Electrophysiological changes during stimulus generalization*

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Begleiter and Platz have reported systematic changes in the visual evoked potential after a visual stimulus was paired with a train of clicks following a classical conditioning and extinction procedure. In order to test for stimulus generalization, 15 college students were given acquisition trials with an arrow, pointing either straight up or down, as the CS+ and CS—. Test trials were given with arrows rotated 10 deg from the training stimuli. Differences in the waveform recorded at the vertex to the positive and negative generalization stimuli were statistically significant.

Recently, Rosenfeld Rudell, & Fox (1969) demonstrated that in human Ss, the characteristics of the evoked potential to an auditory stimulus could be modified by instrumental conditioning. Begleiter & Platz (1969a), using a classical conditioning procedure with human Ss, reported that the evoked potential elicited by a conditioned stimulus (light flash) changes systematically during acquisition and extinction trials. Changes due to conditioning are shown most clearly in the late components of the evoked potential. These changes in the evoked potential waveform during classical and instrumental conditioning may represent changes in neural functioning. The question of stimulus generalization was investigated in the present study in order to determine if the evoked potentials elicited by two stimuli physically similar to the positive and negative training stimuli would also show differences following classical conditioning.

METHOD

In the present experiment, visual evoked potentials were recorded during conditioning and stimulus generalization. All data were derived from two monopolar scalp recordings of 15 college students. One active electrode (O_z) was located on the midline 2.5 cm above the inion; the other active electrode (C_z) was located at the vertex. In both cases, the

combination of the two ear lobes formed the reference electrode. Evoked potentials were recorded by means of a Grass Model 7 P5A wide-band ac EEG amplifier. The averaged evoked potentials were computed with the Mnemotron Computer (CAT 1000) and written out on a Moseley X-Y plotter.

The S was seated in an acoustically shielded enclosure, facing directly into a viewing hood, flush against the one-way mirror of the enclosure. On the other side of the glass window, a Grass PS-2 photostimulator was mounted and set at No. 8 intensity. The stimuli were presented in front of the photostimulator, located 50 cm from the S's eyes, and subtended the central 25 deg of the visual field.

The stimuli used during conditioning were two black arrows mounted on a transparent slide, one arrow pointing straight up, the other straight down. The slides were placed in a random-access projector which used the photostimulator as its light source.

One arrow served as the positive conditioned stimulus (CS+) and the other as the negative conditioned stimulus (CS—). The direction of the arrow serving as the CS+ or CS— was counterbalaned across Ss. A successive discrimination procedure was used with the two stimuli being presented randomly for 100 trials (50 trials per stimulus), with a 2- to 4-sec interval between presentations. Habituation of the evoked potentials to the stimuli was established by repeating this procedure three times: Baselines 1, 2, and 3 (B_1, B_2, B_3).

The unconditioned stimulus (UCS) was a train of clicks delivered through a loudspeaker. The onset of the 20-Hz train of clicks began with the onset of the 10-microsec CS+ and lasted for a period of 500 msec. The click was a stimulus of 0.1-msec duration and an intensity of 90 dB with reference to 0.0002 dynes/cm².

During the training procedure (acquisition, A_1), the CS+ was reinforced on 50% of the trials and the CS— was never reinforced. The CS— was presented 50 times, the reinforced CS+ 50 times, and the nonreinforced CS+ 50 times. The three stimulus conditions were randomized across the 150 trials.

For the generalization procedure (Test T1), two novel stimuli physically identical to the training stimuli, but differing in degree of slant, were presented. As in the training procedure, one arrow pointed upward, while the other pointed downward. However, the two test stimuli differed from the training stimuli by a slant of 10 deg. The arrows used to test for generalization effects were visually discriminable from the arrows used during the initial conditioning trials, as reported by all Ss.

During the generalization procedure, both test stimuli were presented randomly without the UCS for 50 presentations per stimulus.

The characteristics of the visual evoked potential were measured in accordance with previously described methods (Begleiter et al, 1967). Statistical comparison of the data obtained was always done between the CS— and the nonreinforced CS+. Significance levels of the obtained differences were evaluated by means of the Wilcoxon signed ranks test for matched pairs (two-tailed) in order to avoid making assumptions about the underlying normality of the evoked response distribution.

RESULTS

The evoked responses from a typical S recorded during conditioning and the subsequent test for generalization are shown in Fig. 1. Data from a previous study had indicated that changes in the evoked response during conditioning were most prominent in the late negative component, C (negative peak at 150-160 msec), recorded from the occipital. The mean value of amplitude C to the CS+ during the conditioning trials of the present study was 14.05 microV, with a standard deviation of 6.38. The mean and standard deviation of the response to the CS— were, respectively, 11.20 and 6.79. The mean response to the CS+ was thus approximately 25% larger than the response to the CS—. Thirteen of the
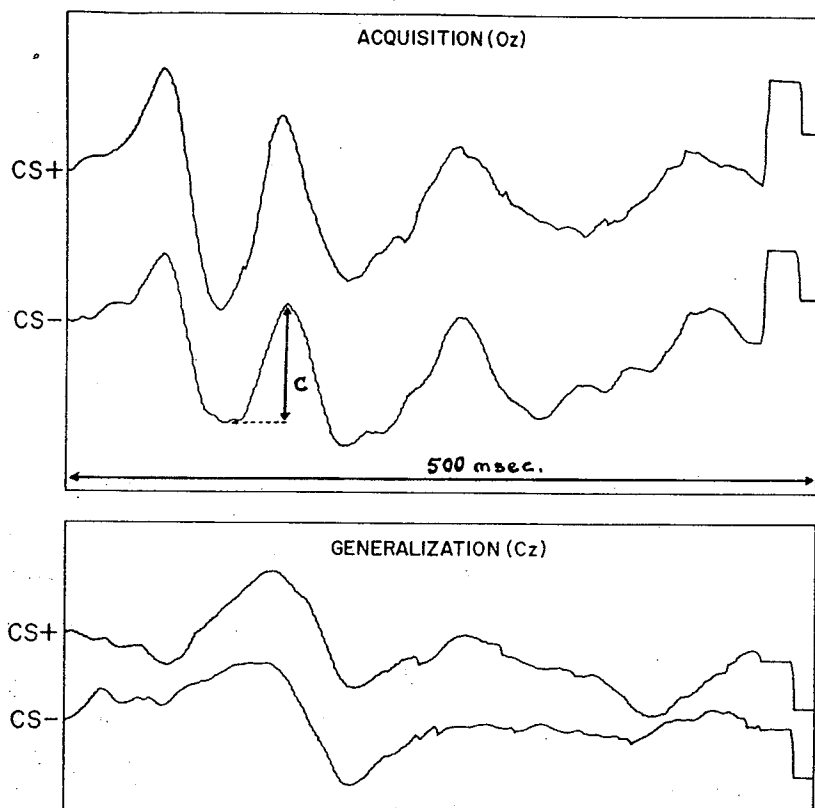
Fig. 1. Top: Visual evoked potentials to the positive (CS+) and negative (CS-) conditioned stimuli recorded at the occipital during conditioning. Bottom: Visual evoked potentials to physically similar stimuli recorded at the vertex during the test for stimulus generalization. Negative deflections are up, time base is 500 m-sec. The calibration pulse at the end of the waveform is equal to 5 micro V.

15 Ss showed a greater response to the CS+, one showed no difference, and one a slightly larger response to the CS—. These differences are significant at the .01 level. Most Ss also typically showed an enhancement of the response to the CS+ when the conditioning trials are compared to B_3, and a further habituation of the response to the CS— from B_3 to A_1. The early components of the evoked potential recorded at the occipital were not significantly different for the positive and negative CS, nor was there a significant difference in the potentials recorded at the vertex during A_1.

Differences in the wave form to the two stimuli physically similar to the CS+ and CS— also occurred after conditioning. Positive results were found at the vertex, with the generalized CS+ eliciting a response (M = 8.94 microV; SD = 4.73) which on the average was approximately 30% greater than the response elicited by the generalized CS— (M = 6.87 microV; SD = 4.04). Twelve of the 15 Ss gave a larger response to the positive stimuli, and the three reversals were small in magnitude. The difference in response to the two

generalization test stimuli was significant at the .01 level of confidence.

DISCUSSION

The present results confirm the initial finding of an enhancement in the late component of the evoked conditioning (Begleiter & Platz, 1969a) and further indicate that stimulus generalization to physically similar stimuli also occurs, as shown by the enhanced response to the generalized CS+ recorded at the vertex. In the previous study, several additional control Ss were run following the same procedure so that eye movements and changes in myogenic potential could be recorded. The failure to find changes in these measures paralleling the changes in the evoked potential suggests that the observed changes in the cortical response are not mediated by peripheral response mechanisms but, rather, reflect changes within the central nervous system itself.

These data appear quite consistent with a series of studies reported by John and his associates (1963, 1967, 1969), investigating the evoked potential correlates of conditioning

and generalization using a labeled response technique. In a typical study, cats were trained to make an instrumental food response to a 4-Hz flickering light and a shock avoidance response to a 10-Hz flicker. After training, cats were exposed to a flicker at an intermediate frequency. On those trials in which the animal pressed the food lever, the evoked potential to the intermediate flicker showed a striking correspondence to the waveform elicited by the 4-Hz flicker during training. However, when the avoidance response was made to the intermediate stimulus, the evoked potential was similar to that originally evoked by the higher frequency flicker. Since the physical stimulus is the same in both cases, the differences in waveform are related in some way to the neural representation of past experience, which is stored in the brain and released by the generalization stimulus.

John (1967) has argued that the evoked response to a CS has two major determinants, one reflecting exogenous activity evoked by the physical stimulus and a second reflecting endogenous activity which is released by the stimulus. The latter is modified by the organism's experience with the stimulus and thus reflects the effects of past learning. Several studies suggest that the late component of the evoked potential shows the greatest change during conditioning and that characteristics of the late waveform also appear to reflect the psychological significance or meaning of the stimulus to the organism (cf. John, 1967; Begleiter & Platz, 1969a, b). The present study extends these findings by showing that a novel stimulus which is physically similar to the positive stimulus used during conditioning will also elicit an augmented response at the vertex which is quite different in waveform from that elicited by a stimulus similar to the negative CS.

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