Temporal factors in the sensitivity of the alpha rhythm to habituation and conditioning

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A delayed conditioning paradigm with ISIs of .5, 1.0, 1.5 and 2.0 sec was administered to four groups of 14 human subjects. First, 15 3-sec tones and lights each were presented randomly, providing tone and light blocking baselines as well as pseudoconditioning control; this was followed by 15 tone-light trials. The pattern of occipital alpha blocking was obtained by integrating the alpha band (7.5-13.5 Hz) over .1-sec epochs. An analysis of the last block of three conditioning trials yielded a significant ISI effect in which the 1.0-sec group manifested the most conditioning. Unexpectedly, the .5-sec group did not have significantly different habituation and conditioning trends as did the other groups. This result is explained by evidence from the baseline trials of all subjects pooled that there is a regular unconditioned block to tone stimuli, smaller than, but similar to the block to light stimuli. The alpha system appears insensitive to experimental treatments during the block, but after about 90 msec can be further modified.

Conditioned blocking of the alpha rhythm has typically been studied with qualitative judgments of whether or not alpha blocking has occurred. In contrast, early works by Shagass (Shagass, 1942; Shagass & Johnson, 1943) and recent experiments by Putney (1973) and his co-workers (Braggio & Putney, 1975; Putney, Erwin, & Smith, 1972) have demonstrated the efficacy of using continuous measurements of alpha amplitude. Moreover, the literature on conditioned blocking contains few attempts to investigate parameters with known and fairly general effects for other kinds of classically conditionable responses. The interstimulus interval between tone-conditioned and light-unconditioned stimuli (ISI) was selected for this experiment, since it is one of the most thoroughly investigated parameters of conditioning. The investigation of ISI is particularly important because Torres (1968), in one of the few published parametric studies of conditioned alpha blocking, reported no effect of ISI, which was an unusual effect in the conditioning literature. Although Torres' data reduction procedure was more precise than that used by most investigators, it provided only the binary categories of blocking or not blocking, which may not have been sufficient to reveal an ISI effect.

A major problem in the study of conditioned alpha blocking has been that neither the latency distribution of conditioned alpha reduction nor the time course of the response has been carefully explored, as these time related functions have been closely examined with other kinds of classically conditionable responses (e.g., Grant & Norris, 1947). Typically, ISIs of 1 sec or more have been used, and CRs were scored without reference to when they occurred in the interval.

The usual procedure, following Knott and Henry (1941), has been to score a conditioned block if at least three waves in the scoring interval were at least 50% of the amplitude of the three waves just preceding stimulus onset. This procedure has a number of deficiencies, the main one of which is a loss of precision from reducing continuously variable amplitude to a binary form. Also, true CRs cannot be distinguished from spontaneous spindling in which 50% reductions frequently occur, particularly when long ISIs are used (e.g., Davidoff & MacDonald, 1964). Finally, since the CR scoring is made on the basis of alpha amplitudes just preceding stimulation, an unknown amount of variability is introduced into the results from factors which determine when stimuli are presented. The standard procedure has been to decide, on the basis of visual inspection, whether a sufficient amount of alpha is present to manually present stimuli. Thus, any combination of these factors may have contributed to Torres' (1968) failure to find variation of the level of conditioning with different ISIs.

Putney (1973) found that a more restricted scoring interval around the point of UCS onset, and a continuous measure of alpha amplitude were effective in distinguishing conditioned alpha blocking from pseudoconditioning. Milstein (1965) and Stern, Das, Anderson, and Bidy (1961) were unable to make this differentiation using the 50% reduction criterion. In order to explore the ISI effect, a method similar to Putney's was used in the present study. Additionally, a standard trial initiation procedure was used, in which a minimum criterion amount of alpha was required to initiate stimulus presentations.

METHOD

Subjects

Fifty-six student volunteers from introductory psychology classes were selected on the basis of having sufficient alpha to produce the occurrence of 75 trials within 45 min.

Apparatus

The EEG was recorded using a Grass Model 78 polygraph and filtered by Krohn-Hite variable band pass filter. The EEG was recorded from polished silver electrodes (Grass) placed on O_2 referenced to the left ear lobe. The 3-dB down points were 7.5 and 12.5 Hz. The rectified filtered signal was used as input to a Grass Model 7P10A polygraph integrator which was sampled by an IBM 1800 computer.

The CS was a 3-sec 540 Hz tone approximately 30 dB above auditory threshold. The unconditioned stimulus was a 3.0-sec 2.065 log fL light, presented through a 50.5-cm circular mask in the translucent window of the experimental chamber. Trial initiation was controlled by logic circuitry which monitored the filtered alpha activity. Any alpha wave above a preset Schmitt trigger threshold could initiate the computer sample. The threshold was adjusted independently for each subject to insure that only higher amplitude waves were counted. If the criterion of four waves above an amplitude threshold within .45 sec was not satisfied, computer sampling was terminated. If the criterion was satisfied, the computer continued to sample, while presenting the scheduled stimulus followed by the intertrial interval.

The subjects were seated approximately 1.7 m from the stimulus sources in a soft chair located in an electrically shielded soundproof chamber (Industrial Acoustics Co.). A response switch was located on the arm of the chair.

Procedure

Forty-two subjects were assigned randomly to the .5-, 1.0-, and 2.0-sec ISI groups. Later, 14 more subjects were selected to form a 1.5-sec ISI group. The subjects were instructed to keep their eyes open, press the response switch when the light went off, and avoid unnecessary movements.

Each treatment group initially received 15 tones and 15 lights in a restricted random sequence in which the same stimulus occurred at most twice in succession. This sequence served the dual function of habituating alpha reduction to the tones and providing a within-subject pseudoconditioning control in which a nonspecific facilitation of blocking to tones from unpaired light stimuli could be used as a baseline with which to compare conditioning. Fifteen tone-light conditioning trials were then presented, followed by extinction consisting of 15 each of the tones and lights randomized as in the habituation sequence. The intertrial interval (ITI) was variable, depending on the amplitude and persistence of the subject's alpha. A minimum ITI of 5, 10, or 15 sec was randomly interposed, after which the trial was initiated when the subject's alpha level satisfied the previously described criterion.

Data Reduction

The increasing ramp function from the integrator was sampled by an IBM analog-to-digital converter at 10-msec intervals. Sampling started .5 sec before stimulus onset and continued throughout each trial. Each 10 successive samples were averaged by the computer to provide a mean value every .1 sec. By subtracting the average value for a given .1 sec from the previous one, a difference value was obtained which directly reflected amplitude in the alpha band for that .1 sec, the approximate period of an alpha wave.

The mean values were proportioned after partitioning the sets of 15 trials defined by their stimulus and experimental condition. The two .1-sec mean values just before stimulus onset indicated by the two leftmost dots in Figure 1 were averaged for each of the 15 sets of trials for each subject. This prestimulus average was divided

into each .1-sec value within each set for each trial, to obtain the proportion of the prestimulus amplitude at successive .1-sec intervals following stimulation, placing all the trials on a common scale. The data from the habituation tones, conditioning tone-lights, and extinction tones provided the basis for the major analyses. The data from the lights presented before conditioning were used to compute an average light blocking trend for all subjects to compare with the tone block in Figure 4 during the same part of the experiment.

The main analysis involved values taken near the point of UCS onset. Putney (1973) found that the first .3 sec after the UCS onset, before substantial unconditioned blocking occurred, was the region in which conditioned reduction was most easily demonstrated statistically. In the present data, because of an artifact not detected until the summary analysis of the data had been performed, the first measure after the onset of the light did not reflect the underlying alpha amplitude. Rather than select a scoring interval further into the region of unconditioned reduction, two .1-sec values just prior to light onset and the second measure after light onset were used in the main analyses. The values analyzed for each group are shown in Figure 1 in terms of .1-sec intervals following stimulus onset, and are indicated by the round dots. Thus, the ordinal positions following tone onset (S on the abscissa of Figure 1) of the four ISI groups are as follows: .5 sec—4, 5, 7; 1.0 sec—9, 10, 12; 1.5 sec—14, 15, 17; and 2.0 sec—19, 20, 22. Proportions were obtained by dividing the mean for the left-hand prestimulus pair of values for each condition into the mean of the three values around light onset, as shown for each ISI. These were then compared to the proportions for the corresponding values in habituation on the top line of Figure 1, directly above the .1-sec positions used for each ISI group.

RESULTS

The response of alpha to tone and tone-light presentation as a function of trials is presented in Fig-

Figure 1. Sampling intervals of the integrated alpha amplitude used to score alpha blocking during habituation and conditioning in the different ISI groups. Tone onset is indicated by a line shift after the left pair of dots, light onset by the line shift after the next pair of dots.

Figure 2. Mean proportion amplitude in blocks of three trials for tone habituation and tone-light conditioning.

ure 2 in terms of the mean proportion of amplitude for the measures appropriate to each group averaged for blocks of three trials. An increasing amplitude trend for the 1.0-, 1.5-, and 2.0-sec ISI groups can be seen in the left panel of Figure 2. L tests of monotonic trend (Page, 1963) yielded significant upward trends for the 1.0-sec group ($L = 14,428.5$, $p < .001$), the 1.5-sec group ($L = 14,411.5$, $p < .001$), and the 2.0-sec group ($L = 14,293$, $p < .001$), indicating that habituation occurred in these groups. In contrast, very little change and no significant upward trend ($L = 13,737.5$, $p > .10$) were obtained for the .5-sec group.

During conditioning, there was a downward trend (decreased amplitude) for the 1.0-, 1.5-, and 2.0-sec groups, followed by an increase in the 1.5- and 2.0-sec groups (see Figure 2). The present nonmonotonic conditioning trends were comparable to those reported by Putney et al. (1972) and Torres (1968). The conditioning trends for the three groups were clearly different from the habituation trends. The conditioning trends are in the direction of increased alpha blocking as a function of trials in contrast to the decreasing responsiveness found in the habituation results presented above. Thus, pseudoconditioning and conditioning operations apparently produce opposite patterns of response change. In contrast, the .5-sec group conditioning was not substantially different

from habituation. In order to compare habituation and conditioning trends to provide statistical evidence that conditioning occurred, tone habituation trial values were subtracted from corresponding conditioning trial values for each subject to obtain the difference between the two trends (see Putney, 1973). L tests on the resulting differences were significant for the 1.0-sec group ($L = 14,650$, $p < .001$), the 1.5-sec group ($L = 14,143$, $p < .001$), and the 2.0-sec group ($L = 14,032.5$, $p < .01$). However, the .5-sec group trends were not significantly different ($L = 13,379.5$, $p < .70$).

The ISI effect on conditioned alpha reduction was examined using the later conditioning trials, where differences among groups were the greatest. A Kruskal-Wallis test over the last block of three trials resulted in a significant difference among groups ($\chi^2 = 8.80$, $df = 3$, $p < .05$). Since the ISI effect obtained here was not found by Torres (1968), an approximation of his scoring technique was performed on the proportioned data. The application of his 25% reduction criterion resulted in CRs scored on almost every trial without any clear effects between groups. The common 50% criterion yielded results similar to the continuous quantification procedure used here. However, the groups were not significantly different on the last block of three trials ($\chi^2 = 6.36$, $df = 3$, $p > .05$), as they were using the proportioned data.

Analysis of blocking on the first five extinction trials around the point of UCS onset did not show a significant upward trend for any group, as in the habituation and conditioning analyses. Therefore, following Putney (1973), the same trials were quantified during the period when the UCR would have occurred on conditioning trials. Thus, the mean proportion amplitude for the 6-10th measures after light onset on conditioning trials can be seen in Figure 3 for the first five extinction trials. They were five ordinal positions beyond those used for the previous analyses, as in Figure 1. The trials were analyzed individually rather than in the blocks used for conditioning because extinction was rapid. Significant upward trends were found for the .5-sec ISI ($L = 717$, $p < .001$), the 1.0-sec ISI ($L = 698$, $p < .001$), and the 1.5-sec ISI ($L = 676$, $p < .001$), but not the 2.0-sec ISI ($L = 665$, $p > .05$). The ISI effect upon conditioning was also assessed by using the first extinction trial as a test trial. However, a Kruskal-Wallis test did not show significant differences between the groups ($\chi^2 = 4.198$, $df = 3$, $p > .10$).

The clear extinction trend for the .5-sec group is in sharp contrast to the other analyses for that group based on the scoring interval around the point of UCS onset. In order to determine whether measuring conditioned reduction so close to tone onset resulted in peculiarities not found at the more delayed intervals of the other groups, an examination of the average

Figure 3. Mean proportion amplitude for the first five trials of extinction.

response to the tone was made as follows. The 15 tone trials presented to all of the four groups during the habituation were pooled so that the time course of average alpha reduction could be examined for a large sample of trials ($N = 840$) in which there was no difference in treatment. As can be seen in Figure 4, the pattern of response to the tone appears to be a steep reduction, followed by a slight recovery beginning approximately 600 msec after tone onset. The closed (black) triangles indicate locations where measures were taken for the analyses of the different ISIs. The open triangles indicate the point where the artifact would have occurred for each group interval in Figure 3 when tone and lights were paired during conditioning. The trend for the light block is provided for comparison and is obviously much more extensive than the tone block.

The .5-sec scoring interval was located within the initial reduction period of the tone block, just beyond the first vertical line in Figure 4, whereas the other three intervals were within the recovery portion of the block. In contrast to the data for the .5-sec group alone, the analysis of data from the same interval for all subjects yielded a significant upward trend ($L = 55,607$, $p < .001$). However, the increase was

small when compared to the three scoring intervals located on the amplitude recovery portion of the tone response, all of which also had significant upward trends. The 1.0-sec interval displayed the most gradually increasing habituation trend, which did not reach the level of the others until the 10th trial, indicating that it was the scoring interval most sensitive to the auditory stimuli. Most of the habituation for the 1.5- and 2.0-sec scoring intervals occurred within the first few trials.

DISCUSSION

The contrasting trend analyses of alpha blocking as a function of trials before and after tone light pairing provide clear evidence for conditioning in all but the .5-sec ISI group. In the other groups, tone stimuli produced decreasing responsiveness across trials, reflecting habituation as found in previous experiments with this methodology (Braggio & Putney, 1975; Putney, 1973; Putney et al., 1972), when tones are presented unpaired with randomly mixed lights. Thus, pseudoconditioning, if it occurs under these conditions, is functionally the opposite of conditioning during tone-light pairing, which results in increasing alpha blocking to the tone for 10 or more trials.

Figure 4. Averaged alpha blocking response to tone and light stimuli for the 15 baseline trials of all subjects pooled. Solid black triangles indicate the location of values in the data analysis.

Although an ISI effect was reflected in several ways in the results of the present study, there are several inconsistencies which can be resolved by an examination of the varying responsiveness of alpha in the different time intervals sampled in the different ISI groups. The main evidence for an ISI effect was found in the last block of conditioning trials. The effect was also reflected in the conditioning trends obtained for the different groups. The most substantial conditioning was found in the 1-sec group, which had a monotonic trend in contrast to the response decrements occurring in the 1.5- and 2.0-sec groups. The trend of the .5-sec group was in sharp contrast to the other three, in that there was no evidence of conditioning and no significant difference in trend when compared to the pseudoconditioning control. This result in itself is highly inconsistent with the human conditioning literature, in which the optimal ISI has typically been found in the neighborhood of .5 sec.

Evidence that extinction occurred was provided by a significant upward trend only when alpha was measured in a somewhat later region after tone onset than that used to demonstrate habituation and conditioning. Although the groups were not significantly different on the first extinction trial, several aspects of the extinction trend analyses of four groups taken together strongly suggest the usually obtained ISI function. First, in contrast to the conditioning data, the trends begin at points reflecting a somewhat orderly decrease in responsiveness from the .5-sec to the 2.0-sec group. Second, the slopes of the extinction functions also show a fairly orderly decrease from .5 to 2.0 sec, also reflected in the values of *L* for the extinction trends, the value for the 2.0-sec group not being significant.

An understanding of these apparently contradictory results can be found in the blocking pattern of the preconditioning tone stimuli pooled from all groups. The initial reduction of alpha to the tone was not as great as the block following light stimuli, but it was substantial and of the same form as the light block (see Figure 4). This pattern suggests that tone stimuli also may produce a consistent unconditioned alpha reduction similar to light. This interpretation is supported by the substantial refractoriness of the period of initial amplitude decrease to habituation. Recalling that this region contained the interval for scoring the .5-sec group, no significant habituation was obtained in that group by itself, and only a shallow and uncharacteristic habituation was obtained from the data pooled for all groups. In contrast, the more usual curvilinear habituation functions were found for the other intervals, particularly the 1-sec interval, which may be in a region of optimal responsiveness of alpha to experimental treatments. Thus, measuring alpha amplitude in this region of

low responsiveness to experimental treatments provides an obvious explanation for the lack of evidence for conditioning in the .5-sec group. Further, substantial and significant extinction was found in the .5-sec group by measuring alpha amplitude somewhat beyond the refractory region during the initial alpha reduction. It thus appears that there is probably an ISI effect for conditioned alpha blocking much like other response systems. Test trials would be required to demonstrate the effects of short ISIs, and, therefore, longer ISI groups as well, to provide comparable results. However, pilot work has shown that the use of test trials is not particularly feasible, since not enough test trials can be administered to counteract the large intrinsic variance of the alpha rhythm. Either conditioning cannot be produced with too few reinforced trials, on the one hand, or it cannot be demonstrated with too few test trials, on the other.

The discovery of the varying responsiveness of the alpha rhythm at the different intervals following tone stimulation has implications for understanding both the nature of alpha blocking and its use to index psychological processes not studied here (e.g., orienting responses). The varying responsiveness probably results from the unconditioned reflex nature of the tone block. Thus, during the reduction phase, no other process is markedly effective in further modifying the alpha amplitude. However, the region just beyond the point of minimum reduction can be modified by a number of basic experimental treatments (habituation, conditioning, and extinction), and appears to vary as a function of a basic conditioning parameter, the ISI.

The reason why this property of the alpha blockade has not previously been discovered is rooted in the devotion in previous research to using the presence and absence of an alpha blockade or, at best, the amount or percentage of alpha present in relatively long intervals (e.g., 1 sec or more) as the dependent variable, rather than determining the whole pattern of alpha blocking. Thus, a consistent, but short duration, response was not detected by these relatively coarse measures. The detection of conditioning (Putney, 1973) and the effects of related variables (Braggio & Putney, 1975; Putney, Erwin, & Smith, 1973), as well as the effects found here, thus all argue strongly for the use of continuous measures over relatively small time intervals to discover the subtleties in responsiveness of the alpha rhythm.

The origin of the apparently reflexive response to the tones is of interest, since the bulk of evidence from the earliest studies of alpha blocking has indicated that light is the only form of stimulation which persists in blocking the alpha rhythm with repeated presentations, while blocking to acoustic and other stimuli of various kinds sub-

stantially habituates. Although there has been some controversy concerning habituation to light stimuli, flashes of sufficient duration (3 to 4 sec) produce responses which don't habituate (Braggio & Putney, 1975; Wells, 1959). However, the present results indicate that a similarly shaped but lesser amplitude unconditioned reduction to tone stimuli does occur with little habituation.

The probable underlying mechanism of this tone-related reduction is provided in the accumulation of recent evidence (Goodman, 1976; Lehtonen & Lehtinen, 1972; Mulholland, 1972; Plotkin, 1976), which suggests that alpha blocking has a primary relation to oculomotor activity involved in fixation (vergence and accommodation), rather than simply afferent input or a purely CNS state of visual "attention." Since oculomotor activity is a substantial part of normal orienting responses, it would appear that it is part of the orienting reaction to acoustic and perhaps other nonvisual stimuli. Both the habituation of blocking, commonly found in the literature, and the resilient initial alpha reduction could be understood in relation to the oculomotor orienting to acoustic stimuli, in which the short initial reduction is relatively resistant to habituation, while the more delayed reduction undergoes the increasingly rapid habituation found here in the 1-, 1.5-, and 2.0-sec groups.

If this account is correct, then the present kind of approach represents a valuable tool in studying the orienting reaction to acoustic and other stimuli under conditions which provide varying psychological processes. Such a result was reported by Putney and Cooper (Note 1) for different blocking trends during simple and choice reaction time tasks, and by Putney and Butler (Note 2) in exploring the relation between alpha blocking and saccadic eye movements. Knowledge of the presently obtained varying responsiveness of alpha at different delays following stimulation and use of the present methodology should provide an ability to maximize the chance of finding relationships by measuring alpha reduction at a point most sensitive to experimental treatments, or examining the whole trend of alpha reduction for possible effects.

REFERENCE NOTES

1. Putney, R. T., & Cooper, L. R. *Does "attention" block the alpha rhythm?* Paper presented at the Midwestern Psychological Association, Chicago, Illinois, May 1975.
2. Putney, R. T., & Butler, J. E. *The relationship between saccadic eye movements and blocking of the occipital alpha rhythm*

to visual stimuli. Paper presented at the meeting of the Society for Psychophysiological research, Philadelphia, Pennsylvania, October 1977.

REFERENCES

- BRAGGIO, J. T., & PUTNEY, R. T. The effects of unconditioned stimulus intensity on conditioned alpha blocking. *Physiological Psychology*, 1975, 3, 355-362.
- DAVIDOFF, R. A., & McDONALD, D. G. Alpha blocking and autonomic responses in neurological patients. *Archives of Neurology*, 1964, 10, 283-292.
- GOODMAN, D. M. The effect of oculomotor activity on alpha blocking in the absence of visual stimuli. *Psychophysiology*, 1976, 13, 462-465.
- GRANT, D., & NORRIS, E. B. Eyelid conditioning as influenced by the sensitized beta-responses. *Journal of Experimental Psychology*, 1947, 37, 423-433.
- KNOTT, J. R., & HENRY, C. E. Conditioning of blocking of the alpha rhythm of the human electroencephalogram. *Journal of Experimental Psychology*, 1941, 28, 134-144.
- LEHTONEN, J. B., & LEHTINEN, I. Alpha rhythm and uniform visual field in man. *Electroencephalography and Clinical Neurophysiology*, 1972, 32, 139-147.
- MILSTEIN, V. Contingent alpha blocking: Conditioning or sensitization. *Electroencephalography and Clinical Neurophysiology*, 1965, 18, 272-277.
- MULHOLLAND, T. B. Occipital alpha revisited. *Psychological Bulletin*, 1972, 78, 176-182.
- PAGE, E. B. Ordered hypotheses for multiple treatments: A significance test for linear ranks. *Journal of the American Statistical Association*, 1963, 58, 216-230.
- PLOTKIN, W. B. On the self-regulation of the occipital alpha rhythm: Control strategies, states of consciousness, and the role of physiological feedback. *Journal of Experimental Psychology: General*, 1976, 105, 66-99.
- PUTNEY, R. T. Conditioned alpha blocking re-examined with the measurement of individual wave amplitudes. *Electroencephalography and Clinical Neurophysiology*, 1973, 34, 485-493.
- PUTNEY, R. T., ERWIN, T. J., & SMITH, S. T. The facilitation of conditioned alpha blocking with an overt response. *Psychonomic Science*, 1972, 26, 16-18.
- SHAGASS, C. Conditioning the human occipital rhythm to a voluntary stimulus. A quantitative study. *Journal of Experimental Psychology*, 1942, 31, 201-209.
- SHAGASS, C., & JOHNSON, E. P. The course of acquisition of a conditioned response of the occipital alpha rhythm. *Journal of Experimental Psychology*, 1943, 33, 201-209.
- STERN, J. A., DAS, K. C., ANDERSON, J. M., BIDDY, R. L., & SURPHLIS, W. "Conditioned" alpha desynchronization. *Science*, 1961, 134, 388-389.
- TORRES, A. A. Alpha blocking "conditioning," sensitization, and interstimulus interval. *Psychological Reports*, 1968, 22, 669-675.
- WELLS, E. C. Modification of alpha-wave responsiveness to light by juxtaposition of auditory stimuli. *Archives of Neurology*, 1959, 1, 689-694.

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