A PARADOXICAL CONDITIONING EFFECT
IN THE HUMAN PUPIL*  

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A. INTRODUCTION

While autonomic conditioning is of importance to a number of psychological theories, controversy has continued over the very basic aspects of this phenomenon. Some workers have been severely critical of this type of work and a great deal of attention has recently been directed to a number of methodological issues in such widely studied autonomic response variables as GSR and heart rate (11, 14).

Since the early findings claiming the possibility of conditioning the pupillary response of the eye there has been a continuous stream of reports of negative findings, usually associated with further control and specification of the procedures. F. A. Young in 1958 (15) described careful replications of the central experiments of Baker (1) and Hudgins (9) and provided negative results.

Somewhat in contrast to these American studies reflecting methodological concern and yielding generally negative findings are the reports of a number of Russian investigators. On the assumption that conditioning of pupillary contraction has been convincingly demonstrated, they appear to be moving ahead in attempts to delineate factors influencing the conditioned-reflex activity of the pupil (5). In his recent book Perception and the Conditioned Reflex Sokolov (13) proposes to explain the habituation or weakening of the contraction to light through the influence of newly formed conditioned reflexes.

The results of these Russian investigators are somewhat difficult to evaluate in terms of criteria generally used by American research workers. Those studies available in translation present examples of individual trials illustrative of conditioning rather than any systematic group statistical analysis of a

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2 Deceased.

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set of data or even all or a part of an individual's data summarized in any form.

Not all recent American findings have been negative. In 1957 Gerall et al. reported a series of experiments including a sensitization control group that indicated successful conditioning of pupillary dilation in humans. No recent American report, however, has reported the successful conditioning of the contraction response in humans. Most of the negative reports have stressed the need for continuous investigation of this problem. Hilgard, Dutton, and Helmick (8, p. 689) wrote, "Unless satisfactory pupillary conditioning can be obtained, classical conditioning theory will have to be revised. It is important that the negative results not be allowed to stand until every effort has been made to discover more favorable conditions."

Possibly the major methodological issue in conditioning experimentation is the development of a criterion for demonstrating the production of a conditioned response. Since almost any sensory stimulus elicits changes in heart rate, GSR, and pupil diameter, it becomes necessary to ensure that the response change to be designated be produced by the specific experimental operations of conditioning per se rather than by other circumstances including the mere introduction of the UCS. A great deal of attention has thus been given to problems of pseudoconditioning and sensitization, and numerous efforts have been made to control these alternative explanations of response change.

Somewhat related is the recent work of Grings, Lockhard, and Dameron (6) who have been calling for more precise study of the conditioned responses by varying the time intervals between the onset of CS and UCS. They have demonstrated that when this CS-UCS interval is longer than the latency of the response system a complex double-hump conditioned response is generated. Grings thus specifies a first interval response which appears at approximately the usual latency of a response to the stimulus, and a later second interval response appearing at about the time the UCS has been applied during acquisition. While a demonstration of a newly formed complex response may be of some help in demonstrating conditioning as opposed to sensitization, the generation of these second interval responses is of basic interest in itself and should be considered in any theory of autonomic classical conditioning.

There has always been great difficulty in obtaining accurate measurements of pupillary reactions. Recent technological improvements have made it possible to measure the human pupil with a high degree of accuracy in complete darkness. The apparatus used in the present experiments has been described elsewhere in detail (7). Essentially it consists of an electronic infrared scanning device, which uses the time during which an infrared light spot is ab-
sorbed by the pupil, rather than reflected by the iris or sclera, to generate a voltage which is proportional to the diameter of the pupil. Sixty such measurements are obtained per second and form a continuous analog output. This output is stored on magnetic tape and later fed into a computer of average transients. The output from the computer is then plotted with an x-y plotter, after a compensation for the number of trials has been made. These average response curves permit us to detect very small time-locked signals in the rather large noise level of the pupil. The data in this study are presented in the form of average response curves of the diameter changes of the pupil. It should be noted that the data are summarized for individual subjects.

Several variations of a conditioning paradigm were used and will be described in turn. All included the basic individual trial which began with a half-second warning signal which was followed by the onset of the stimulus to be conditioned at a randomly variable interval (2-4 seconds). The subject was requested to maintain fixation and avoid blinking from the onset of the warning signal until a beep was sounded announcing that the trial was over. Eight seconds after the beep the warning signal started a new trial. Trials were given in blocks of 10 with short rests in between.

There were a number of variations in the stimuli to be conditioned, which will be described. Two unconditioned stimuli were used: (a) sharp clicks of .01 second duration were presented through earphones or an eight-inch speaker located above the subject's head, which produced a pupillary dilation, and (b) a Ganzfeld light stimulus of .3 millilambert intensity, which produced a contraction about one and a half millimeters in extent. The light stimulus was produced by a Sylvania glow modulator tube.

The subjects of the experiments to be reported were students who were informed that the authors were interested in studying the influence of a number of simple stimuli on the behavior of the pupil. Each experimental session began with a 10 minute period of dark adaptation.

**B. Experiment I**

The results of the first experiment are presented in Figure 1. Due to an interest in the work of Grings, Lockhard, and Dameron (6) the authors used a 30 db 1000 cps tone of 2.5 seconds duration as the conditioned stimulus (CS), which is more than twice the latency of a dilation to a sound stimulus under the authors' experimental conditions. After 20 trials of habituation to the CS alone, a series of 90 acquisition trials followed. During 60 of the 90 trials the unconditioned click stimulus was delivered at the exact end of the 2.5 second CS. Randomly interdigitated among these trials were 30 unrein-
forced test trials. This might be referred to, then, as a .67 reinforcement schedule. After acquisition, 20 extinction trials were given. Examination of the results indicates, first of all, that in comparison with the last 10 habituation trials there is a strong increase in the initial dilation response during acquisition, test trials, and the extinction period. In addition to this heightened response which reaches its maximum at about 1.25 seconds after the beginning of the CS in both the habituation trials and all of the other trials during the conditioning procedure, another response appears during acquisition which reaches its maximum well after the termination of the CS. The curve of the first 10 extinction trials runs remarkably parallel to the 10 trials sample acquisition curve in a clear double-humped curve. The test trial curve, and the curve of the second 10 extinction trials, also show an increase in diameter well after the presentation of the CS which is clearly different from the habituation trials. Similar results were found with two additional subjects.

The results of the above experiment may be viewed as support for the po-
sition that it is possible to condition the dilation response of the human pupil. Gerall, Sampson, and Boslov (4) attributed their successful dilation conditioning to fear rather than to the light reflex mechanism of the system. From an analysis of the literature they concluded that only shock was able to produce systematic conditioning. It is of interest, then, that the authors were able to obtain similar results with a sharp click. It is, however, possible that the noxious qualities of such a click are functionally similar to shock and thus provide the basis for conditioning.

The next experiments were an attempt to obtain a conditioned pupillary contraction. In these experiments the CS was a 600 cps tone at approximately 40 db above threshold. Twenty trials of habituation to the CS alone were followed by 60 trials of acquisition in which the .1 second light flash came on exactly at the end of the tone. All of the acquisition trials included a pairing of the UCS with the CS, since there is evidence to suggest that maximum classical conditioning is obtained with 100 per cent reinforcement. Twenty extinction trials followed the acquisition.

C. Experiment II

Two subjects, A. F. and B. S., were tested with the use of a conditioned stimulus of one second duration. Note (Figure 2) that the acquisition trial responses only include a small part of the contraction following the presentation of the light UCS. These responses were about a millimeter and a half, and could, therefore, not be presented at this scale. While there is some tendency for a heightened and extended dilation response to occur during the extinction trials, no indication of conditioned contraction appears in these results.

D. Experiment III

Two more subjects were tested using the same design, but a conditioned stimulus of two seconds duration was utilized. The results of these two Ss are presented in Figure 3. The following can be noted:

1. There is the usual pupillary dilation about one second after the onset of the CS.

2. There is again no indication of a pupillary constriction in the extinction trials.

3. Some systematic dilation occurs after cessation of the CS.

This second dilation response begins at approximately the time the light UCS "should" appear, and reaches its maximum well after the termination of the conditioned stimulus. Note that with subject H. G. a doubled scale had to be employed to get the data on one graph. It is clear that there are strong indi-
individual differences in the extent of the dilation responses under discussion. The data of two other subjects are not presented. One was deemed a poor subject because of a very high rate of blinking. The results of the other subject showed no particular dilation throughout the conditioning procedure used. In none of the six subjects was there any significant or systematic evidence of the conditioning of a contraction response.

Use of a two second or longer stimulus permitted the demonstration of a two-humped response curve following the conditioning operations that was not present during habituation. This may be taken as one criterion of conditioning, but is not a complete or perfect control against the alternative of pseudoconditioning or sensitization. One of the possible explanations of the second response is the sensitization of the off-response associated under certain conditions with the termination of the conditioned stimulus.

E. Experiment IV

The following experiment was carried out to deal with this specific problem, as shown in Figure 4. A three second 600 cps stimulus was employed as the CS. The unconditioned stimulus was the same (.1 second light), but this
time it was to be presented exactly one second before the termination of the CS, and therefore two seconds after the CS had started. Twenty habituation trials were followed by 90 acquisition trials. Sixty-six of these included CS-UCS pairings, and the remaining 24 served as test trials. The experiment was completed with 20 extinction trials. The acquisition and test trials in Figure 4 show a second dilation response which starts about two seconds after the onset of the CS. These results suggest a second response closely related to the temporal linkage of the UCS and CS during the paired trials, which cannot be related to the offset of the CS. Similar results were obtained with another subject using a click as a UCS.

F. Experiment V

A discrimination conditioning procedure was employed in a further attempt to deal with sensitization. Randomly varied presentation of an equal number of each of two stimuli, 500 cps and 1800 cps, was carried out through 20 habituation, 60 acquisition, and 20 extinction trials. During habituation both stimuli were, of course, unpaired with the usual light UCS. During 20 of the
30 presentations of the 500 cps tone the light UCS appeared at the end of this two second CS. The 10 other presentations of the 500 cps tone were unreinforced, and served as test trials. The 1800 cps presentations were never reinforced during any part of the experiment. The data of this experiment are presented in Figure 5.

In connection with the 500 cps stimulus there appears to be a clear dilation response developing where the UCS had appeared during acquisition, which

![Graph showing response curves](image)

**FIGURE 4**

**Average Response Curves of D. J. in Off-Response Control Paradigm**

was not present during the habituation trials. This may be noted in both the test and the extinction trials. A much weaker, but nevertheless parallel, trend may be noted to have occurred in the unreinforced trials with the 1800 cps stimulus. It can hardly be noted at all in the extinction trials. While a quantitative analysis should be viewed with reservation, it seems fair to suggest that the second interval response is more evident in the 500 cps trials which is further but limited support for conditioning. It might be relevant to state, at this point, that a more precise analysis using this approach might be possible
using stimuli of two different modalities. For obvious reasons a visual stimulus, such as used by Grings et al. (6) to contrast with a tone, would be problematic in pupillary conditioning.

G. EXPERIMENT VI

When this generalization effect which requires a quantitative analysis of discrimination conditioning was given, a different strategy was attempted with the use of UCS presentation equal to that used for conditioning, but without specific pairing with the CS. In this design a new subject was given the usual habituation trials with the second 600 cps tone (Figure 6, 143 S). During the next 60 trials which were parallel to the usual acquisition trials he received 40 presentations of the UCS interdigitated with 20 trials of the second CS given by itself. The usual 20 trials of extinction ended this session. After this sensitization control session (143 S) a parallel conditioning session (143 A) was run on the same S on a different day. This conditioning session included 20 trials of habituation with the same two second CS. Sixty trials of acquisition followed, 40 of which had the CS paired with the light UCS and the remaining 20 were CS alone. A comparison is thus possible between the
test trials interspersed with paired conditioning trials, and the 20 trials interdigitated among the presentations of the UCS during the sensitization session. It is also possible to compare the trials of extinction. The results indicate the very striking development of a second interval dilation response during the test trials of the paired conditioning run as compared with the sensitization run.

**FIGURE 6**
Average Response Curves of 143 in Sensitization Control Paradigm

**H. Experiment VII**

The most striking and clear-cut evidence for second interval dilation response conditioning over and above sensitization is shown in Figure 7. Once again with the use of a new subject, the experimental paradigm was exactly the same as in Figure 6 except that the click UCS was employed. Examination of Figure 7 shows the expected increase in the first interval response during the sensitization trials (137 S). No second response, however, was generated. During the later conditioning session (137 A), however, a clear, strong, second response appeared. It is of interest to point out that this occurred in spite of a smaller dilation response to the UCS during the conditioning run probably due to adaptation or habituation to the click UCS.
I. Discussion

The clearly negative results in regard to conditioning the contraction response to light must be added to the long list of failures to demonstrate contraction conditioning. No recent American investigator has obtained positive results; and even the Russian scientists speak of difficulty in the formation of a conditioned myosis to an auditory stimulus with photic reinforcement. Smirnov (12), for example, attributes this to the fact that "regardless of the physical nature of the photic signal announced by the auditory stimulus, the sound itself produces first of all an 'orienting reflex mydriasis'—a reaction opposite to the conditioned myosis being developed. Thus, in the competition between the two responses—the mydriatic and the myotic—to the same auditory stimulus, the former, as a rule, predominates over the latter."

To the degree that this model stresses the competition of response with the dilation associated with the onset of a sound stimulus it cannot be related to the second interval response dilation produced within the present experimental paradigm. It is possible that the second interval response dilation plays some role in inhibiting the appearance of the expected contraction, but the fundamental problem would then be to explain the occurrence of this dilation response.
A previous report of a systematic dilation response to an auditory CS after pairing with a UCS producing pupillary constriction was made by Ban and Shiroda (2). In this experiment on a cat the UCS producing contraction had been the stimulation of the lateral hypothalamic nucleus of the brain rather than a light stimulus. It would appear worthwhile, then, to investigate further possible sympathetic components that are elicited by stimuli expected to elicit a conditioned parasympathetic response. What is the actual theoretical meaning of a "conditioned" dilation produced by a light UCS?

Using sound stimuli longer in duration than the limits of response latency permitted the extension of Grings et al. analysis of GSR conditioning to the pupillary dilation response. Though the specific experimental methodologies differed, very similar results were found which demonstrated the second dilation response at about the same time relationship to the CS as the previously applied UCS. At the very least, evidence was provided for time-locked sensitization. While not absolutely conclusive, the control experiments offer support that conditioning took place over and above any sensitization present.

The present data may provide an opportunity to examine a question raised in regard to the explanation of this second response. In agreement with Grings et al. (6) and as opposed to Kimmel (10) the present data do not seem to support the notion of inhibition of delay first proposed by Pavlov. Examination of the data does not seem to indicate that the first response either decreases in magnitude or tends to move closer in time to the UCS, and thus provides the basis for the second response.

J. SUMMARY

Additional attempts to obtain pupillary contraction conditioning failed to demonstrate such a phenomenon. Analysis of the data generated by these attempts indicated the possible existence of a systematic dilation response where contraction might have been expected. This paradoxical effect was examined with CS-UCS intervals that permitted the demonstration of a two-component dilation response similar to that previously found in longer CS-UCS interval GSR conditioning. A number of sensitization control experiments were carried out.

REFERENCES


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