

Effects of bisensory stimulation on reaction time and the evoked cortical potential

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Reaction times and evoked cortical potentials to visual and auditory stimuli alone and to the two in combination (bisensory stimulation) were studied. It was found that bisensory stimulation resulted in significantly faster reaction times than those obtained with visual or auditory stimulation alone. Auditory reaction times were faster than visual. The amplitudes of evoked potentials were significantly higher at both recording sites (O_2 and C_z) under conditions of bisensory as compared to unisensory stimulation. Evoked potential latencies were in the expected direction, i.e., all conditions using auditory stimulation resulted in shorter latencies than the visual stimulation alone condition. It was concluded that evidence for sensory interaction (facilitative) had been obtained in this experiment and that the amplitude increases with bisensory stimulation were reflected in faster reaction times. A definitive statement regarding the central nervous system locus of this sensory interaction is not yet possible.

Bisensory stimulation refers to the simultaneous or near simultaneous stimulation of two sensory systems, e.g., visual and auditory, auditory and proprioceptive, etc. Bisensory stimulation may result in sensory interaction, which is defined here as the change in response to a stimulus in one sense modality when that stimulus is accompanied by an accessory stimulus in a different modality. The effect of the change in response may be facilitative (response enhancement) or inhibitory (response decrement).

The purpose of the present research is to examine the role of sensory interaction with regard to both reaction time (RT) and the evoked cortical potential (EP). The basic questions which this research seeks to answer are: (1) Will the simultaneous arrival of two stimuli at cortical areas enable faster reaction times? (2) What is the effect upon cortical evoked potentials when two senses are simultaneously stimulated?

In an attempt to account for factors affecting RT, Vaughan, Costa, Gilden, and Schimmel (1965) conducted an experiment using both photic and auditory stimuli. Their results indicate that EP latencies were shorter for auditory stimuli than for visual, with the latency of the visual EP increasing as stimulus intensity decreased. Their estimate of the central delay for simple RT ranged from 20 to 60 msec and varied from trial to trial, the variation being attributed to attention and level of arousal.

Morris (1971) measured both the VEP and RT to a light flash, VEP being recorded at O_2 and C_z , and found that significantly larger amplitudes of N2 and P2 components were associated with faster reaction times. Morrell and Morrell (1966) also measured visual RT and evoked potential. Their results agree with those of Morris in that increased amplitudes of both positive and

negative VEP components were associated with faster reaction times. Component latency showed no clear relationship to RT. The authors suggest that factors such as selective attention and fluctuations in alertness are possible determinants of the relationship between RT and VEP amplitude.

Donchin and Lindsley (1966) measured RT to a light flash using a warning click and a variable foreperiod (1.0-2.5 sec). The authors found that EP amplitude and RT were definitely related, with faster RTs associated with larger EP amplitudes. Knowledge of results tended to shorten RT and increase response amplitude. Karlin, Martz, Brauth, and Mordkoff (1971) sought to verify the findings of Donchin and Lindsley (1966) and Morrell and Morrell (1966) using auditory rather than visual stimuli. Employing both simple and choice RT paradigms, subjects were exposed to tones of high or low intensity, with RT and EPs recorded under each condition. Unlike the visual RT studies, auditory stimulus intensity had no effect on RT. This is in agreement with several auditory RT studies (Bernstein, Rose, & Ashe, 1970; Henriksen, 1971; and Sanford, 1971). In terms of RT speed and EP amplitude, Karlin et al. (1971) found that trials with faster RTs were associated with a more negative N1 peak, less negative peaks at N2 and N3, and more positive peaks at P3 and P4.

The present experiment involves an investigation of the nature of the changes in both RT and the EP when the stimuli of interest (visual and auditory) are presented with a temporal offset between them. Two methods of determining the temporal offset were used. The first, called Δ RT, sets the offset equal to the difference between the mean individual visual and auditory RTs of the subjects. The second method, designated Δ N2, uses an offset equal to the average latency of each subject's N2 component of the EP to light and sound stimuli. Thus, the second method should produce bisensory stimulation which is simultaneous, i.e., the EPs to the

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sense stimuli used should occur at the appropriate cortical areas at the same time.

The Δ RT method was used by Hershenson (1962), who first determined the mean RT for each subject to auditory and visual stimuli, and then during actual testing, the visual stimulus was presented prior to the auditory by the amount of this mean temporal difference. For example, if a subject's mean RT was 250 msec to visual stimulation and 220 msec to sound, then in actual testing, the visual stimulus would precede the auditory by 30 msec. Hershenson (1962) studied RT to light alone, sound alone, and a light/sound combination with varying times between light and sound. He found that bisensory stimulation resulted in facilitation (i.e., faster RTs) when the time offset between presentations of the "simultaneous" light and sound was equal to the difference between RTs to the single stimuli.

In the present experiment, we wish to explore a new method of offset time between the visual and auditory stimulus, in addition to the one used by Hershenson. We propose to take the mean difference between the latencies of one of the major components of the visual evoked potential (VEP) and the auditory evoked potential (AEP) and use this as the offset time between the presentation of a visual and an auditory stimulus. Thus, if a subject's mean VEP (N2 component) is 180 msec for the visual stimulus and his mean AEP (N2 component) is 160 msec for the auditory stimulus, the time offset would be such that the visual stimulus precedes the auditory by 20 msec. In this second method, the cortical areas for these two types of stimuli would be responding simultaneously.

METHOD AND MATERIAL

Subjects

Evoked potential and reaction time data were obtained from a total of eight subjects who participated in two separate experimental sessions. The subjects ranged from 22 to 32 years of age, with a mean of 25. The subjects had no visual, auditory, or motor defects.

Experimental Design

The work was carried out in two phases. In Phase I, basic RT and EP data were obtained from each subject. Phase II consisted of gathering RT and EP data for the "simultaneous" presentation of light and sound stimuli.

Two experimental conditions were used in Phase I, viz, Condition A used a brief flash of light as the stimulus, and Condition B used a short burst of noise. Each of the stimuli were presented in blocks of 100 with a variable (1 to 4 sec) interstimulus interval (ISI) between presentations. The experimenter manually controlled the ISI for each trial in a run; the ISIs were assigned at random prior to the start of the experiment. Phase I required one experimental session lasting slightly longer than 1 h. Stimulus conditions were counterbalanced across subjects. Each stimulus condition was replicated four times.

Phase II also used two stimulus conditions (C and D), both of which were light/sound combinations. The stimuli were

presented with a slight temporal offset between them, the value of the offset was determined in one of two ways: (1) For Condition C, the visual stimulus was initiated before the auditory stimulus by a small amount of time, that time being equal to the difference between the subject's mean RT to each stimulus mode individually (Δ RT offset). (2) For Condition D, the light stimulus was initiated prior to the sound by a time equal to the difference of the average latency of the N2 component of the subject's evoked potential (EP to light minus EP to sound) which we have termed Δ N2 offset.

As in Phase I, four ISIs (varying from 1 to 4 sec) were assigned at random and used between stimulus pair presentations, and stimulus conditions were again counterbalanced across subjects. The subjects were seated in an electrically shielded sound-attenuated room (IAC chamber), and the entire experiment was conducted with the lights dimmed.

The EEG was recorded on a Beckman Type RM Dynograph from Grass silver cup electrodes placed at O_2 and C_z , respectively, according to the "Ten-Twenty" system (Jasper, 1958). The O_2 and C_z electrodes were referenced to a silver clip electrode on the left earlobe. Eye movements (EOG) were monitored by means of another electrode, and EP traces suspected of being contaminated by eye movements were discarded. Inspection for eye movement contamination involved a comparison of the averaged EOG trace with the VEP trace. A straight line EOG trace indicates very little or no eye movement. A rise then dip in the EOG trace would indicate a consistent eye movement, and, if the EOG trace is superimposed over the VEP trace, the effect is noticeable by rises and dips in the VEP at the same temporal positions.

EEG and EOG potentials were fed into a Mneotron computer of average transients (CAT/1000) to produce averaged O_2 , C_z , and EOG traces. Five hundred millisecond duration samples were taken for 100 presentations of the stimulus. At the end of each run, O_2 , C_z , and EOG were traced out on a Hewlett-Packard X-Y plotter. Reaction time data (in milliseconds) was measured by a Lafayette digital RT apparatus and recorded manually by the experimenter. The visual stimulus was a 10-microsec flash of light produced by intensity setting "1" of a Grass Model PS2 photostimulator at a distance of 28 in. from the subject's eyes. The light was presented to the subject through a 3 x 6 in. rectangular opening in a shield placed over the window of the IAC booth. The auditory stimulus was a binaural burst of white noise (40 msec duration, at 80 dB) produced by a Grason-Stadler noise generator and presented via headphones.

A 40-msec burst of noise was chosen as the auditory stimulus because earlier experimentation (Andreassi, Mayzner, Beyda, Davidovics, Stern, & Okamura, 1972) indicated that subjects subjectively judged this burst length to be equal to the duration of the light flash. Even though the flash was only of 10 microsec duration, it was intense enough to flood the visual system with a stimulus which appeared equal in duration to that of a 40-msec noise burst presented to the auditory system. White noise was chosen instead of a pure tone since it (random frequency noise) is analogous to the wide wave length range of the white light used. The C_z area was used for recording the auditory evoked potential since it has been found to be an optimal area (e.g., see Vaughan, 1969).

Presentation of the stimulus triggered both the CAT and the RT apparatus. Each subject was given 200 practice trials on each of the stimuli before the start of each session. The four conditions were: (1) RT_v = Reaction time to visual stimulus. (2) RT_a = Reaction time to auditory stimulus. (3) RT_{va} (Δ RT) = Reaction time to bimodal stimulation when the visual stimulus is presented first by an amount equal to the mean RT difference. (4) RT_{va} (Δ N2) = Reaction time when the visual stimulus is presented first by an amount equal to the mean difference in N2 latency.

RESULTS

Reaction Time Data

The average RTs to unimodal and bimodal stimulation were obtained for each subject. The mean RT for visual stimulation alone (RT_v) was 188 msec for the eight subjects while for auditory alone (RT_a), it was 156 msec, a clear advantage for auditory RT (by 32 msec). The RT measures for bisensory stimulation (both ΔRT and $\Delta N2$) were taken from the time of auditory stimulation since, it was reasoned, this measure would best reflect the time of simultaneous cortical stimulation by the two stimuli and would enable a more accurate comparison to the two unisensory conditions (RT_v and RT_a). Thus, the mean RT for the visual-auditory combination, RT_{va} (ΔRT), was 127 msec, while for RT_{va} ($\Delta N2$), it was 120 msec. This result indicates that bisensory stimulation, using either offset method, produces faster RTs than either auditory or visual stimulation alone. To determine the statistical significance of these RT differences, two-tailed t tests for correlated data (Winer, 1971) were used after a log transformation of the data was performed. The results indicated that RT_a was significantly faster than RT_v ($t = 8.58, p < .001, df = 7$) and that both methods of bisensory stimulation ($RT_{va}\Delta RT$ and $RT_{va}\Delta N2$) resulted in significantly faster RTs than RT_a ($t = 12.19$ and 8.27 , respectively, $p < .001, df = 7$). The comparison of $RT_{va}\Delta RT$ and $RT_{va}\Delta N2$ did not yield a significant difference ($t = .58, p > .05, df = 7$).

Evoked Potential Data

Evoked potential data were obtained for two electrode placements (O_2, C_z) for the eight subjects under four stimulus conditions. The mean amplitudes (microvolts) and latencies (milliseconds) were computed for each of the eight subjects from the VEP tracings. The N1 component was considered to be the first negative

dip in the plot which occurred 50 msec after the stimulus. The amplitude of the N1 component was measured as the vertical distance from the trace baseline to the trough of the first depression. The P1 component was measured as the vertical distance from N1 to the peak of the first positive component, N2 was measured as the vertical distance from the peak of P1 to the trough of the second major depression, while P2 was measured as the vertical distance from N2 to the peak of the second positive component, etc. Latencies (or time after stimulus presentation) were measured to the midpoints of each positive and negative peak. If the "peak" was flat, and appeared more as a plateau, the midpoint of the plateau was taken as the latency measurement. The mean amplitudes for the various EP components for each stimulus condition, across the eight subjects, are shown in Table 1 for the O_2 and C_z placements.

The mean latencies for the various EP components for each stimulus condition, across the eight subjects, are shown in Table 2 for O_2 and C_z . The data show a larger EP to light than to sound at O_2 and the opposite at C_z when the unisensory conditions are compared.

They also show shorter EP latencies to the auditory stimulus at both O_2 and C_z .

The averaged EPs for bisensory stimulation show little difference between the two offset methods. Amplitudes of EPs with bisensory stimulation are greater than for unisensory stimulation, especially at C_z . Figures 1 and 2 show superimposed EP tracings for one subject (L. S.) under the four stimulus conditions at the two recording sites. The EPs for this subject are representative of the seven other subjects.

Latency and amplitude data were subjected to analysis of variance (ANOVA) for each of the major components (N2 and P2). The model used for the ANOVA was a three-factor mixed-model factorial design with four observations per cell. Factors A (electrode

Table 1
Mean Amplitude (μV) for Major EP Components Under Conditions A (Light), B (Sound), C (Light/Sound Offset by ΔRT), and D (Light/Sound Offset by $\Delta N2$)

EP Component	Stimulus Condition			
	A	B	C	D
Scalp Location O_2				
N1	2.05		2.12	2.36
P1	7.49	5.28	8.54	8.86
N2	9.88	7.81	11.05	10.93
P2	9.20	7.94	12.23	12.35
Scalp Location C_z				
N1	1.93		1.32	1.28
P1	5.34	4.79	4.52	5.45
N2	9.56	10.07	11.43	12.00
P2	10.84	15.27	19.30	20.65

Note— $N = 8$

Table 2
Mean Latency (Msec) for Major EP Components for Conditions A (Light), B (Sound), C (Light/Sound Offset by ΔRT), and D (Light/Sound Offset by $\Delta N2$)

EP Component	Stimulus Condition			
	A	B	C	D
Scalp Location O_2				
N1	69.69		69.53	71.15
P1	113.13	90.23	103.59	106.56
N2	166.88	135.58	145.47	151.56
P2	225.63	200.94	212.06	211.56
Scalp Location C_z				
N1	65.00		63.33	62.85
P1	103.90	76.25	91.40	92.97
N2	152.34	125.72	133.59	135.63
P2	223.75	208.28	208.75	211.88

Note— $N = 8$

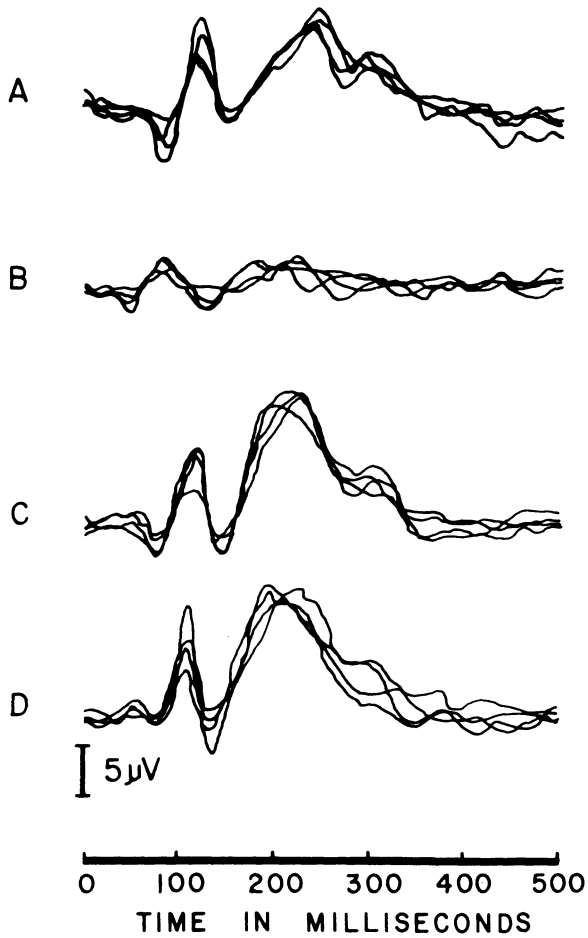


Figure 1. Evoked potentials for L. S. under Conditions A (light), B (sound), C (light and sound, offset by Δ RT), and D (light and sound, offset by Δ N2). Recordings are from O₂. Negativity is downward.

placements) and B (conditions) were considered to be fixed factors, while Factor C (subjects) was considered to be random. The raw data were subjected to a logarithmic transformation, to produce homogeneity of variance and normality of distribution. The ANOVA for N2 latency data indicated that all of the main effects and interactions were significant: placements, $F(1/192) = 15.84$; conditions, $F(1/192) = 17.19$; and subjects, $F(7/192) = 21.00$ ($p < .01$ in all instances).

The Newman-Keuls (N-K) procedure was applied (see Winer, 1971, p. 191) to test specific comparisons for statistical significance. The eight stimulus condition means (four conditions, each at two locations) were tested in all possible pairs within the constraints of the N-K procedure. The following comparisons were significant: At the .01 level of significance—(1) N2 latency for light from O₂ was longer than N2 latency for sound from both O₂ and C_z. (2) N2 latency for light from O₂ was longer than N2 latency for light/sound (Δ RT) from C_z. (3) N2 latency for light from O₂ was longer than N2 latency for light/sound (Δ N2) from C_z.

These results indicate that bisensory stimulation produced changes in the EP as compared to unisensory stimulation. The ANOVA for P2 latency data resulted in the same findings as for N2 latency.

N2 Amplitude Data

Application of the ANOVA to N2 amplitude data led to the finding that of the three main effects, only electrode placement was not significant. For both conditions, $F(3/192) = 7.69$, and subjects, $F(7/192) = 73.11$, significance was at $p < .01$.

P2 Amplitude Data

Analysis of the P2 amplitude data indicated all main effects to be significant: placements, $F(1/192) = 24.97$; conditions, $F(3/192) = 9.84$; and subjects, $F(7/192) = 86.77$. Application of the N-K procedure resulted in the following differences for pairs of P2 amplitude means: At the .01 level of significance—(1) P2 amplitude for light/sound (Δ N2) at C_z was greater than P2 for sound at O₂. (2) P2 amplitude for light/sound

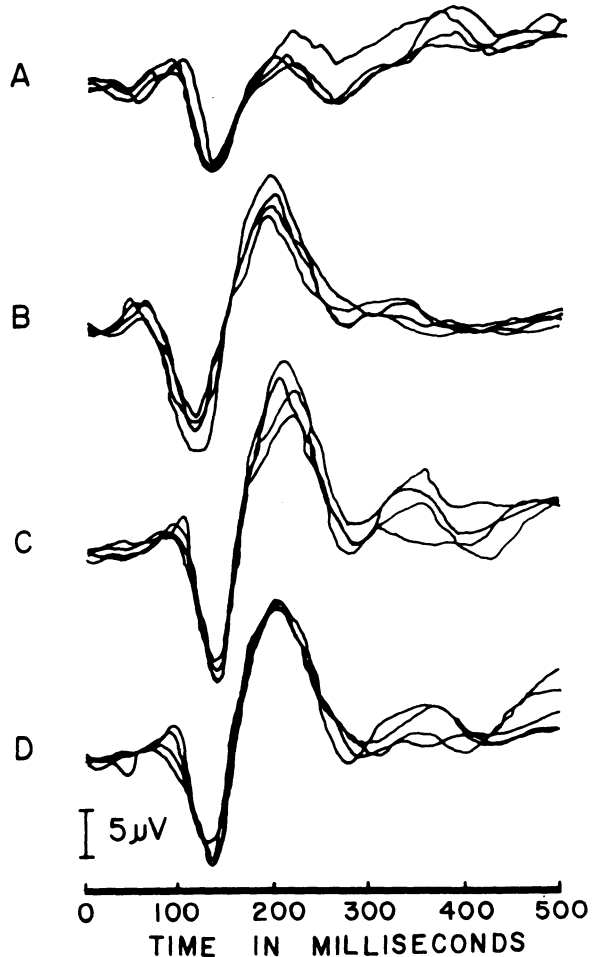


Figure 2. Evoked potentials for L. S. under Conditions A (light), B (sound), C (light and sound, offset by Δ RT), and D (light and sound, offset by Δ N2). Recordings are from C_z. Negativity is downward.

(ΔN_2) at C_z was greater than P2 for light at both O_2 and C_z . (3) P2 amplitude for light/sound (ΔN_2) at C_z was greater than P2 for light/sound (ΔRT) at O_2 . (4) P2 amplitude for light/sound (ΔRT) at C_z was greater than P2 for sound at O_2 and greater than P2 for light at both O_2 and C_z . (5) P2 amplitude for sound at C_z was greater than P2 amplitude for sound at O_2 ; At the .05 level of significance—(1) P2 amplitude for light/sound (ΔRT) at C_z was greater for P2 for light/sound (ΔRT) at O_2 and greater than P2 for light/sound (ΔN_2) at O_2 . (2) P2 amplitude for light/sound (ΔRT) at O_2 was greater than P2 for sound at O_2 . (3) P2 amplitude for light/sound (ΔN_2) at O_2 was greater than P2 for sound at O_2 .

The results indicate that sensory interaction occurred and that the effect was facilitative. The fact that the P2 amplitude shows a more marked change than N2 amplitude indicates that the facilitative effect here (i.e., in reference to amplitude) occurred later in time than the facilitation for latency (N2 latency showed greater decreases than P2 latency).

DISCUSSION

The basic questions which guided the present research effort can be answered as follows: (1) Bisensory stimulation resulted in faster reaction times than unisensory stimulation and the ΔN_2 offset was as effective in improving RTs as was the ΔRT offset. (2) Bisensory stimulation produced larger amplitude evoked potentials than did unisensory stimulation, but latency differences with EPs did not occur. The only EP latency differences were between the visual condition and the others. Our results confirm past findings in which auditory RT have consistently been found to be faster than visual (e.g., see Woodworth & Schlosberg, 1954) and in which EP latencies have been found to be shorter for auditory than visual stimuli (Vaughan et al., 1965).

It appears that the addition of another stimulus resulted in faster reaction times than did one stimulus alone. This agrees with findings of Hershenson (1962) and Morrell (1967, 1968). Bisensory stimulus conditions produced consistently larger evoked potential amplitudes than light or sound alone. Further, the enhancement effect was greater at C_z than at O_2 . Combined auditory and visual stimulation resulted in more pronounced amplitude changes at C_z and suggests that the visual stimulus produced wider spread effects than did the auditory stimulus. This result is consistent with those of Vaughan (1969), who plotted isopotential maps to binaural tones and to light flashes. His results indicated that maximum auditory response was obtained at the vertex (C_z) and progressively decreased to zero at the level of the plane of the Sylvian fissure. On the other hand, visual stimulation produced a response at C_z which was only slightly less than the response at the occiput. This secondary maximum, he attributed to the

later components of the VEP, and this may provide an explanation for the P2 amplitude enhancements to visual and auditory stimulation in the present experiment. Since the P2 components to the bisensory events were consistently greater than were the unisensory P2 amplitudes, it is suggested that the secondary maximum produced by the visual stimulus interacted with the auditory maximum and resulted in significantly larger bisensory P2 amplitudes.

The N2 component latencies (at both O_2 and C_z) for bisensory and auditory stimulation are shorter than N2 latency for light alone. This is in keeping with both classical RT data and our RT results and may be partially explained by the additional photochemical reaction which takes place at the retina in the processing of visual stimuli (Woodworth & Schlosberg, 1954). However, consider the data further. The N2 latency for light alone at O_2 was 167 msec, while it was 152 msec at C_z . The bisensory conditions (C and D) produced N2 latencies of 145 and 152 msec, respectively, at O_2 , and 134 and 136 msec, respectively, at C_z . This suggests that the same stimuli may arrive earlier at the cortical area under C_z than the area represented by the O_2 site.

The findings that bisensory stimulation produced faster RTs than unisensory stimulation and that larger EP amplitudes occurred with bisensory stimulation appear to support a position that sensory interaction occurs in the central nervous system, and, in certain instances at least, this interaction can be facilitative. The present state of neurophysiological knowledge does not allow a definitive conclusion as to the central nervous system locus of this type of sensory interaction.

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