ENERGY INTEGRATION AND PREPARATORY SET EFFECTS IN INTERSENSORY FACILITATION

by

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Reaction time (RT) research has a long and varied history. One of the more recent developments in RT research was the discovery of facilitory effects that occur under some conditions of multimodal stimulation. Hershenson (1962) found that intersensory facilitation (ISF) occurred if the reaction stimulus was accompanied by a stimulus in another modality. The facilitory effect was that of lowering the reaction time to the reaction stimulus.

Since Hershenson's study, a number of investigators have examined ISF (e.g. Morrell, 1968; Bernstein, Clark, and Edelstein, 1969; Bernstein, 1970; and Bernstein, Rose and Ashe, 1970). The thrust of most of this research has been to attempt to ascertain more exactly the parameters of ISF. Based on this research, Bernstein has proposed two different ways in which the ISF effect might be explained. The experiment presented in this paper was an attempt to compare these two theories under conditions in which the theories would make differential predictions.

Survey of Literature

Simple RT to a visual stimulus has been shown by Raab, Fehrer, and Hershenson (1961) and Kohfeld (1968) to be inversely related to the intensity of the stimulus. Furthermore, once a critical duration is reached, RT to a visual stimulus is independent of further increases in stimulus duration (Raab and Hershenson, 1962). Raab and Hershenson found that the critical duration of a stimulus is dependent upon the intensity of the stimulus. Within the range of intensities utilized in their study (30 to 300 fL) the RT to any given intensity remained unchanged over stimulus durations of 10 to 500 msec.

Hershenson (1962) found that RT to a visual or auditory stimulus is facilitated when the eliciting signal is accompanied by a signal in another mode. The stimuli utilized by Hershenson consisted of a visual event (Sv) and an auditory event (Sa). Any given trial could be made up of either Sv alone, Sa alone, or the two in combination (Sav). The presentation of stimuli could be simultaneous or asynchronous. The temporal separation of the two stimuli (from onset of the first to onset of the second) ranged from 5 to 85 msec in 10 msec steps, with Sa never preceding Sv. The subject's task was to respond to the first stimulus. It was predicted that maximal facilitation would occur when the stimulus asynchrony was approximately equal to the difference in RT to Sv and the RT to Sa. The assumption here was that maximal facilitation would occur when the signals simultaneously arrived at some undefined internal processor. Because Sa is encoded more rapidly than Sv, Sv must occur before Sa if they are to arrive at an internal processor at the same time. If the RT for the two modalities are assumed to be the same once encoding has occurred, then the difference in the encoding rate should be reflected by the overall RT difference. The results of Hershenson's 1962 study indicate: (1) maximal facilitation occurred at a point where Sv preceded Sa by a time approximately equal to the difference in RT to the stimuli when presented singly; (2) ISF did occur, since RT to the combined stimuli was faster than the RT to either stimulus alone; and (3) the magnitude of facilitation varied directly with the intensity changes in Sv, whereas changes in the intensity of Sa had no effect on the magnitude of facilitation. The magnitude of facilitation was a difference measure defined by subtracting the RT to the combined stimuli from the RT to a single stimulus, e.g. RTv - RTva. Thus the magnitude of facilitation is not a measure of RT, but rather is based on RT.

The preceding study utilized a procedure similar to that in a Donder's A reaction task. In a Donder's A task, there is only a single stimulus and a single response to be made upon the occurrence of that stimulus. Lenore Morrell (1968a) was interested in determining if ISF would occur in a choice reaction time (CRT) experiment as well. She utilized a modified Donder's C reaction task. This procedure has two stimuli either of which may be presented. The subject knows the reaction stimulus and is required to withhold responding to the nonreaction stimulus. Morrell's procedure was as follows: the subject was exposed to either a 10 msec light flash, to an auditory "click" (a short duration 120 db sound), or to a combination of the two. The subject was instructed to respond only when Sv was presented. Presentation of the Sa alone served as catch trials. When both stimuli were presented on a given trial, their onset was always asynchronous. The asynchrony varied from 20 msec to 120 msec in 20 msec steps. The Sa never preceded Sv in this design. The results showed that as the interstimulus interval increased, RT increased linearly. The minimum RT occurred when the interstimulus interval was smallest. These findings indicate that ISF occurs in a Donder's C task as well as in a Donder's A task.

In a follow up of her 1968a study, Morrell (1968b) utilized a comparable procedure, except she was interested in the effects of the order of the two stimuli. Therefore, she had the subjects respond to the Sv in one condition, and to the Sa in the other condition. In both conditions the subject was instructed to make no response to the secondary stimulus. For example, the subject was to respond to Sva, but to make no response to Sa. A different time course was predicted for the two conditions due to the differences in neural latency between auditory and visual events. As predicted, there was facilitation both conditions, but the temporal range of facilitation was shortened for the click-flash condition when compared to the flash-click condition. In both conditions, the reaction stimulus was always presented first.

Morrell's work was followed by a pair of studies by Bernstein, Clark, and Edelstein (1969a, 1969b). In one study Bernstein, et. al. (1969a) used a procedure that was very similar to Morrell's 1968a study. There were however, some modifications, namely: utilization of more interstimulus intervals (0 to 90 msec in 10 msec steps), and use of a warning signal that preceded Sv. The order of events was: warning signal; foreperiod delay (time between warning signal and stimulus event); the visual event; and finally the auditory event at the proper interstimulus interval. The results of this study indicated that maximal facilitation occurred when the interstimulus interval was approximately equal to the difference in simple RTv and RTa. This indicated that when the two events arrived in functional synchrony, the maximal amount of facilitation was obtained.

In Bernstein, Clark, and Edelstein's 1969b study, the RT task of the subject was a Donder's B type. In a Donder's B task, the subject must make differential responses to different stimuli. Each stimulus is associated with a different response. In Bernstein, *et. al.* (1969b) the subject had to respond by pressing a left or right switch in response to a left or right stimulus light. All responses were homolateral. Each trial required a response from the subject, but Sa was presented on only some of the trials. The Sa occurred equally often with the right and left stimulus light. The Sa never preceded the Sv, and 10 interstimulus intervals were used (0-90 msec in 10 msec steps). A warning signal and foreperiod delay of 2 seconds preceded Sv. The results again indicated that RT to the Sva was less than the RT to the Sv alone, and that the magnitude of facilitation was inversely related to the interstimulus interval. On the basis of this study, Bernstein, *et. al.* postulated that the facilitation could either be due to an alerting function of Sa or to a summation of the Sa and the Sv. Bernstein reasoned that if it was an energy integration of the Sa and the Sv, the effect would be comparable to increasing the intensity of a reaction stimulus.

The preceding study suggested that the ISF effect could be accounted for by a system where the intensity of the stimulus inputs were summed, even though they were in different modalities. Thus the energy of the two inputs would be integrated. Bernstein, Rose, and Ashe (1970a) proposed that if this were the case, two predictions could be made concerning facilitation. First, if the intensity of the Sa was increased, the facilitation effect should increase. Also, if the intensity of the Sv was increased while the intensity of the Sa was held constant, there should be a decrease in the magnitude of facilitation. The rationale for this prediction is based on the finding by Woodworth and Shlossberg (1954) which showed that equal intensity increments have progressively less effect on Rt as intensity increases. Applying this finding to ISF, Bernstein, et. al. predicted that as the intensity of the Sv was increased, the facilitative effect of the Sa would be relatively less although RTva would still decrease. Secondly, Raab and Fehrer (1962) have shown, once a critical duration of a stimulus is exceeded, the RT is insensitive to further increases in stimulus duration. Therefore, one would expect that the interstimulus interval would be important to bisensory RT. If the temporal separation of the two stimuli was too great, one would have no influence on the other. As the stimuli moved closer to one another in time, the effect should increase to some maximal value. It is also likely that the function would be U-shaped with facilitation decreasing as the onset times reverse order and again separate in time.

In an attempt to examine these predictions experimentally, Bernstein, Rose, and Ashe ran two studies. The first of these (1970a) utilized three levels of intensity of the Sv, three intensities of the Sa, and four different interstimulus intervals. Any given trial could consist of the Sv alone, the Sa alone, or the two in combination. In the first study, the Sa was never allowed to precede the Sv. Experiment II was identical to Experiment I except the Sv was preceded by the Sa on half the trials. As predicted RT to the Sva was inversely related to both the intensity of the Sv and the intensity of the Sa. The magnitude of facilitation was directly related to the intensity of the Sa and inversely related to the intensity of the Sv. Furthermore, the magnitude of facilitation was symmetric with respect to the asynchrony of the Sa and the Sv.

Finally, Bernstein, Rose, and Ashe (1970b) performed the following experiment. Reaction time to a stimulus that could be either unisensory or bisensory (i.e. Sa, Sv, or Sva) was measured. The Sa alone event was always a catch trial. A foreperiod delay of either 0.5 or 5.5 seconds was utilized between the warning signal and the stimulus onset. In condition 1 both the stimulus presented (unisensory or bisensory) and the length of the foreperiod delay were randomly determined. In condition 2, the stimulus order was random but the subject knew in advance the foreperiod delay. Results indicated that the greater foreperiod delay was associated with the greatest facilitation, and the greatest facilitation occurred in conditions where the foreperiod delay was a constant 5.5 seconds. These results seem to indicate that the preceding auditory stimulus acts as an alerting signal, preparing the subject for response.

Bernstein (1970) has proposed two types of explanations for the ISF effect. The first is a Preparatory Set theory, and the second is an Energy Integration theory. The preparatory set theory is explained in the following fashion: "A preparatory state refers to a generalized disposition or readiness to respond as ordinarily induced by a warning signal." (Bernstein, 1970, p. 29). As changes in the foreperiod delay occur, differences in RT occur. The auditory event in ISF serves as a supplimentary warning signal. Thus it would be the most effective when the subject is least prepared to respond, because it would serve to alert him to the upcoming signal. Since the Sa does not have as great a neural latency as the Sv, it can serve as a warning signal even when the Sv precedes the Sa. In addition, the theory assumes that response preparation procedes in parallel with specific stimulus and response selection.

Bernstein explains the energy integration theory as follows: "RT to unisensory stimulation is an inverse function of stimulus intensity, limited by an irreducible minimum RT" (Woodworth and Shlossberg, 1954). Bernstein assumes in his energy integration theory that this intensity effect holds across modalities. When inputs to two different modes arrive in near synchrony, the combined effect is comparable to increasing stimulus intensity in a single mode. RT to the combined stimuli is less than RT to either stimulus alone. Secondly, the critical event in RT is the "leading wave" of energy. As the two stimulus events become more asynchronous, the combination has less effect on RT. Thirdly, the magnitude of facilitation is determined primarily by three factors: (a) the intensity of the Sv, (b) the intensity of the Sa, and (c) the temporal relationship of the Sa and the Sv. As stated earlier, increases in the intensity of the Sa should bring corresponding increases in the magnitude of facilitation, whereas an increase in the intensity of the Sv while holding the Sa constant would lead to less facilitation. This assumes, of course, that the Sv is the reaction stimulus.

In the research previously cited, support for both the preparatory set theory and energy integration theory has been presented. These studies typically varied the time from stimulus onset to stimulus onset, and also varied the intensity of both the Sa and the Sv. However, no systematic examination of stimulus overlap was made. If two experimental conditions were established, one where the auditory and visual stimuli overlapped in time and one where they did not overlap (i.e. were sequential) and if the temporal sequence and spacing was the same for both conditions, the two theories would predict different experimental results. For example, assume that two conditions had the same difference in the time of the onsets of the Sa and the Sv. Suppose also that in one condition the Sa and the Sv were sequential but did not overlap and in another condition the Sa and the Sv were sequential and also overlapped in time. If the time between the onset of the Sa and the Sv was the same in both conditions, the two theories would predict different results. The preparatory set theory would predict no difference in RT to the two conditions as both would have identical preparatory warning times. The energy integration theory would predict that the condition with stimulus overlap would have a shorter RT than the condition without stimulus overlap. This prediction would be based on the reasoning that the first condition would have energy integration of the two stimuli as they overlap in time. The opportunity for energy integration would be minimized in the second condition because the stimuli are sequential and do not overlap in time. Thus the purpose of the present study was to examine these predictions experimentally.

METHOD

Subjects:

The Ss were two male and two female students. Each S was paid for participation in the experiment.

Stimuli:

Two stimuli, one auditory and one visual, were utilized in this experiment. The auditory stimulus consisted of a 1000 Hz tone of 100 db SPL. The auditory stimulus (Sa) was presented through a pair of headphones. The duration of Sa varied with the experimental condition. The photometric brightness of the visual stimulus (Sv) was 500 fL. The duration of Sv was 120 msec for all experimental conditions. The visual source was a GE glow bulb, number A1A.

Conditions:

Figure 1 illustrates the temporal relationships between the Sa and the Sv under the three experimental conditions.

Overlapping Stimuli: In this condition both the Sa and the Sv had durations of 120 msec. The Sa always preceded the Sv. The interval from the onset of the Sa to the onset of the Sv was either 40 or 80 msec. Since the duration of the Sv was 120 msec, the overlap of the Sa and the Sv was either 33% or 67% of the duration of the Sv.

Nonoverlapping Successive Stimuli: In this condition, the Sa always preceded the Sv and always terminated at the onset of the Sv. The Sa originated either 40 or 80 msec prior to the onset of the Sv. The two stimuli were sequential, and the lead time of the Sa in this condition was the same as

Figure Caption

Figure 1. OS: Overlapping Stimuli Condition
NS: Nonoverlapping Sequential Stimuli Condition
SO: Simultaneous Onset Condition

This figure illustrates the temporal relationship of the auditory and visual stimuli in the various conditions and levels of those conditions. Each condition has two levels, 40 and 80 msec. The dashed lines in the Simultaneous Onset condition indicate that the onsets are subjectively simultaneous. The figures representing the other two conditions show the objective relationship of the two stimuli. The scale on the abscissa indicates time from the onset of the first stimulus.

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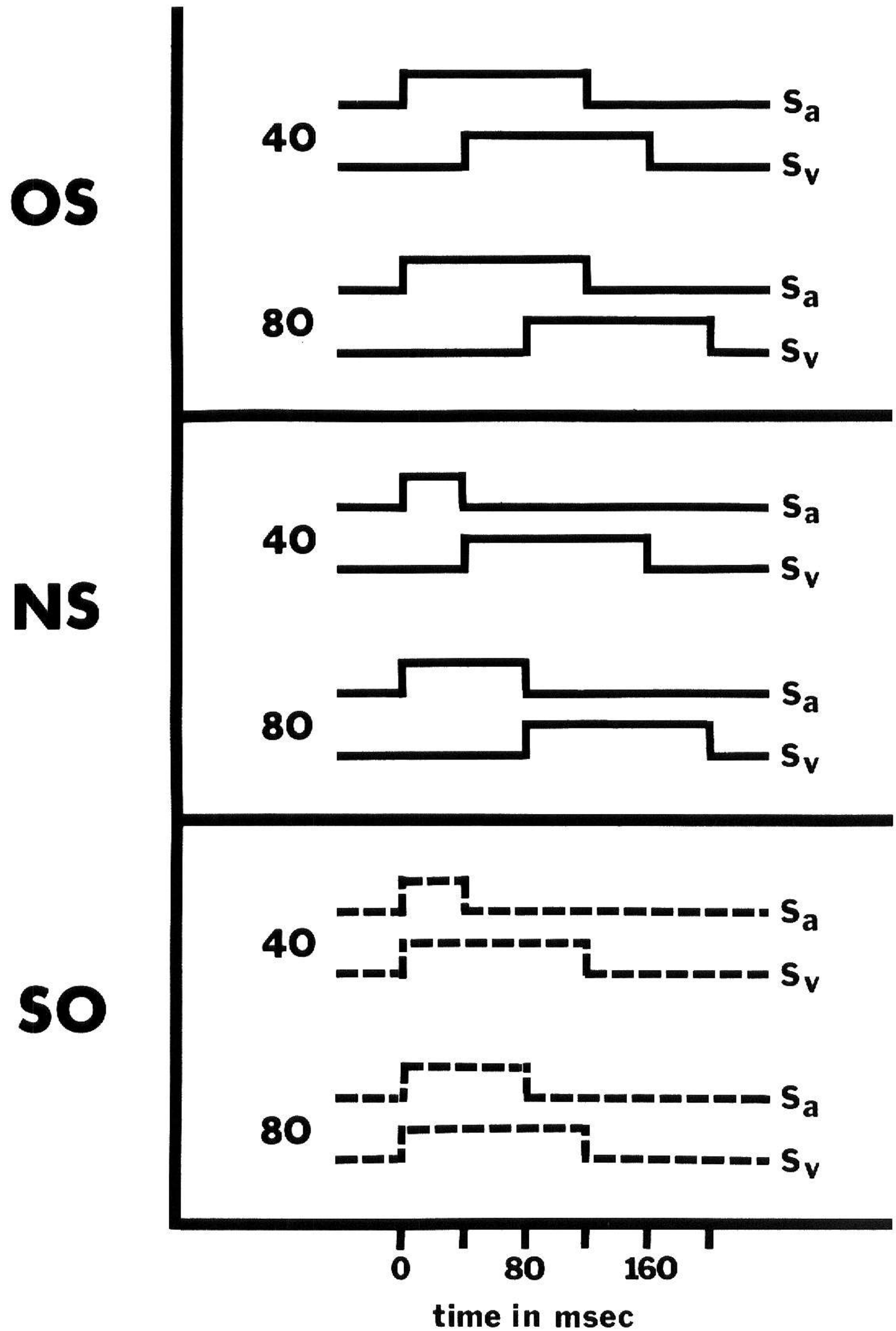
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the lead time of the Sa in the Overlapping Stimuli condition.

Simultaneous Onset: In the Simultaneous onset condition, the Sa and the Sv were presented so the onset of the two stimuli were subjectively simultaneous. There is a difference in neural latency for visual and auditory stimuli (Morrell, 1968b; Bernstein, Clark, and Edelstein, 1969a), therefore objectively simultaneous stimuli would be subjectively asynchronous. To achieve subjectively simultaneous onset, the auditory stimulus must have its onset at some time after the onset of the Sv, because the Sa is processed more quickly. The amount of auditory delay necessary was determined by the following procedure. The subject was seated in front of a light source (the glow bulb) and wore a pair of headphones. The auditory and visual stimuli were presented, and with each presentation the subject signaled if the stimuli were simultaneous. The subject was instructed to say "Yes" is the two stimuli were simultaneous in onset, and to say "No" if the stimuli were asynchronous with respect to onset. Both stimuli were terminated at the same time in either case. The interval between stimulus onsets varied in 5 msec steps from -40 msec (the Sa preceding the Sv) to +160 msec (the Sv preceding the Sa). A double staircase method (Underwood, 1966) was used to determine the points at which S perceived that the stimuli were synchronous. There were two different thresholds determined: one for the Sa preceding the Sv, and one for the Sv preceding the Sa. The point of subjective simultaneity for

for each subject was the mean of the two threshold values obtained by the double staircases for that subject. A point of subjectively simultaneous onset was selected for each subject. The double staircases were continued until the experimenter was satisfied that they were relatively stable. Each staircase was carried on at least 15 trials after the initial crossing of the two staircases.

The stimulus duration in the Simultaneous Onset condition was 120 msec for the Sv and either 40 or 80 msec for the Sa. The duration of periods in which both stimuli were present was the same as in the corresponding levels of the Overlapping Stimuli condition.

Procedure:

Each S served in six sessions. The first session was used to establish the point of subjective simultaneity of the onset of the Sa and the Sv (as previously described). The other five sessions were experimental sessions. Each experimental session consisted of 300 RT trials, plus 25 warm up trials. The only exception to this was the first experimental session, which was preceded by 50 warm up trials.

The S was seated in front of a desk. On the desk, directly in front of the S was a telegraph key. The key was centrally located with respect to the subject, so it could be operated with either hand. The subject was instructed to operate the key with the preferred hand. A flat black plywood square was vertically mounted on the desk in front of the S.

The plane of the square was perpendicular to the S's line of sight. Projecting through the square, ten inches above the desk top, was the GE glow bulb. The subject wore a pair of headphones that were used to present the Sa and also helped to attenuate extraneous sound. For all conditions S was instructed to respond to the visual stimulus only, and his response was to press the telegraph key as quickly as possible whenever the light came on. The S's response time was measured to the nearest msec. Timing started at the onset of the visual stimulus and ended when the S pressed the telegraph key.

The instructions to the subject were as follows:

> This experiment is a study of reaction time. I am interested in measuring your reaction time to a light. You will notice that on some of the trials the light will come on by itself, but sometimes a sound will come on with the light. On still other occasions, the sound will come on alone. You are to respond to the light by pressing the telegraph key as quickly as possible when the light comes on. If the light does not come on, do not press the key. If you do, that is an error. Your task is to react to the light as quickly as possible, while making as few errors as possible.
>
> At some time immediately prior to a trial I will say "ready". That is your signal that a trial is beginning. At the conclusion of each trial, I will take time to record the reaction time and we will go on to the next trial. Do you have any questions?

These instructions were not read to S verbatim, but were presented informally. The E insured that the subject understood the task before proceding with the experiment.

A typical trial consisted of the following sequence of events: (1) the E said "ready", (2) approximately 1/2 second following the ready signal the E pressed a button that initiated the appropriate stimulus configuration, (3) S responded and (4) the E recorded S's response (either the time was recorded or a mark indicating that no response had been made). At the conclusion of the recording of the response a new trial was initiated. The intertrial interval typically ranged from 5 to 8 seconds.

Each experimental session was preceded by 25 warm up trials, except for the first session which was preceded by 50 warm up trials. Each experimental session included 300 trials, with three minute rest periods after each 100 trials. The experimental sessions were run on successive days.[1] Each S served in all experimental conditions. The order of presentation of the various stimulus configurations was randomly determined. The only restriction was that the following stimulus frequencies must occur in each session: Sv alone, 20% of trials; Sa alone, 20% of trials; 10% each for the other six experimental conditions (i.e. the six Sav combinations shown in Figure 1). The Sa alone trials served as catch trials, while the Sv alone trials served to provide the measure of unisensory RT.

Results and Discussion

The primary findings of this experiment are the differences

1. Subject #2 was ill for four days following the second experimental session, thus did not serve on consecutive days. Her abscence however, had no discernible effect on results for successive experimental sessions.

in RT to the four different stimulus conditions. Analysis of Variance of these data is presented in Table I. This analysis showed that the main effect for Conditions was statistically significant ($F [3,348] = 428$).

Pairwise comparisons of the four stimulus conditions were made using Duncan's New Multiple Range tests. These are shown in Table II. With the exception of the Nonoverlapping Successive Stimuli and Overlapping Stimuli comparison, this table shows that all pairs compared differed significantly ($p < .01$).

	Nonoverlapping Successive Stimuli	Overlapping Stimuli	Simultaneous Onset	Visual Alone
RT ($\bar{x}$)	239.77	243.41	277.61	297.01
239.77		3.64	37.83**	57.23**
243.41			34.20**	53.60**
277.61				19.40**

Range: Alpha = .05 $R_2 = 3.66$ $R_3 = 3.86$ $R_4 = 3.99$

* $p < .05$
** $p < .01$

Table II: Pairwise Comparisons of the Four Stimulus Conditions using Duncan's New Multiple Range Tests.

The mean RT to the Visual Alone condition was 297.01 msec. Each of the three experimental conditions showed facilitation when compared to the Visual Alone condition. The magnitude of facilitation for each of the experimental conditions is shown

Source	Sum of Squares	df	Mean Square	F	p<
Total	15,927,953.83	4,799			
Between	2,519,269.81	119	21,170.34		
Subjects (Sub)	2,280,583.09	3	760,194.36	369.45	.01
Error B	238,686.72	116	2,057.64		
Within	13,408,684.02				
Conditions (Cn)	2,696,732.61	3	898,910.87	428.47	.01
Sub x Cn	605,139.32	9	67,237.70	32.05	.01
error	730,089.39	348	2,097.96		
Duration (Dr)	23.66	1	23.66	0.01	NS
Sub x Dr	25,016.46	3	8,338.82	4.25	.05
error	227,853.35	116	1,964.25		
Days (Dy)	40,519.03	4	10,129.16	4.73	.01
Sub x Dy	486,217.39	12	40,518.12	18.93	.01
error	993,066.73	464	2,140.23		
Cn x Dr	14,516.73	3	4,838.91	2.49	NS
Sub x Cn x Dr	40,864.34	9	4,540.48	2.34	.05
error	675,801.36	348	1,941.96		
Cn x Dy	69,739.98	12	5,811.66	3.08	.01
Sub x Cn x Dy	122,333.46	36	3,398.15	1.80	.01
error	2,627,707.61	1,392	1,887.72		
Dr x Dy	11,055.08	4	2,736.77	1.54	NS
Sub x Dr x Dy	76,643.16	12	6,386.93	3.56	.01
error	832,233.41	464	1,793.61		
Cn x Dr x Dy	58,347.02	12	4,862.25	2.30	.05
Sub x Cn x Dr x Dy	129,966.41	36	3,610.18	1.71	.01
error	2,944,817.53	1,392	2,115.53		

Table I: Analysis of Variance of data. Explanation of abbreviations are as follows:

Sub: Individual subjects in experiment.
Cn: Major conditions of experiment.
Dr: Levels of conditions, i.e. the 40 and 80 msec level for each condition.
Dy: Days, representing the 5 successive days of experimental sessions.

in Table III. The magnitude of facilitation is found by subtracting the mean RT of the condition from the mean RT of the Visual Alone condition (i.e. magnitude of facilitation = $RT_{v_{\bar{X}}} - RT_{av_{\bar{X}}}$).

Condition	Magnitude of Facilitation
Nonoverlapping Successive	57.2 msec
Overlapping Stimuli	52.7 msec
Simultaneous Onset	19.5 msec

Table III: Mean Magnitude of Facilitation for each Experimental Condition.

The results shown in Table III show the largest facilitory effect for the Nonoverlapping Successive Stimuli condition (MF = 57.2 msec). This condition allowed a preparatory set because the Sa preceded the Sv in time, and it would minimize energy integration because the stimuli do not overlap. Thus, the facilitory effect found in this condition provides support for the Preparatory Set theory proposed by Bernstein (1970).

The Simultaneous Stimuli condition showed a facilitory effect of 19.5 msec when compared to the Sv alone condition. This condition was designed to prevent any preparatory warning by having subjectively simultaneous onset of the Sa and the Sv. Although preparatory warning was minimized, the possibility of energy integration was not interfered with. Thus, the facilitory effect that results from this condition provides support for the Energy Integration theory proposed by Bernstein (1970).

The Overlapping Stimulus condition showed a magnitude of facilitation of 52.7 msec. This condition was designed to allow the possibility of both preparatory set and energy integration by having the Sa preceding the Sv in onset, and also overlapping with it in time. RT to the Overlapping Stimulus condition was statistically different from the RT to the Visual Alone condition (Table II). However, a paired comparison of the Overlapping Stimuli condition and the Nonoverlapping Successive Stimuli condition showed no statistically significant difference (Table II). The failure to find a difference between these two conditions will be discussed later in this paper.

These results imply that it is quite possible that the phenomenon of ISF is generated in part by both energy integration and preparatory set effects. The magnitude of the facilitory effect is the Nonoverlapping Successive condition and in the Simultaneous Onset condition (57.2 msec and 19.5 msec respectively) suggest that the most important factor in ISF is the preparatory warning. That preparatory set might have an effect on RT is not unreasonable. It is possible that it functions as an alerting signal, or as in the model proposed in this paper, serves to activate an "accumulator" similar to the one proposed by Stone (1960). Previously cited research by Raab, et. al. (1961) and Kohfeld (1968) has shown that RT is inversely related to stimulus intensity.

There is also physiological evidence indicating that various areas of the brain contain single cells that respond to both visual and auditory stimulation (Dubner, 1966; Bignall, 1967). It is not implausible to postulate a mechanism that responds in some additive way to bisensory stimulation and produces results similar to those obtained by increasing the intensity in a single modality.

Two additional findings of note result from this research. The first relates directly to the original hypothesis that there would be a difference in the magnitude of facilitation obtained under the Nonoverlapping Successive stimuli and Overlapping Stimuli conditions. The magnitude of facilitation was not statistically different however ($p > .05$). In the former condition the primary feature is the opportunity for preparatory set. In the latter, the opportunity for preparatory set plus the possibility of energy integration exists (See the Methods section for a discussion of the conditions). Since both of these have been shown to influence RT, it would not be unreasonable to expect them to interact in some way (e.g. additively). Of course, the failure to find a difference does not prove that no difference existed. It may be that the test was not sufficiently sensitive to detect the differences. It is also possible that a ceiling effect occurred due to the large facilitation of the preparatory set component. The addition of the much smaller energy integration effect to the large preparatory set effect may not have resulted in a detectable difference in the two conditions. It could also be argued that in the Overlapping Stimuli condition there was no subjective overlap of the stimuli at the 80 msec level (i.e. where the Sa led the Sv by 80 msec). This experiment indicated that there was approximately a 45 msec difference in onset time of the Sa and the Sv required for the S to perceive them as having a simultaneous onset (i.e. the Sv must precede the Sa by @ 45 msec. Subject means were: S_1= 37.5, S_2= 42.5, S_3= 45.0, S_4= 55.0). Assumint that this difference reflects neural latency differences in the auditory and visual systems, there may have been no subjective overlap of the Sa and the Sv, since the Sa had a duration of only 120 msec. Thus, even if energy integration effects normally interacted with preparatory set effects, it would not be obvious from the 80 msec level of this condition. However, there should be stimulus overlap in the 40 msec level, as the duration of the Sa was still 120 msec. If there was an interaction of the preparatory set and energy integration effects, it should show as a difference in RT to the 40 and 80 msec levels of this condition. No such difference was found however (RT_{40} = 246.8 msec, RT_{80} = 241.8 msec: $p > .05$). Table IV shows the comparisons of the two levels of the conditions which had preparatory warning (i.e. where the Sa preceded the Sv). Only two conditions are shown in Table IV because only two conditions had preparatory warning. The other two conditions (i.e. the Visual Alone and the Simultaneous Onset) did not have a preparatory warning feature.

Condition	$\bar{x}_{40}$	$\bar{x}_{80}$	n	t
Nonoverlapping Successive Stimuli	240.5	239.0	600	0.49 NS
Overlapping Stimuli	246.8	241.8	600	1.67 NS

Table IV: Comparison of the two levels of the conditions involving preparatory warning. Comparison is by t-test. Means are in msec.

This failure to find a difference in the 40 and 80 msec levels of the conditions with preparatory warning is surprising for another reason as well. It would seem likely that the amount of time between a preparatory stimulus and a reaction stimulus would be critical to the effectiveness of the preparatory signal. These data indicate that a 40 msec warning is as effective as an 80 msec warning. There seem to be two plausible explanations for this finding. First, the measure may not have been sensitive enough to detect whatever differences existed, and/or secondly, the preparatory set effect was at asymptote across the time intervals in this experiment. This study does not provide data that can answer that question.

A summary of the primary findings of this experiment can be listed as follows:

1. Under the conditions of this experiment, there are preparatory set effects on bisensory RT.
2. Under the conditions of this experiment, there are energy integration effects on bisensory RT.
3. Preparatory set effects may be asymptotic across the times utilized in this experiment.

4. Preparatory set effects and energy integration effects may not be interactive.

There are several secondary findings of this experiment. First, the Subjects by Conditions interaction was statistically significant ($p < .01$) indicating that the conditions had differential effects on the RT of the Ss. That these differences were generally differences of magnitude rather than differences of direction can be seen in Figure 2, which shows the mean RT of each subject for each condition. It can be seen that except for S #4, the effects of conditions is consistent with respect to direction. S #4 shows a reversal for the Overlapping stimuli and Nonoverlapping Successive stimuli conditions, when compared to the other Ss. This reversal is responsible, in part, for the significance of the Subjects by Conditions interaction. Although S #4 showed a reversal of the magnitude of the effects of these two conditions, the differences in RT to the two conditions was not statistically significant ($p > .05$).

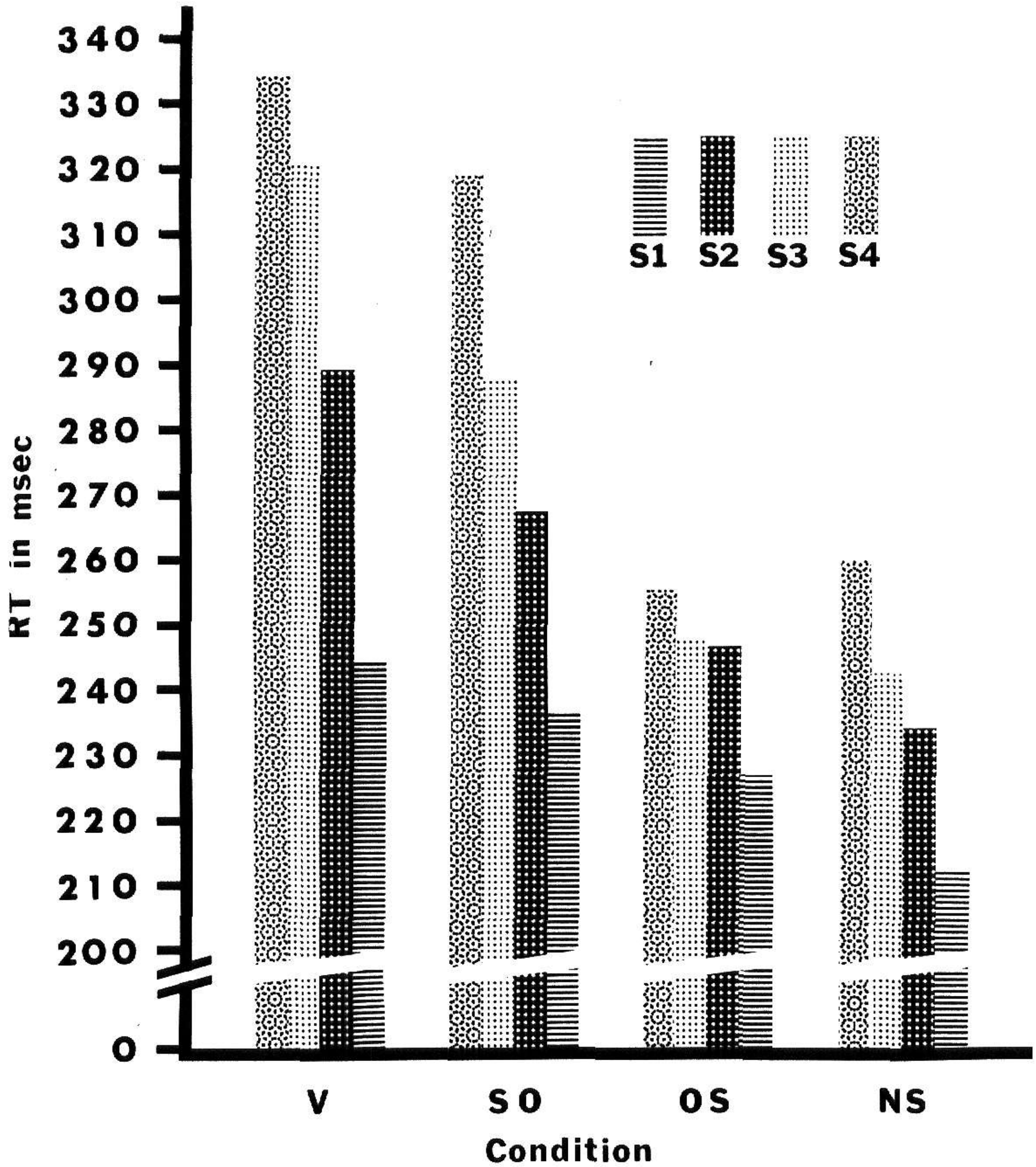
Pairwise comparisons of conditions for each S was made using Duncan's New Multiple Range tests. The Duncan's analyses for Conditions by subjects are shown in Table V. Duncan's tests indicate, in general, that the effect of conditions is the same for individuals as it is for the group data. These data indicate that, although there are magnitude differences in RT to the different conditions, the direction of the effect is consistent across subjects. (See Figure 2).

Another minor finding was that the Conditions by Duration interaction was not significant. This indicates that the

Figure Caption

Figure 2: Mean reaction time of individual subjects for each condition.

Conditions:
V - Visual Alone
SO - Simultaneous Onset
OS - Overlapping Stimuli
NS - Nonoverlapping Successive Stimuli


340
330
320
310
300
290
280
270
260
250
240
230
220
210
200
0
RT in msec
S1 S2 S3 S4
V
S O
O S
NS
Condition

Conditions

Subject #1

$\bar{x}$	Nonoverlapping Successive	Overlapping Stimuli	Simultaneous Onset	Visual Alone
	222.84	226.75	235.53	244.49
222.84		3.91 NS	12.69**	21.54**
226.75			8178*	17.74**
235.53				8.96**

Subject #2

$\bar{x}$	Nonoverlapping Successive	Overlapping Stimuli	Simultaneous Onset	Visual Alone
	234.52	247.93	267.74	289.17
234.52		13.40**	33.22**	54.65**
247.93			19.82**	41.24**
267.74				21.43**

Subject #3

$\bar{x}$	Nonoverlapping Successive	Overlapping Stimuli	Simultaneous Onset	Visual Alone
	242.37	248.59	287.32	320.42
242.37		6.22NS	44.95**	78.05**
248.59			38.74**	71.83**
287.32				33.09**

Subject #4

$\bar{x}$	Overlapping Stimuli	Nonoverlapping Successive	Simultaneous Onset	Visual Alone
	253.99	259.38	319.85	333.96
253.99		5.39NS	65.86**	79.97**
259.38			60.47**	74.58**
319.85				14.01**

Range: alpha = .05 R_2 = 7.331 R_3 = 7.717 R_4 = 7.988
alpha = .01 R_2 = 9.634 R_3 =10.038 R_4 =14.214

* $p < .05$
** $p < .01$

Table IV: Pairwise comparisons of conditions for each S. Analysis is Duncan's New Multiple Range tests.

duration did not have differential effects across conditions. The Subjects by Duration interaction was statistically significant however ($p < .05$). For two Ss, RT to the 40 msec level of the different conditions was slightly longer than RT to the 80 msec level of the same conditions. For the other two Ss the reverse was true. These differences were of a magnitude of about 3 to 4 msec.

Finally, the following interactions were found to be statistically significant: Conditions by Days; Subjects by Conditions by Days; Conditions by Duration by Days; Subjects by Duration by Days; and Subjects by Conditions by Duration by Days. The remainder of the interactions were nonsignificant statistically (See Table I). Finally, examination of errors provided no discernible pattern, except that the error rates tended to decrease over trials and days. Mean error rates for the subjects were as follows: S #1 - 6%; S #2 - 7%; S #3 - 5%; and S #4 - 2%.

Results of previously cited research relevant to ISF can be summarized as follows:

1. RT to a unisensory stimulus is inversely related to stimulus intensity.
2. Equal intensity increments have a diminishing effect on RT as intensity increases.
3. Once a critical duration is reached, further increases in the duration of a stimulus has no effect on RT.
4. RT to a unimodal stimulus is slower than RT to the same stimulus plus a stimulus in another mode.
5. With bisensory stimuli, facilitation increases as the intensity of the nonreaction stimulus (Snr) increases.

5. (continued) Facilitation decreases as the intensity of the reaction stimulus (Sr) increases if the intensity of the Snr is held constant.

Based on the experiment presented in this paper, the following points can be added to the above list:

1. Preparatory warning has a significant effect on the magnitude of facilitation.

2. Energy integration has a significant effect on the magnitude of facilitation.

3. Preparatory set effects are greater in magnitude than are energy integration effects under the conditions of this experiment.

Two more findings of this research can be tenatively added to the list:

1. Preparatory set and energy integration effects may not be interactive.

2. Over a limited range of times (i.e. 40-80 msec) the lead time of the preparatory signal has equal effects.

A model that could encompass the previously listed results is described below:

The basic unit of the model is a decision maker that is comparable to a logical AND gate. This decision maker has the following properties.

1. There are two input "legs" to the unit.

2. Each input leg is activated by an adequate stimulus.

3. If the input legs are activated the response in initiated by the decision unit. However, both legs must be activated before the response is made.

The input legs are preceded by analyzers which respond to stimuli of the proper characteristics. The first of these analyzers operates like an accumulator. It responds to the overall level of input. In operation, this accumulator is like some other commonly used RT models. For example, Stone (1960) has generated a model that is similar in operation to this proposed accumulator. The accumulator functions by monitoring the incoming activity. It is multimodal in sensitivity, and before it activates its leg to the AND decision unit, the activity must exceed some threshold level. The other analyzer is a Feature Analyzer and responds only to a stimulus of the proper modality. Its function is to insure that the incoming stimulus is of the proper modality before it activates its leg to the AND decision unit. This Feature Analyzer leg is a new addition to the typical RT model (e.g. Stone's model, 1960).

The output from these units form the input legs to the AND decision unit. The model can be diagrammed schematically as shown in Figure 3.

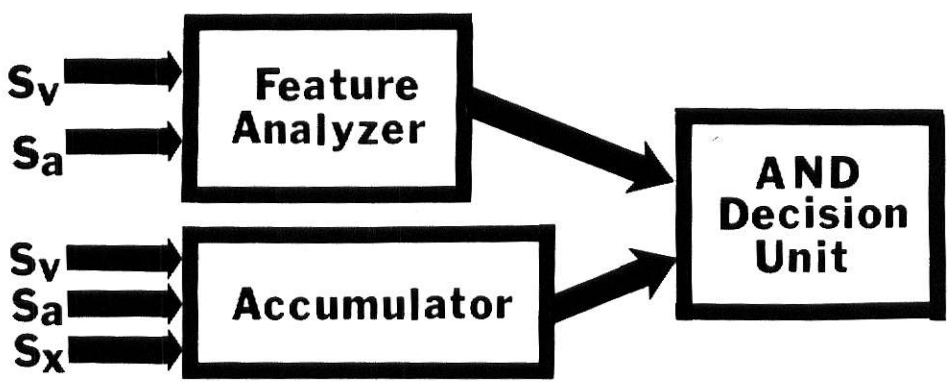
In a RT situation, the appropriate feature analyzer is selected for input to the AND unit (i.e. a visual feature detector for visual stimuli). The accumulator has a threshold level that must be exceeded before that unit is activated. Incoming information is channeled to the analyzer units. Suppose the task is a simple RT task. The reaction stimulus is fed to both the Feature Analyzer and the Accumulator. The Accumulator monitors the overall level of incoming information, and when the threshold is exceeded, it activates one of the input legs to the AND unit. The feature analyzer also receives stimulus

Figure Caption

Figure 3: A schematic diagram of the proposed RT model.

Abbreviations are:

Sa - Auditory stimuli
Sv - Visual stimuli
Sx - Stimuli other auditory or visual


Sv
Sa
Feature
Analyzer
Sv
Sa
Sx
Accumulator
AND
Decision
Unit

input and determines if the stimulus is the proper one. If the proper stimulus comes in, the feature analyzer activates the other input leg to the AND unit. With both legs activated, the response is initiated. If the stimulus input is increased in intensity, the accumulator builds up to its response more quickly, thus decreasing the response time of the system. This assumes, of course, that the feature analyzer has already activated its leg. The assumption is that the feature analyzer reaches its decision more quickly than the accumulator reaches threshold.

Once a critical duration of the stimulus is reached, further increases in stimulus duration have no effect on RT. This is due to the fact that the analyzers have received all the information necessary for their decision, and further information input will not speed up the reaction of the system.

Since the accumulator is sensitive to multimodal inputs, a given threshold level is reached more quickly if the reaction stimulus is received in conjunction with another stimulus. The effect of bimodal input is comparable to the effect of increasing intensity in a single mode. Increases in the intensity of the nonreaction stimulus results in a greater magnitude of facilitation because the accumulator reaches threshold more quickly. However, the facilitative effect of a nonreaction stimulus of a fixed intensity decreases as the intensity of the reaction stimulus increases. This is because of the diminishing effect of constant increments in intensity.

As the base level of activity is raised (i.e. the intensity of Sr is increased) the effect of the nonreaction stimulus is relatively less. The rate at which information is accumulated varies linearly with proportional changes in activity level, not absolute changes. Thus the magnitude of facilitation associated with a Snr of a fixed intensity decreases as the intensity of the Sr increases.

Preparatory warning has the effect of building the accumulator to near the threshold of response. Incoming activity accumulates prior to the arrival of the reaction stimulus (Cowan and Monroe, 1970). When the reaction stimulus arrives the accumulator reaches response threshold more quickly (if it has not reached threshold already) than it would have without the preparatory signal. Thus this leg of the system is quickly activated. As soon as the feature analyzer is activated, the AND gate initiates the response.

Preparatory set effects are of greater magnitude than the energy integration effects at the levels of stimulation in this research, because the accumulator has time to build to near threshold (or to threshold) before the reaction stimulus comes on. If the reaction stimulus and the nonreaction stimulus come on simultaneously, the accumulator still requires some time to build to threshold. This is accomplished more rapidly than with one stimulus alone, but still requires more time than in the preparatory set condition.

Preparatory set effects and energy integration effects do not appear to be additive only because the difference in preparatory set with and preparatory set without energy integration is slight. For example, in a condition that provides for both energy integration and preparatory warning, the incoming warning would boost the accumulator to near threshold (or to threshold). When the reaction stimulus comes on, the accumulator reaches threhsold quickly if it has not already done so. The difference in this condition and a sequential stimulus condition is only in the portion of the accumulator buildup commencing with the onset of the reaction stimulus. Although the buildup of the accumulator would be faster in the overlapping stimulus condition, if it is near threshold the difference in the two conditions would be very small. If the preparatory signal pushed the accumulator past threshold, there would be no difference in the preparatory set condition and the preparatory set plus energy integration condition. This would also predict that if the preparatory set time is decreased, or if the intensity of the preparatory signal is decreased, the effects of preparatory set and energy integration should be seen to interact.

Finally, the finding of this research that the preparatory set effect at 40 and 80 msec lead time are of the same magnitude can be accounted for by assuming that the accumulator had reached threshold (or nearly so) by the end of the 40 msec warning interval. Additional increases in warning time then would not add to the facilitory effect. If this were the case, it should be possible to find a point in time at which the effectiveness of the preparatory warning falls off due to the lack of time for accumulator buildup. That is, as the onset of the warning signal moves closer and closer to the onset of the Sr, its effectiveness should become impaired at some point, and decrease as it moves even closer to onset of the Sr.

Summary

Reaction time under conditions of bimodal stimulus presentation was measured. The bimodal stimuli were auditory and visual and were presented in one of three ways: sequential with temporal overlap; sequential without temporal overlap; or simultaneous onset. The reaction stimulus was the visual stimulus. The visual stimulus alone provided a baseline reaction time, and the auditory stimulus alone served as catch trials. Reaction times indicated that both energy integration and preparatory set effects occur in intersensory facilitation. The magnitude of facilitation was greatest in the preparatory set condition. A model was proposed to account for these and other related reaction time findings.

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ENERGY INTEGRATION AND PREPARATORY SET EFFECTS IN INTERSENSORY FACILITATION

by

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Reaction time under conditions of bimodal stimulus presentation was measured. The bimodal stimuli were auditory and visual, and were presented in one of three ways: sequential with temporal overlap; sequential without temporal overlap; or with simultaneous onset. The reaction stimulus was the visual stimulus. The visual stimulus alone provided a baseline reaction time, and the auditory stimulus alone served as catch trials. Reaction times indicated that both energy integration and preparatory set effects occur in intersensory facilitation. The magnitude of facilitation was greatest in the preparatory set conditions. A model was proposed to account for these and other related reaction time findings.