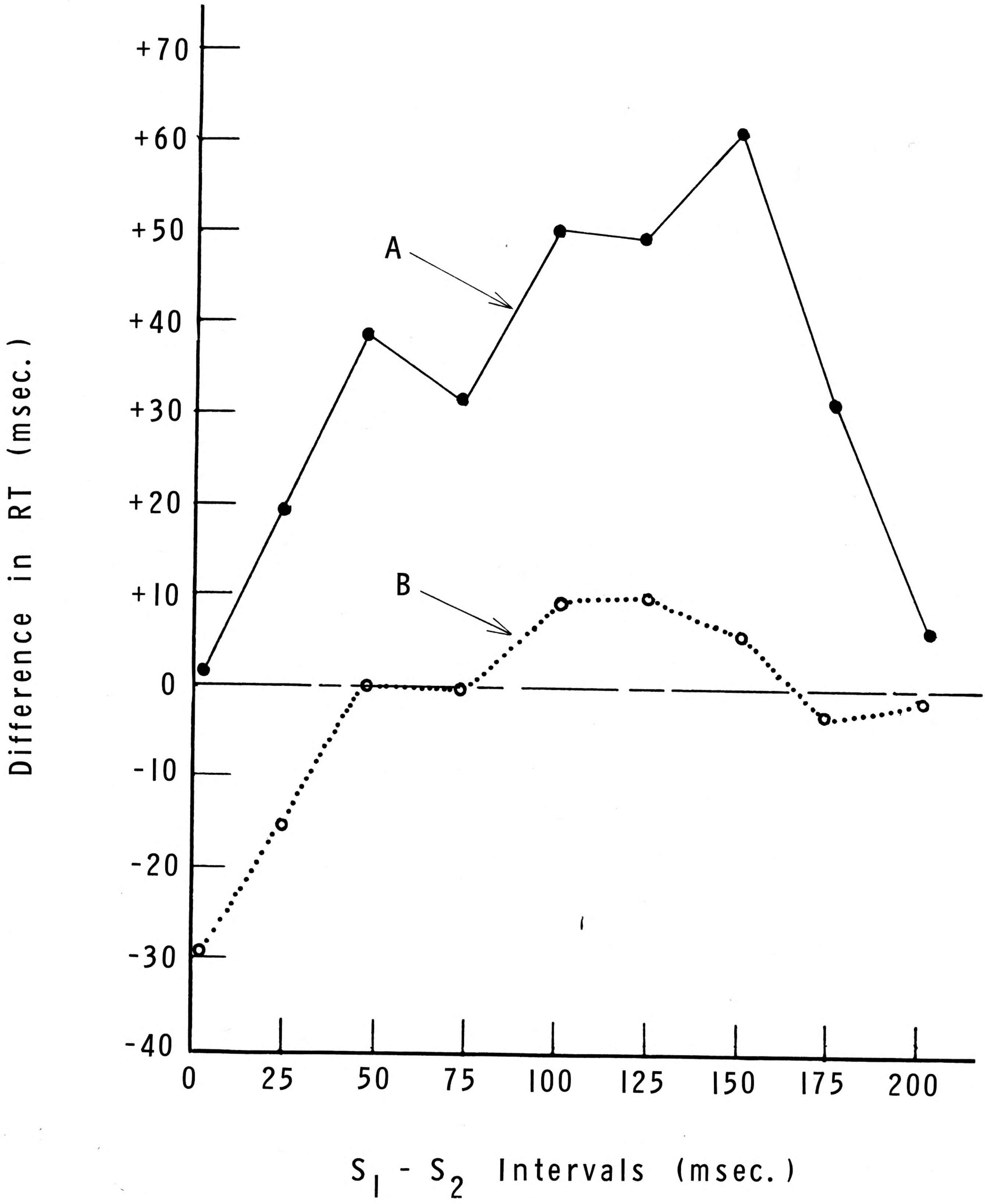

Fig. 10. Individual differences in reaction time at same intensity and $S_1 - S_2$ order relation over the $S_1 - S_2$ intervals (both Ss taken from LdTs group).

Facilitation and Inhibition

The facilitating effects of a second stimulus following the action stimulus can be understood in terms of an increase in stimulus intensity when both S_1 and S_2 are presented in the simultaneous onset condition. Todd (1912) found this same decrease in RT when sound and light were presented simultaneously. He concluded that the stimulus which has the shortest RT initially will cause the greater reduction in RT when added to another stimulus of longer initial RT. This same effect is apparent in the present study. The RT to light was greatly facilitated by the tone, but the faster initial RT to tone was very little, if any, facilitated by the addition of a light. Of the nine groups reacting to light, eight were significantly facilitated by tone, whereas only three of the nine groups reacting to tone were significantly facilitated by the simultaneous presentation of light. Two of the three groups reacting to tone that were facilitated by the presentation of light were reacting to a soft (20 dbs) tone so the intensity difference between S_1 and S_2 may be why the light was able to affect reaction to the tone.

The inhibitory effects of the second stimulus leave many questions to be answered and challenge some notions held regarding certain phenomena in human performance.

Relation to Psychological Refractory Phase

Telford, in 1931, found that the second of two consecutive responses was longer than the first when the time interval between two successive stimuli was reduced to 500 msec. This finding initiated a large amount of research (Craik, 1948; Davis, 1956, 1957; Vince, 1948; Welford, 1952, 1959). Two hypotheses as to the nature of this delay in the second reaction have been suggested. Davis (1957), Welford (1952, 1959), and Vince (1948) all suggested that the human is a one channel data processing system. They assumed that the appearance of a second signal to react cannot be processed while the organism is reacting to the first signal so this second signal is put aside, so to speak, until the completion of the response to the first. The organism can only process through one channel. They explained facilitation of a response by a second signal if it arrived close to the first by "Grouping," that is, both signals are grouped and reacted to as one. But the inhibition so clearly present in this study and the Helson & Steger study raises serious questions as to the validity of a psychological refractory period hypothesis based on a one channel process. The insistence that the second signal must wait until the processing of the first has ended, implies that the reaction to the first is not contaminated by the second signal. Yet, this is exactly what does happen under the conditions of this study wherein the second signal has no response meaning attached to it. Vince (1948) found that in 20 per cent of the trials his subjects failed to respond if the $S_1 - S_2$ interval was very short (50 msec.)! Not only does the arrival of S_2 slow the RT to S_1 as in this study but some conditions it may completely inhibit the response to the first.

The second hypothesis regarding the nature of the psychological refractory period has been put forth by Elithorn & Lawrence (1955), Hick (1948), and Poulton (1950). They proposed that expectancy is the process that slows the reaction to the second stimulus. Although the organism is assumed to be a multi-channel system they disregard the effect S_2 has upon S_1. They assumed the organism learns statistically defined time relations between S_1 and S_2 and that the subject is most alert when the inter-stimulus interval is the mean of the delay in the series. This pooling idea would be quite applicable in this study if we were concerned with a second response to a second stimulus, but since the S_2 was "irrelevent" in this study and the subject was only to make a simple movement in response to the first stimulus their expectancy hypothesis still leaves the question as to whether an organism can "put off" or ignore the second stimulus. This was found definitely untrue in this study.

Relation to Pre-Planned Movements

A proposal by Taylor & Birmingham (1948) closely allied with the hypothesis of psychological refractory period is that simple responses are pre-planned and run their course without modification. That this is not the case in this study is clearly evident. Even in such a simple movement as closing a telegraph key in a simple reaction time design the movement does allow modification. The question may be asked, "What about conditions when the S_2 is also to be responded to?". A recent study by Gottsdanker & Braley (1961) using a tracking task where the subject had to move a pointer from S_1 to S_2 as they appeared in succession, shows again that the second signal did inhibit the reaction to the first. They concluded that the RT to the first signal was not influenced but that the amplitude of the movement was. They did not compute RT at $S_1 - S_2$ intervals and noted only the total RT mean of the $S_1 - S_2$ conditions. These values are only slightly higher than the normal RT in this choice situation. The data in Table 6 taken from the Gottsdanker & Braley (1961) study show very clearly that the group RT was lengthened by the introduction of a second stimulus closely following the first to react. At 70 msec. and 100 msec. $S_1 - S_2$ intervals RT was definitely increased. It is unfortunate that a control RT is not available against which to compare all of the RTs at all $S_1 - S_2$ intervals.

Table 6

Data Approximated from Gottsdanker & Braley.
Mean RT of Subjects (msec.).

Subjects	$S_1 - S_2$ interval (msec.). 30	50	70	100	200
Jo	190	190	220	220	190
Ha	200	190	210	220	175
Br	220	210	200	240	210
Ca	220	240	300	230	250
Group mean	207.5	207.5	232.5	227.5	296.25

Taken from Gottsdanker, R., & Braley, L. S. Commitment time: a preliminary study. Tech. Note AF 49 (638), 1961. Santa Barbara, California.

Reflex Arc Hypothesis

Since the findings presented in this study are clearly opposed to the psychological refractory phase and pre-planned movement hypotheses how can we explain RT as a function of the $S_1 - S_2$ interval? This phenomenon does resemble external inhibition in Pavlovian conditioning and what Raab, Fehrer, & Hershenson (1961) have called "retroactive masking." But both of these explanatory concepts deal with disrupting signals or masking stimuli that come <u>before</u> the signal to react. A physiological explanation would be purely speculative and probably of little value since it would require an undue number of assumptions. A hypothesis less suggestive of specific neurological or physiological mechanisms may be stated as follows: Let us assume that the reaction to a stimulus is a total arc, an ongoing process such that a disturbance in any part of it disrupts the ongoing activity to be resumed or completed. On this basis S is set to react to a single stimulus and when the second stimulus appears, even though he has not been instructed to react to it or attend to it, he has to process it or assimilate it into the ongoing response and this breaks the ongoing response which consequently causes an increase in RT. Along with this hypothesis can be stated that both in the Helson & Steger (in press) study and in the present study the most effective range of $S_1 - S_2$ inhibition was approximately 50 to 150 msec. On either side of this range a decline is found in the inhibitory effect of S_2. This breaking of the ongoing circuit, so to speak, seems to be optimal at approximately the 100 msec. interval in the Helson & Steger study. If one assumes the average RT to light was 200 msec. and the receptor to central nervous center transmission time was 10 to 15 msec. then the second stimulus breaks in at approximately 115 msec. after S_1 if S_2 is being presented at 100 msec. From this let us assume that the central process takes approximately 100 msec. or longer in which case S_2 can inhibit S_1 from approximately 15 to 120 msec. after S_1 has been presented. This same model can be applied to the present findings for hetermomodal presentation of $S_1 - S_2$. The optimal inhibitory S_2 interval for tone was 133 msec., with an effective range of 75 to 150 msec. For the $S_{1L} - S_{2T}$ condition we would assume S_{2T}

could effect RT to S_{1L} from 20 to 140 msec. since tone is reacted to initially 20 msec. faster than light. For the S_{1T} - S_{2L} condition we could assume the S_{2L} could effect RT to S_{1T} from approximately 20 to 120 msec. However, this hypothesized model still does not explain the comparatively long intervals during which S_2 inhibits RT to S_1.

Individual Differences

Another question raised by the findings reported here are the large individual differences in the effects produced by S_2. One explanation could be that the differences were due to the S's set. The Ss who were not affected were "movement set" and not "stimulus set" and hence S_2 did not have as great an effect. This, however, does not explain why the same S's RT is affected differentially by S_2. And the question still remains "Why was one S's RT facilitated and another S's RT inhibited over the same intensity and S_1 - S_2 intervals?".

It seems some questions regarding the heteromodal nature of this facilitating and inhibiting effect of S_2 have been answered, but that more questions have been raised than have been answered.

SUMMARY

An investigation of the intermodal effects of a second stimulus following the primary stimulus to react was conducted. The following hypotheses were examined:

1. S_2 when presented over a limited time range will significantly increase RT to S_1.
2. The inhibiting effect of S_2 will depend on its intensity

relative to S_1.

3. A stimulus in one modality, at some delay interval, will be equivalent in inhibiting power to a stimulus in another modality.
4. Where there are differences in RT among sense modalities to a single stimulus, the inhibiting effect of S_2 will be greater for the sense modality stimulus that elicits a quicker initial RT than for the modality in which a stimulus elicits a slower initial RT.

The use of a simple reaction time experimental design allowed the presentation of an auditory and visual stimulus both as the primary stimulus to react and as the secondary stimulus which was presented at intervals of 0 to 200 msec. in steps of 25 msec. The intensity of both S_1 and S_2 were varied in a 3 x 3 factorial design employing independent groups for each combination of intensities.

Data were collected from 90 Ss, 5 in each intensity-combination group. The data were analyzed in terms of: (a) intensity and order of tone and light combinations, (b) $S_1 - S_2$ time interval effects and (c) practice effects.

The results clearly indicate that:

1. The order of presentation of $S_{1T} - S_{2L}$ vs. $S_{1L} - S_{2T}$ significantly affected RT. The tone stimulus yielded a faster control RT and tone as S_2 exhibited more pronounced facilitating and inhibiting effects not only in degree but also over a longer temperal period than did the light.
2. Changes in the intensity of the light stimulus both as S_1

and S_2 resulted in differential effects on RT. Generally, the dim light was least effective, the medium next, and the bright light the most effective. The tone intensities did not yield differential effects as S_1 but did to some extent as S_2.

3. RT as a function of $S_1 - S_2$ intervals showed a parabolic trend, with the S_2 facilitating at simultaneous or extremely short intervals after S_1, increasing to inhibitory maximal height at approximately 110 msec. interstimulus interval and then decreasing in effect as the $S_1 - S_2$ interval length increased. The 90 msec. $S_1 - S_2$ interval appears to be the point at which the tone and light stimuli are equal in inhibitory effect.
4. The practice effects appear to be of little significance. Generally, an initial decrease of 10 to 20 msec. in RT is achieved with practice. After this initial decrease there is little consistent effect produced. It is concluded that 120 trials are not enough to evaluate practice effects.
5. Individual differences are clearly in evidence and two Ss from the same group are used to demonstrate the large individual differences encountered with this phenomenon.

The findings raise serious questions about the validity of the psychological refractory phase and pre-planned movement hypotheses. The relation of the findings reported in this study to these and other explanatory concepts are evaluated and none seem completely satisfactory to explain all the facts.

A tentative hypothesis based on a total ongoing reflex arc is offered but it also lacks the power to account for the inhibitory effectiveness of the second stimulus long after the onset of the first stimulus.

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APPENDICES

APPENDIX A

Treatment of the Data

The $S_1 - S_2$ intervals from 0 to 200 msec. in steps of 25 msec. also included a 15 msec. and a 185 msec. interval. These were included to augment the very short and very long intervals. These intervals were not found to elicit significantly different RTs from the 25 and 200 msec. intervals respectively ($A \geq 4.18$, df 4, $p = .20$). They were disregarded in the final analysis of interval effects in order to facilitate analysis in terms of equally spaced $S_1 - S_2$ intervals. They were, however, included in the analysis of the practice data where the $S_1 - S_2$ interval RTs were combined and practice effects examined.

Wherever a test of the difference between correlated means was carried out a simplification of Student's t suggested by Joseph Sandler (1955) was used. This involves computation of a statistic $A = \frac{\Sigma d^2}{(\Sigma d)^2}$. Values of A are significant at a given level of p and df if equal to or less than tabled values of A given by Sandler (1955).

An analysis of variance was computed for the control, 0, and 100 msec. $S_1 - S_2$ intervals. The analysis was based on the actual RT values and the 0 and 100 msec. intervals were chosen because they represent facilitating and inhibiting points on the $S_1 - S_2$ continuum. The analysis of the control condition was made to examine RT differences to the intensity of S_1 alone. Fisher's Least Significant Differences (LSD) test was conducted where the F test was found to be significant.

The RT means shown in all the figures were computed in terms of differences from the control means. These RT means were computed by comparing RT at each interval with the control RT for each subject and summing the differences for each subject to give the group mean difference at each interval. The differences also serve to standardize the data so one may compare different groups or individuals with one another.

The practice data were computed for each group in terms of actual reaction times. The RT means across trials were broken down into facilitating, inhibiting and control conditions. The rationale for the selection of the breaking points for the conditions of facilitation and inhibition was based on the plots of the mean RTs as a function of $S_1 - S_2$ intervals. For example, the TsLb group practice data were computed as follows: First the plot of RT across $S_1 - S_2$ intervals was examined to see where the facilitating and inhibiting effects separate. It can be seen from Figure 6 that the 0 msec. interval is facilitating and the 25 msec. interval inhibiting. The second step was to sum for the 0 msec. interval, the 25 to 200 msec. intervals, and the control interval at 12, 24, 36, 48, 60, 72, 84, 96, 108, and 120 trials to yield means at these trial points for the facilitating, inhibiting and control conditions.

APPENDIX B

Practice Data

The practice data are not clearcut and are very limited since the total number of trials was 120. Generally, it can be seen in Plates 2 through 7 that a drop of approximately 10 to 20 msec. occurred in the control conditions. The facilitating effect at some intensities of $S_1 - S_2$ lessens with practice. This would be expected since the control RT is becoming faster and approaching the facilitating RT in some cases. The inhibitory effect on RT across trials in some groups remains stable, in some groups decreases in effect and in other groups increases. There seems to be little relation between the $S_1 - S_2$ intensity effects on RT and practice effects. The only clearcut relation is found in the absolute value of RT, with RT being faster for the tone than the light. Practice appears to affect both RT to tone and RT to light in the same irregular manner regardless of which RT is faster.

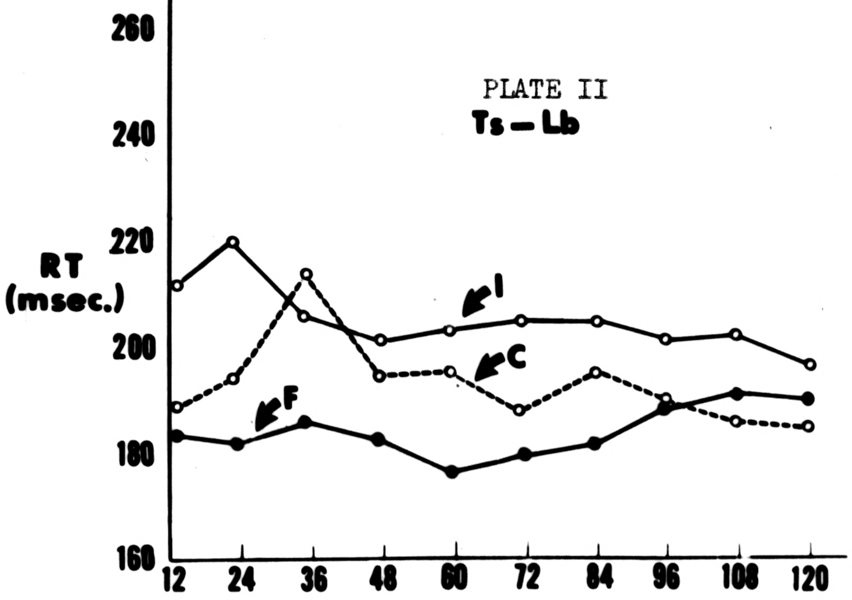
Generally, practice in the limited sense of 120 trials is slight in its effect and of little consequence to RT as a function of the $S_1 - S_2$ relation.

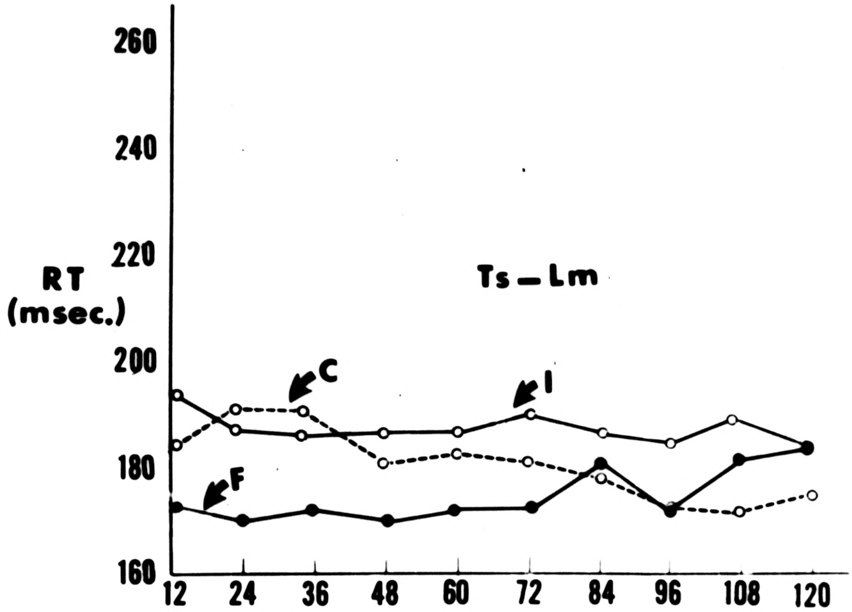
EXPLANATION OF PLATE II

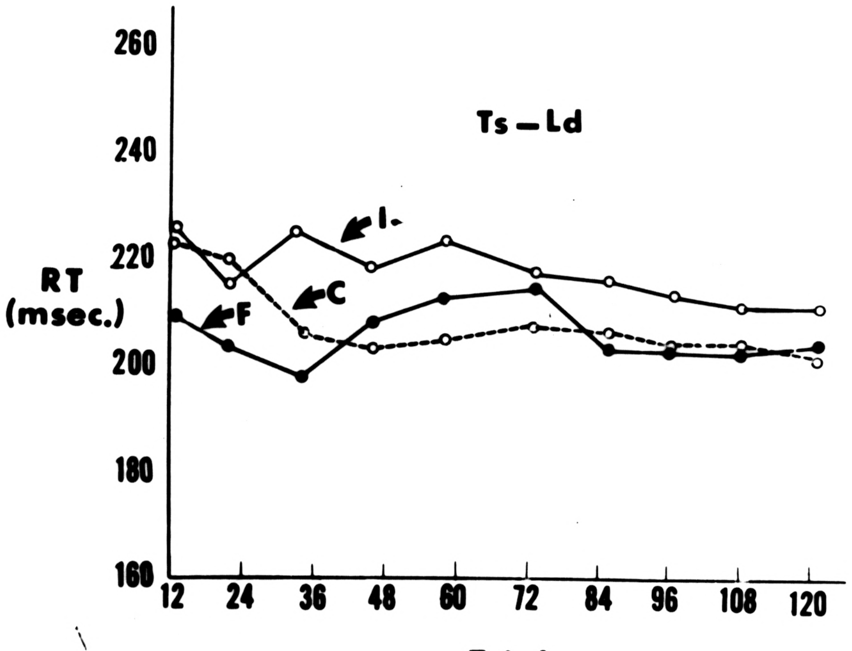
The reaction time to a soft tone under three intensities of light as a function of practice.

l = inhibition
f = facilitation
c = control

PLATE II


Ts — Lb
RT (msec.)
260
240
220
200
180
160
12 24 36 48 60 72 84 96 108 120
I
C
F


Ts — Lm
RT (msec.)
260
240
220
200
180
160
12 24 36 48 60 72 84 96 108 120
C
I
F

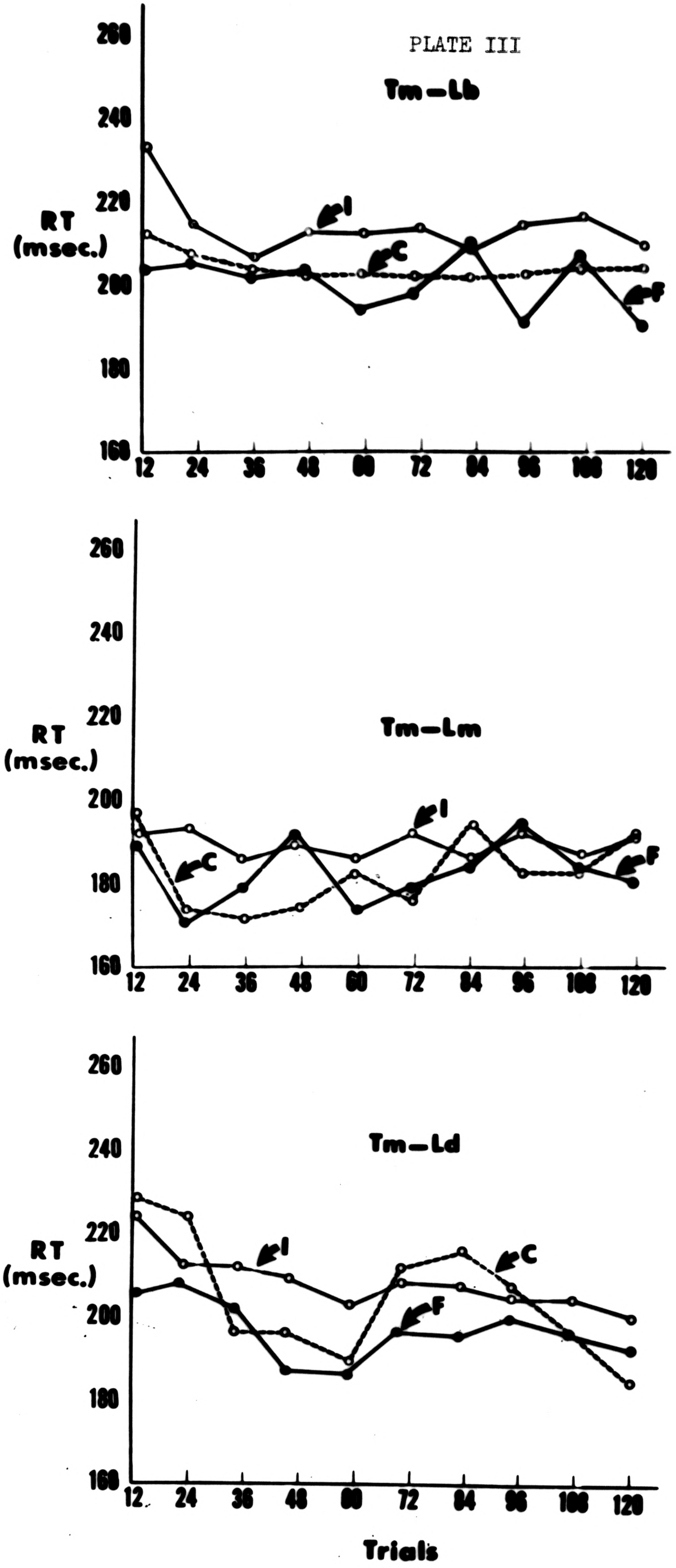

Ts — Ld
RT (msec.)
260
240
220
200
180
160
12 24 36 48 60 72 84 96 108 120
I
C
F
Trials

EXPLANATION OF PLATE III

The reaction time to a medium tone under three intensities of light as a function of practice.

l = inhibition
f = facilitation
c = control

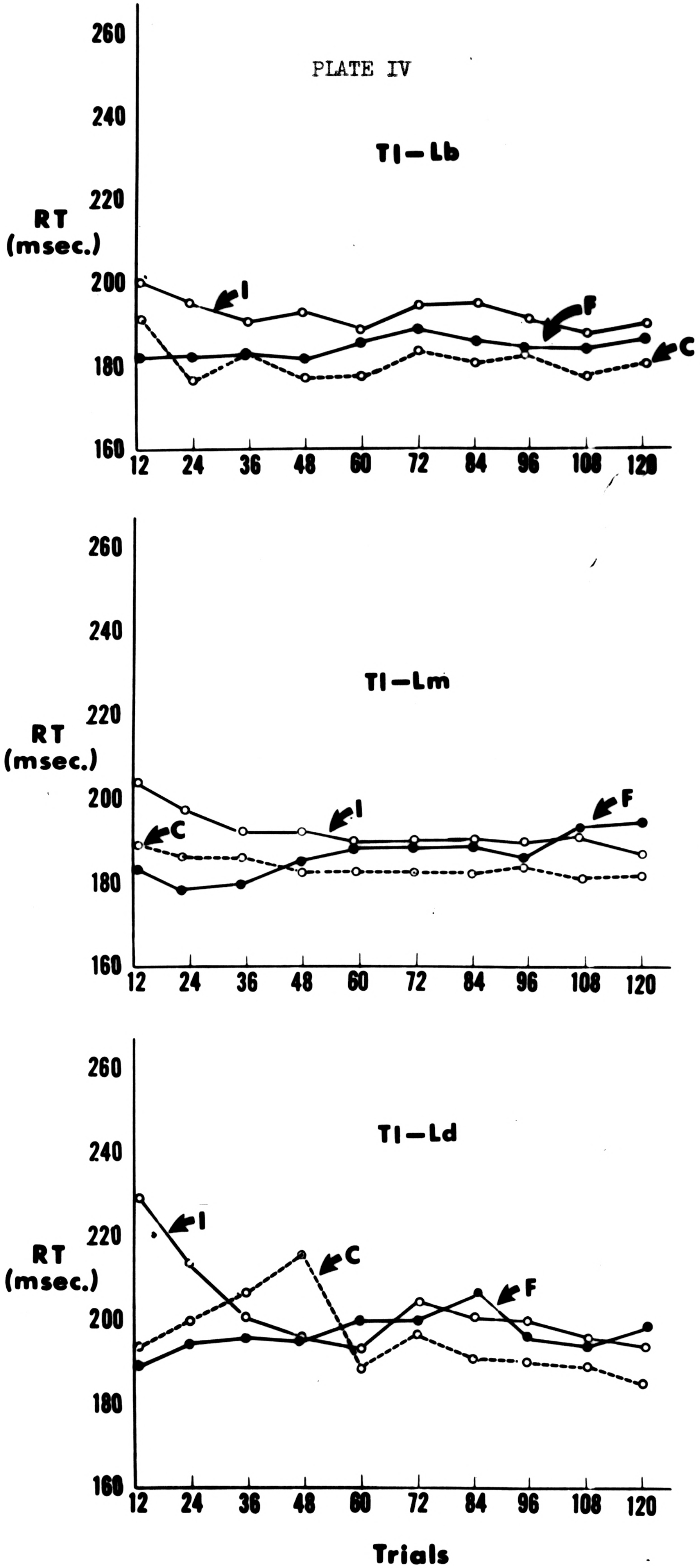
PLATE III


Tm—Lb
RT (msec.)
260
240
220
200
180
160
12 24 36 48 60 72 84 96 108 120
I
C
F
Tm—Lm
RT (msec.)
260
240
220
200
180
160
12 24 36 48 60 72 84 96 108 120
I
C
F
Tm—Ld
RT (msec.)
260
240
220
200
180
160
12 24 36 48 60 72 84 96 108 120
I
C
F
Trials

EXPLANATION OF PLATE IV

The reaction time to a loud tone under three intensities of light as a function of practice.

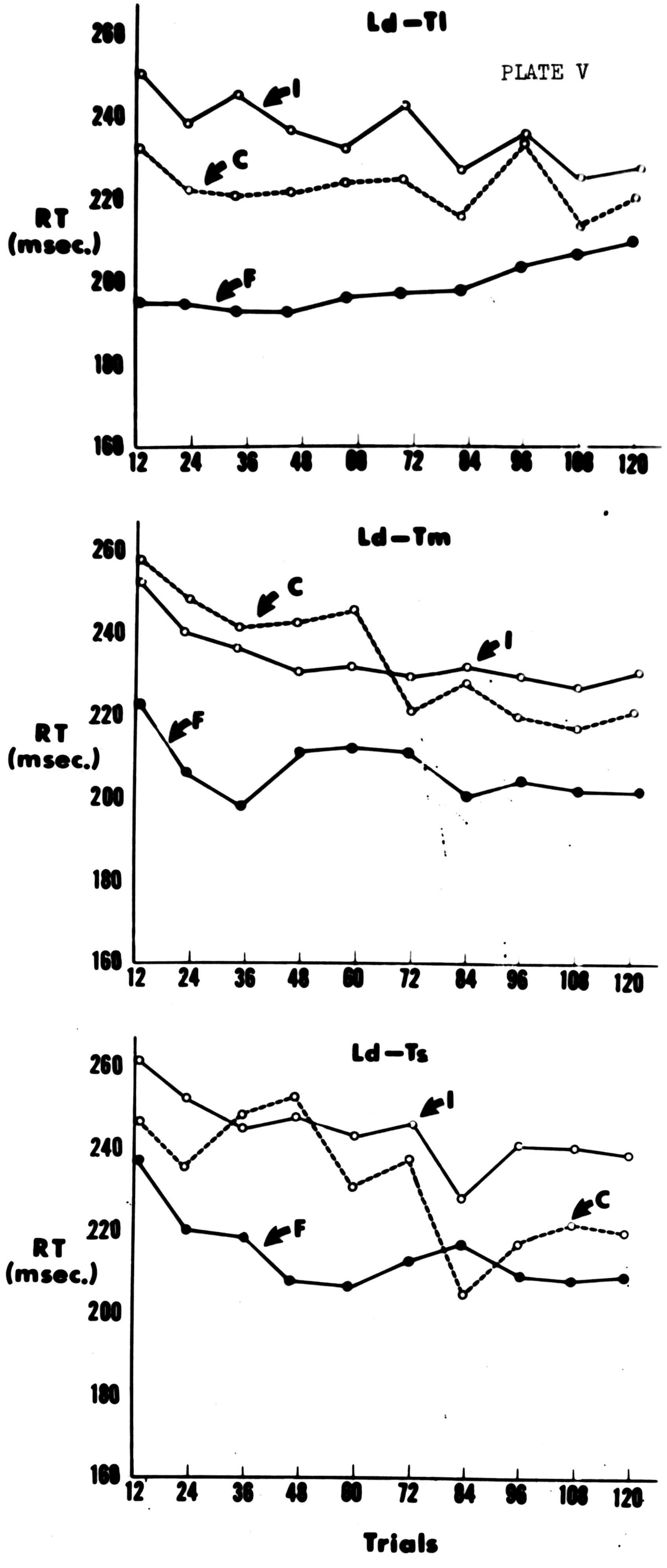
l = inhibition
f = facilitation
c = control


TI—Lb
RT (msec.)
260
240
220
200
180
160
12
24
36
48
60
72
84
96
108
120
I
F
C
TI—Lm
RT (msec.)
I
F
C
TI—Ld
RT (msec.)
I
C
F
Trials

EXPLANATION OF PLATE V

The reaction time to a dim light under three intensities of tone as a function of practice.

l = inhibition
f = facilitation
c = control

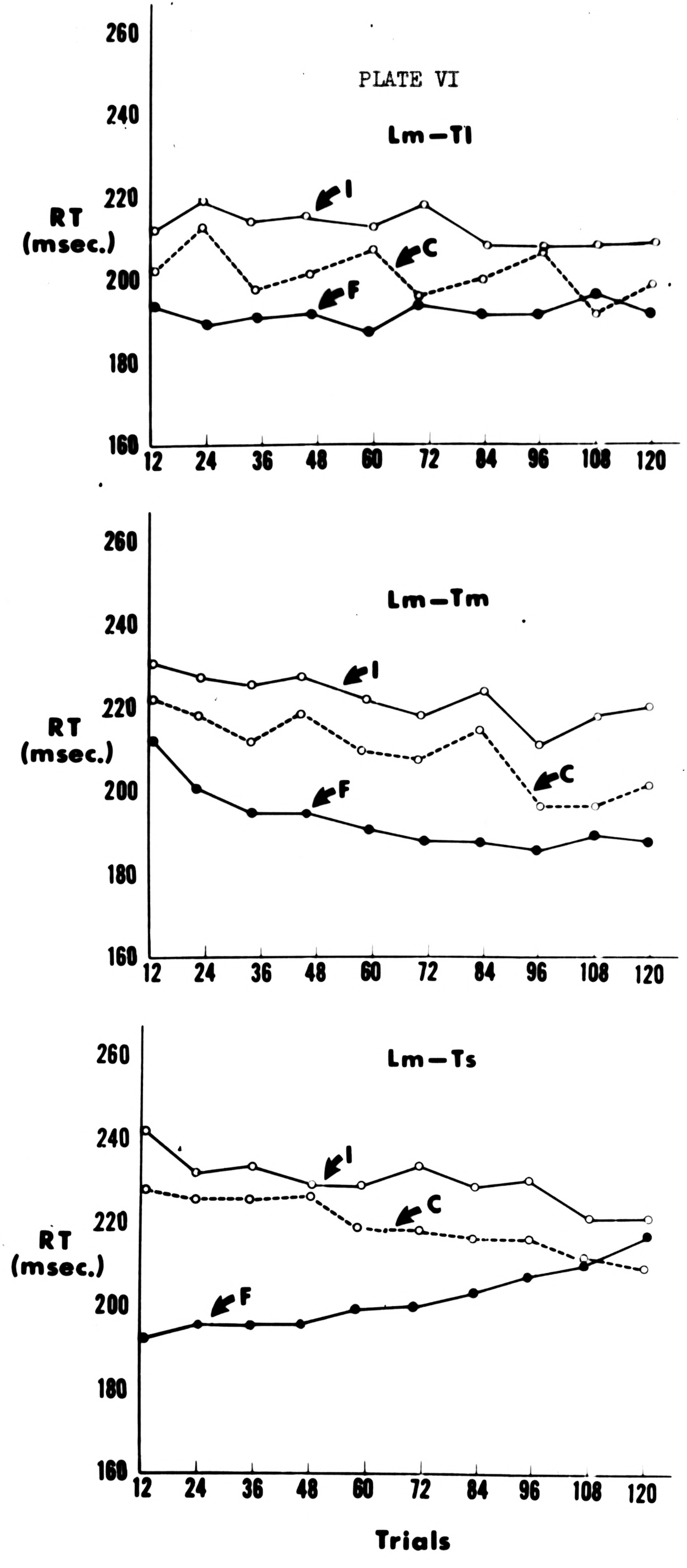

Ld—Tl
Ld—Tm
Ld—Ts
RT (msec.)
I
C
F
260
240
220
200
180
160
12 24 36 48 60 72 84 96 108 120
Trials

EXPLANATION OF PLATE VI

The reaction time to a medium light under three intensities of tone as a function of practice.

l = inhibition
f = facilitation
c = control

PLATE VI

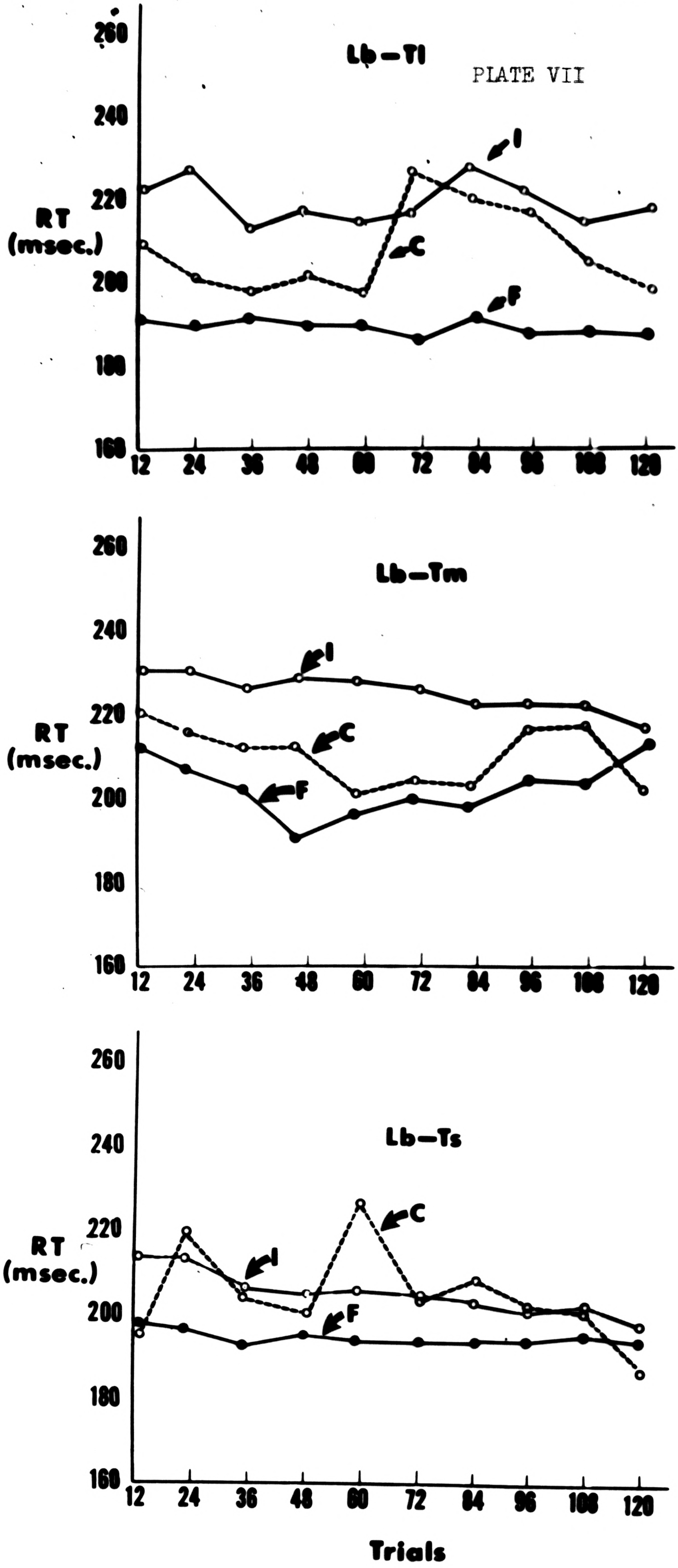

Lm—Tl
RT (msec.)
260
240
220
200
180
160
I
C
F
12 24 36 48 60 72 84 96 108 120
Lm—Tm
RT (msec.)
260
240
220
200
180
160
I
C
F
12 24 36 48 60 72 84 96 108 120
Lm—Ts
RT (msec.)
260
240
220
200
180
160
I
C
F
12 24 36 48 60 72 84 96 108 120
Trials

EXPLANATION OF PLATE VII

The reaction time to a bright light under three intensities of tone as a function of practice.

l = inhibition
f = facilitation
c = control

PLATE VII


Lb—Tl
Lb—Tm
Lb—Ts
RT (msec.)
260
240
220
200
180
160
12
24
36
48
60
72
84
96
108
120
I
C
F
Trials

APPENDIX C

Regression analysis of the curves in Figure 5—the total effects of tone and light on RT^1 as a function of $S_1 - S_2$ intervals.

Table 7

RT^1 to Tone Under All Three Intensities of Light—Regression Analysis

Curve components	df	F	p
Linear	7	1.21	$>.10$
Quadratic	6	22.9	.001

Coefficient of multiple correlation $R^2 = .90$
$R = .82$

Multiple regression equation:

$$\hat{Y} = -5.87 + .28X - .0012X^2,$$
where X is the $S_1 - S_2$ interval

Table 8

RT^1 to Light Under All Three Intensities of Tone—Regression Analysis

Curve components	df	F	p
Linear	7	7.5	.05
Quadratic	6	51.3	.001

Coefficient of Multiple Correlation $R^2 = .97$
$R = .95$

Multiple regression equation:

$$\hat{Y} = -27.77 + .6379X - .0024X^2$$
where X is the $S_1 - S_2$ interval

Table 9

RT[1] to Tone (Y) and Predicted $\hat{Y}$

$S_1 - S_2$ interval X	Y	$\hat{Y}$
0	- 9	- 5.49
25	1.5	.47
50	7	5.22
75	7	8.47
100	10	10.22
125	6.5	10.47
150	5	9.22
175	4.5	6.47
200	3	2.22

Table 10

RT[1] to Light (Y) and Predicted $\hat{Y}$

$S_1 - S_2$ interval X	Y	$\hat{Y}$
0	-32	-27.13
25	-11	-13.32
50	2	- 1.88
75	6	6.57
100	12	12.02
125	10	14.47
150	12	13.91
175	6.5	10.36
200	4	3.23

[1]All times given in msec.; the $\hat{Y}$ and Y values are in terms of the differences from control reaction time. The regression equations are also in terms of differences from control RT.

A STUDY OF FACILITATION AND INHIBITION IN REACTION TO HETEROMODAL STIMULATION

by

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An investigation of the intermodal effects of a second stimulus <u>following</u> the primary stimulus to react was conducted. The following hypotheses were examined:

1. S_2 when presented over a limited time range will significantly increase RT to S_1.
2. The inhibiting effect of S_2 will depend on its intensity relative to S_1.
3. A stimulus in one modality, at some delay interval, will be equivalent in inhibiting power to a stimulus in another modality.
4. Where there are differences in RT among sense modalities to a single stimulus, the inhibiting effect of S_2 will be greater for the sense modality stimulus that elicits a quicker initial RT than for the modality in which a stimulus elicits a slower initial RT.

The use of a simple reaction time experimental design allowed the presentation of an auditory and visual stimulus both as the primary stimulus to react and as the secondary stimulus which was presented at intervals of 0 to 200 msec. in steps of 25 msec. The intensity of both S_1 and S_2 were varied in a 3 x 3 factorial design employing independent groups for each combination of intensities.

Data were collected from 90 Ss, 5 in each intensity-combination group. The data were analyzed in terms of: (a) intensity and order of tone and light combinations, (b) S_1 - S_2 time interval effects and (c) practice effects.

The results clearly indicate that:

1. The order of presentation of $S_{1T} - S_{2L}$ vs. $S_{1L} - S_{2T}$ significantly affected RT. The tone stimulus yielded a faster control RT and tone as S_2 exhibited more pronounced facilitating and inhibiting effects not only in degree but also over a longer temperal period than did the light.
2. Changes in the intensity of the light stimulus both as S_1 and S_2 resulted in differential effects on RT. Generally, the dim light was least effective, the medium next, and the bright light the most effective. The tone intensities did not yield differential effects as S_1 but did to some extent as S_2.
3. RT as a function of $S_1 - S_2$ intervals showed a parabolic trend, with the S_2 facilitating at simultaneous or extremely short intervals after S_1, increasing to inhibitory maximal height at approximately 110 msec. interstimulus interval and then decreasing in effect as the $S_1 - S_2$ interval length increased. The 90 msec. $S_1 - S_2$ interval appears to be the point at which the tone and light stimuli are equal in inhibitory effect.
4. The practice effects appear to be of little significance. Generally, an initial decrease of 10 to 20 msec. in RT is achieved with practice. After this initial decrease there is little consistent effect produced. It is concluded that 120 trials are not enough to evaluate practice effects.

5. Individual differences are clearly in evidence and two *Ss* from the same group are used to demonstrate the large individual differences encountered with this phenomenon.

The findings raise serious questions about the validity of the psychological refractory phase and pre-planned movement hypotheses. The relation of the findings reported in this study to these and other explanatory concepts are evaluated and none seem completely satisfactory to explain all the facts.

A tentative hypothesis based on a total ongoing reflex arc is offered but it also lacks the power to account for the inhibitory effectiveness of the second stimulus long after the onset of the first stimulus.