A Pitfall for the Expectancy Theory of Human Eyelid Conditioning

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Abstract—Two simple eyeblink conditioning experiments with random intermittent reinforcement schedules were performed. In Experiment 1, subjects had to rate their expectancy for an unconditioned stimulus (US) on a seven-level scale prior to each trial. As anticipated, expectancy for US increased with a successive conditioned stimulus (CS) alone, and decreased with successive CS–US pairings. However, Experiments 1 and 2 showed that the frequency of eyeblink conditioned responses (CRs) evolved in a direction opposite to that of expectancy changes: CRs increased, whereas expectancy for US decreased, and vice versa. The possible effect of sensitization on eyeblink response was ruled out by the lack of a run effect in an unpaired control group in Experiment 2. These results tend to disconfirm the expectancy theory of conditioning. Although they were explicitly predicted by the conventional "strength" theory of conditioning, an alternative interpretation is proposed within a cognitive framework.

THE ROLE PLAYED by verbalizable knowledge with respect to the relation between the conditioned stimulus (CS) and the unconditioned stimulus (US) in human Pavlovian conditioning is not well-understood. A broad range of views has been proposed on this subject. Although some authors still affirm that classical conditioning is an automatic, reflexive, and unconscious phenomenon (*e.g.*, Wingfield 1979), and others assert that the so-called conditioned behavior is entirely produced through the operation of higher mental processes (*e.g.*, Brewer 1974), a number of intermediate, multifaceted views have been advanced which may be situated between these extreme positions. Nevertheless, despite the lack of a clear-cut consensus on this issue, a majority of workers may be said to acknowledge that the awareness of CS–US relationships is a necessary but not sufficient condition for the occurrence of human conditioning (Dawson and Furedy 1976).

Although the data favoring such a position are impressive (*e.g.*, review in Perruchet 1979, 1980), it is worth noting that virtually all the available evidence is correlational in nature, that is, founded on the empirical co-occurrence of verbalizable knowledge of the CS–US relation and conditioned responding. In order to assess the causal influence of awareness on conditioning, it would be necessary to specify the kinds of processes that mediate the empirical relationship between awareness and the observed autonomic or skeletal conditioned behavior. The urgent need for cognitive theories of conditioning to pursue this line of inquiry has been underscored by several investigators (*e.g.*, Frcka *et al.* 1983, Pendery and Maltzman 1977).

The concept of expectancy may be usefully introduced at this point. This concept has received repeated mention in the field of conditioning since the well-known work of Tolman (1932). According to Tolman and his followers (*e.g.*, Bolles 1972), exposure to the CS–US contingencies arouses an expectancy for the US at the onset of the CS, which is, in turn, the source of various behaviors.* In order to integrate this older view into a more contemporary framework, Bolles and Fanselow (1980) have advanced the idea that expectancy for the US be considered as an intervening variable between the central representation, or memory, of the CS–US relationship and conditioned behavior. Expectation is said "to con-

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* Elsewhere, I have argued that the relevance of such a theory may be limited to the CRs that slightly anticipate the US onset, and are strictly tied to the characteristics of the impending US (Perruchet 1984). Only this category of reaction will be considered in this paper.

vert memory to action" (Bolles and Fanselow 1980, p. 294).

Introducing expectancy as an intervening variable in the awareness-conditioning relation permits the generation of several empirical predictions. In a recent paper (Perruchet 1985), I tested the implications regarding the relationship between the subjective ratings of expectancy for US and conditioned responding within a traditional eyeblink conditioning situation. On the whole, the experimental result clearly supported an expectancy theory. The following experiments were aimed at testing the prediction of the theory regarding the trial-by-trial conditioned changes in a simple conditioning situation with a random intermittent reinforcement schedule.

Let us consider a situation in which the US randomly follows only 50% of the CSs in a Bernoulli series. Such a situation generates runs (the term "run" is used here to designate a sequence of 1, 2, ..., n identical trials) of CS alone (nonreinforcement) and runs of CS–US pairings (reinforcement) of different lengths. It may be hypothesized that subjective expectancy for the US at CS onset must change in a systematic way when the preceding run goes from a long sequence of nonreinforcements to a long sequence of reinforcements via the intermediate conditions reported on the x-axis of Figure 1. More precisely, the "gambler's fallacy phenomenon" allows one to anticipate that expectancy should decrease along these conditions according to an approximately linear trend. Within the framework of the expectancy theory of conditioning, it seems compelling to anticipate that the probability of the conditioned reaction (CR) changes in the same way.

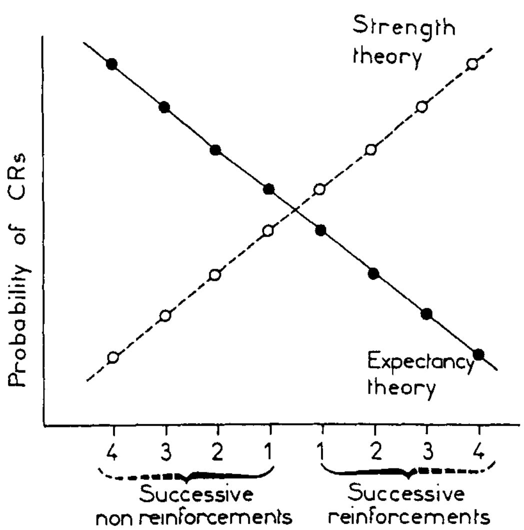

FIG. 1. Hypothetical probability of CR on a given trial as a function of the length and nature of the preceding run, according to the expectancy (●——●) and "strength" (○----○) theory of conditioning.

The primary interest of the above-mentioned situation lies in the fact that only the expectancy theory among the multiple competing theories of conditioning generates such predictions. It is worth adding that the conventional "strength" model of simple associative learning (Bush and Mosteller 1951, Hull 1943) predicts results in the strictly opposite direction; indeed, a basic postulate of the model is that the succession of reinforcements must strengthen the CS–US association and consequently improve conditioned behavior, while the succession of nonreinforcements must have an inhibitory effect upon responding. Thus, interestingly, as presented in Figure 1, the situation of random intermittent reinforcement allows a crucial test of the "neo-Tolmanian" and "neo-Hullian" accounts of conditioning.

Although a large number of experiments exist using an intermittent reinforcement schedule, only a few have included the trial-by-trial analysis suggested above. In electrodermal conditioning, Williams and Prokasy (1977) obtained evidence favoring an expectancy theory in two groups in which the reinforcement ratio was either 0.33 or 0.67. This trend is indirectly confirmed by a previous experiment of Streiner and Dean (1968). However, several experiments suggest that the findings are exactly opposite when the same analysis is carried out in an eyeblink conditioning situation: Prokasy *et al.* (1967), Higgins and Prokasy (1968), and Prokasy and Kumpfer (1969) report that response probability increases with successive reinforcements and decreases with successive nonreinforcements, thus favoring a traditional strength theory of conditioning.

Generally, these findings appear somewhat puzzling. Apparent dependency of electrodermal conditioning on expectancy changes certainly seems to agree with the contemporary cognitive framework. There is no compelling reason, however, for assuming that autonomic and skeletal conditioning should differ to such an extent in their relationship to cognitive factors. Although the automatic component of eyeblink conditioning has occasionally been reported (*e.g.*, Kadlac 1977), results of Baer and Fuhrer (1982), for example, strongly support the conclusion that both response systems involve essentially the same relation to cognition. These considerations cast doubt on the reliability of the findings concerning eyeblink conditioning, deriving from Prokasy's laboratory, or their relevance vis-à-vis the expectancy theory of conditioning.

It may be noted that in all of the three reported experiments, the effect of sequences has a small amplitude. Statistical significance is questionnable. Higgins and Prokasy (1968) provide no inferential test, and although Prokasy *et al.* (1967) and Prokasy and Kumpfer (1969) report significant results, the validity of their analyses is uncertain. Indeed, they include in their tests the probability of the CR recorded on the very first trial of each run, a procedure which results in counting some responses several times. (Williams and Prokasy (1977) remove this shortcoming from their analysis of electrodermal responding, cf footnote no. 4.) The initial purpose of the following experiments is to provide a new artifact-free examination of the changes in eyeblinks CR along runs of reinforcements and non-reinforcements.

Assuming for the moment that these experiments replicate the trends reported by Prokasy *et al.*, at least two points must be clarified before it is possible to formulate inferences regarding the expectancy theory of conditioning. The first involves the assessment of expectancy. Prokasy *et al.* were not concerned with the concept of expectancy and did not attempt to assess its modification in any way. Although support may be found within the traditional field of probability learning (a review in George 1971) for assuming that expectancy varies along the lines described above, the evidence is indirect and rather speculative. The second objective of the present research is to measure US expectancy changes along the conditions of interest. To this end, Experiment I required subjects to provide a direct rating of their expectancy for the US before each trial.

A second difficulty arises in considering the source of the observed changes in performances. Data are potentially relevant to a theory of conditioning as far as the changes in the probability of eyeblinks may be imputed to associative factors. At least another interpretation, however, may be advanced. Let us consider two trials following runs of equal length composed of reinforcements in one case, and of nonreinforcements in the other. Both trials differ with respect to the number of pairings experienced since the beginning of the run; but, they also differ in relation to the number of US received during the same interval. Thus, the differences in performance may be attributed equally to the first or the second factor. Indeed, repetition of US, whatever its pairing with CS, may elicit "sensitized" responses, which vanish with time when no US occurs. The third objective of the present research is to tease apart the effects of conditioning and sensitization on responding. To this end, Experiment 2 included a control group in which CS and US were never paired, although frequency and temporal distribution of US paralleled those of the experimental group.

Experiment 1

Method

Participants. Sixteen second-year university students (15 females, one male, mean age: 25 years) majoring in psychology served as subjects.

Apparatus. The CS was a 70 dB, 1 second tone of 1000 Hz, produced by a Dufour signal generator, and presented through stereo earphones.

The US was a puff of nitrogen of 2 psi and had a duration of 50 msec. It was delivered to the left cornea through a 1mm tube. The eyeblink responses were recorded by means of two photodiodes capturing the reflectance at the orbit of an infrared light-emitting diode (LED). In order to make the device insensitive to ambient light variations, the output of the LED was modulated with a 3300 Hz signal. The output of the photodiodes was processed so that only the 3300 Hz component of the reflected signal was detected. Photodiodes and LED were attached on the left side of a pair of spectacles, to which the airpuff delivery system was also fixed. Eyeblinks and marker signals were recorded on two FM channels of a four-channel R61 TEAC magnetotape.

Two response buttons were available to subjects for their expectancy ratings. When subjects pressed on the left button, a marker on the CRT screen moved toward the left side of a horizontal scale, and an opposite effect was obtained by pressing the button on the right side. The rating scale on the CRT was divided into seven levels; the left (marked −) and right (marked +) ends of the scale indexed respectively the minimum and the maximum expectancy. After each trial, the marker was automatically shifted toward the median position.

The entire experiment was controlled by an Apple II microcomputer.

Procedure. Subjects were escorted into a sound-attenuated, dimly lit room, separate from the apparatus room. They were seated in a chair facing the screen.

Instructions included the information that tones were randomly followed by an airpuff in 50% of the trials. Subjects were instructed to rate their expectancy for airpuff occurrence after the next tone during the intertrial interval; an explanation of the use of the rating device was provided. Regarding eyeblink responses, subjects were requested not to promote or inhibit their natural reactions.

TABLE 1. Organization of Trials*

	Nonreinforcements				*Reinforcements*				*Total*
Run length	4	3	2	1	1	2	3	4	
Number of runs	3	6	12	24	24	12	6	3	90
Number of trials	12	18	24	24	24	24	18	12	156

* The order of the 90 runs is randomized for each subject.

All subjects received ten preliminary trials, then 156 trials with a mean interval of 10 seconds (range: 10–14 sec) between trials. For the reinforced trials, the interval between the onset of the CS and the onset of the US was 950 msec. The sequences of 156 trials were constructed according to the method of randomization with restriction described by Nicks (1959, p. 106). Random drawings were taken, for each subject, from a set of runs (and not a set of trials) from which number and length previously had been computed. Maximum run length was limited to four trials. The number of original runs and the number of trials are reported in Table 1.

Eyeblink recordings were processed by microcomputer following transmission via an A/D transducer. An eyeblink CR was defined as a blink equal to or greater than 5% of the complete closing of the eyelid, occurring at least 500 msec after CS onset, and prior to US onset.

Expectancy ratings were scored from zero (airpuff not expected) to seven (airpuff expected).

Results

Eyeblink conditioning. Percent of CRs as a function of the length and nature of the run *preceding* each trial is plotted in Figure 2 (upper line). Despite an inversion of the first two points, there was a striking tendency for CRs to fit the predictions of the strength theory of conditioning. CR

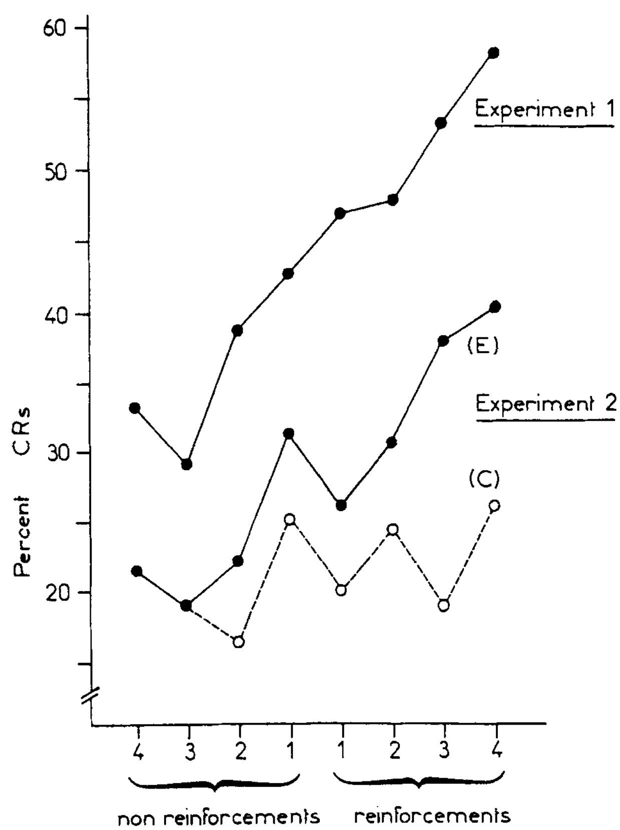

FIG. 2. Mean percent of CRs as a function of the length (1 to 4 trials) and nature (reinforcement/nonreinforcement) of the preceding run in experiment 1 (upper line) and in experiment 2 (bottom lines). Regarding experiment 2, the term "reinforcement" under the x-axis designates CS–US pairing for the experimental group (•——•) and US alone for the control group (○----○).

frequency differed significantly between conditions (F = 2.94, df: 7, 107, $P < .01$), and only the linear trend was significant (Flin. = 5.51, df: 1, 15, $P < .05$; Fnolin <1).

Expectancy ratings. Subjective expectancy as a function of preceding runs is plotted in Figure 3. As anticipated, there was an overall tendency for subjects to expect an alternation. There was a strong run effect (F = 9.98, df: 7, 107, $P < .001$). The decreasing linear trend was significant (Flin. = 17.44, df: 1, 15, $P < .001$). However, the inversion that appears in the middle of the regression line means that subjects must wait for a repetition rather than an alternation after a run of a single trial. This phenomenon is known in the probability learning literature as a "positive recency," or repetition effect (review in George 1971). This latter effect may be responsible for the fact that the F residual from the linear trend was statistically significant (Fnolin = 2.8), df: 6, 92, $P < .05$). Nevertheless, neither the quadratic (F < 1) nor the cubic (F = 2.40, df: 1, 15, $P > .10$) trends attained significance.

Overall, these findings provide a strong challenge for an expectancy theory of conditioning. Indeed, conditioned responding evolved in a direction that was almost exactly opposite to that of the subjective expectancy.

Experiment 2

The second experiment was intended to assess the associative nature of the trend exhibited by the eyeblink responses in Experiment 1. Consequently, a control group in which CS and US were never paired was included. Direct rating of expectancy for US at the CS occurrence would have been meaningless for this latter group, and, therefore, was not required from any of the subjects. As a substitute, subjects were asked to react to the airpuff onset by pressing a key as fast as possible, and reaction times (RT) were recorded. The rationale was that RT strongly depends on the expectancy of the response stimulus (*e.g.*, Perruchet 1985, Experiment 1), and thus might provide an index of subjective expectancy in place of direct rating. However, RT data did not furnish any unequivocally interpretable information, and, consequently, are not reported here.

Method

Participants. Twenty-eight second-year university students (21 females, seven males, mean age: 25 years) majoring in psychology served as subjects.

Apparatus and Procedure. The apparatus, the disposition of the subjects, and the scoring of CRs were identical to those in Experiment 1. Instructions also were identical, with the exception of those pertaining to the expectancy rating device, which were replaced by instructions concerning the RT task.

All subjects received ten preliminary trials, then 156 trials with a mean interval of 10 seconds (range: 6–14 sec). The composition of runs was the same as that in Experiment 1 (cf Table 1). For one half of the subjects (experimental group), a trial was either a CS alone or a CS–US pairing. For the remaining subjects (control group), a trial was either a CS alone or a US alone.

Results

Frequency of CRs as a function of the preceding run is presented in Figure 2 (bottom lines). Regarding the control group, no value is plotted for the longest runs of nonreinforcements; such runs were always followed by a US-alone trial, in which conditioned responding cannot appear. The corresponding values of the experimental group were deleted from the data for the ANOVA.†

† Data were submitted to ANOVA through a BASIC program, permitting the processing of any combination of between- and within-subject factors, and allowing any type of planned comparison and trend analysis (Perruchet 1982).

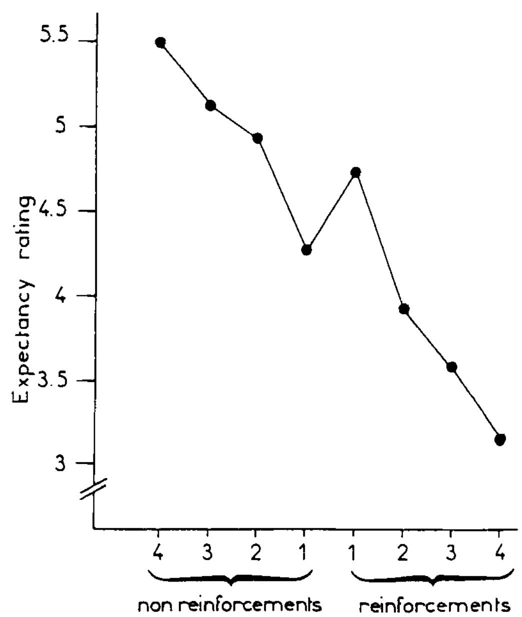

FIG. 3. Mean subjective expectancy (full scale: 0 to 7) for the US as a function of the length (1 to 4 trials) and nature (reinforcement/nonreinforcement) of the preceding run in experiment 1.

Performances of the experimental group were consistently better than those of the control group; however, mean differences in CR frequency did not attain significance.

Although conditioning may not be considered as established in the experimental group according to conventional criteria, it is worth noting that the pattern of performances is not the same for both groups. The nature of the preceding run elicits significant differences in eyeblink CRs for the experimental group ($F = 2.53$, df: 6, 78, $P < .05$) and the linear trend accounts for the greater part of the variance (Flin. = 9.38, df: 1, 13, $P < .01$; Fnolin < 1). Thus, results replicated the trend previously reported. On the other hand, run effect was not significant for the control group ($F < 1$). This latter result stands in agreement with the idea that the run effect observed in Experiment 1 and in the experimental group of the present experiment must be imputed to associative factors, and not to sensitization.

However, a nonsignificant result does not constitute a strong argument in support of any positive inference. For example, it may be due to large measurement errors or to an insufficient sample of subjects. The only valid conclusion allowed by the nonsignificant F-ratio is that the absence of a run effect in the control group is not rejected by the data. The use of Bayesian procedures was adopted because it potentially affords, under the circumstances, a more sensitive analysis of the data (Rouanet and Lecoutre 1983). The running of these procedures led to the conclusion that the upper credibility limits at a Bayesian guarantee of 0.90 for the slope of the regression line was 0.0212, which corresponds to a difference of 0.127 in CR frequency between the extreme (longest) runs. This latter value may be thought of as rather weak. The equivalent differences for the experimental group, estimated from the regression line, was 0.205. Probability for the control group to stand below this value was computed to be 0.992.

On the whole, Bayesian analysis supports the claim that the effect of the preceding run is negligible when conditioning is prevented. Therefore, the trend observed in Prokasy's laboratory, as well as in the present research when CS and US are paired, may be attributed with a fair degree of confidence to associative factors.

Discussion

The aim of the present research was threefold.

The first objective was to replicate the prior results of Higgins and Prokasy (1968), Prokasy *et al.* (1967), and Prokasy and Kumpfer (1969), using a slightly different (and supposedly more valid) method of analysis. Prokasy reported that when subjects are submitted to a random, intermittent reinforcement schedule, the frequency of eyeblink CRs increases with successive reinforcements and decreases with successive reinforcements. Corroboration of these trends was needed because of their apparent discrepancy with an expectancy theory of conditioning, and with the result observed in electrodermal conditioning in the same situation.

Results of Experiment 1 strongly supported the previously reported trends. Although the performances of the experimental group in Experiment 2 also demonstrate the same tendency, a problem is raised by the nonsignificant differences between the mean frequency of CRs in the experimental and control groups. Rough comparison with the performances attained in Experiment 1 (cf Figure 2), and with the comparable published data, suggests that nonsignificance is due to the especially poor responding of the experimental group, rather than the unusually high performances of the control group. The reasons for these poor performances are not entirely clear. It is possible that the keypressing task at airpuff onset may actually serve as a masking task, the detrimental effect of which, upon eyeblink CRs, is well documented (review in Ross 1971). Alternatively, preparatory processes for the required motor reaction may inhibit anticipatory conditioned responding. It should be added that this uncertainty has no major consequences, since the primary focus of Experiment 2 was essentially on the performances of the control group.

The second objective was to assess the changes in subjective expectancy for US within a random intermittent reinforcement schedule. Generality in situations of the "gambler's fallacy phenomenon" and some results from the probability learning field suggested that expectancy for US increases with successive CS alone, and decreases with successive CS-US pairings. Direct ratings of expectancy recorded in Experiment 1 strongly supported this view.

Considering conditioned responding and expectancy together furnishes clear evidence opposing an expectancy theory of conditioning, since both variables evolve in opposite directions as a function of the preceding run. Nevertheless, it remains possible that the trend exhibited by conditioned responding is due to sensitized eyeblink responses.

The third aim of the present research was to test this hypothesis. It was disconfirmed by the performances of a control group in which CS and US were never paired—under such conditions, run effect was nonsignificant. Furthermore, the use of Bayesian procedures of analyses led to the conclusion that run effect was negligible. Yet, the adequacy of the choice of the control procedure could be questioned. In the words of Rescorla (1967), an "explicitly unpaired" control group was used. A "truly random" schedule was incompatible with the aim of the experiment. Indeed, the latter involved randomization of the interstimulus interval, and the testing of the hypothesis, imputing run effect to sensitized responding, required that the intertrial interval be the same for the experimental and control groups. Implications of using an "explicitly unpaired" group must be assessed. This schedule involves a negative contingency between CS and US, which could conceivably elicit conditioned inhibition. Although direct evidence against the development of conditioned inhibition in our experiment may not be given, two points deserve mention. First, sensitivity of CRs to a negative contingency has not received clear support from recent studies (*e.g.*, review in Damianopoulos 1982). Second, assuming that the negative contingency really lowered the performances, this detrimental effect would be effective irrespective of the nature of the preceding run. Therefore, such a hypothesis does not invalidate our conclusion, which concerns run effect.

On the whole these findings provide evidence against an expectancy theory of conditioning.‡ This conclusion is obviously restricted to eyeblink conditioning, and does not prejudge the validity of the expectancy theory for other response systems. As mentioned above, results favoring this theory have been reported for electrodermal responding (Williams and Prokasy 1977). However, it is worth noting that eyeblink CRs unambiguously concern "forward-directed" responses for which expectancy theory seems relevant a priori (Perruchet 1984; cf intra footnote 1).

In the introductory section, predictions based on the concept of expectancy were pitted against predictions deriving from the conventional "strength" model of conditioning. This alternative model was introduced because it anticipates a pattern of results exactly opposite those of expectancy theory. Unexpectedly, this anticipated pattern fits the empirical data well. This surprising result raises a fundamental problem: are the findings obtained sufficiently robust to restore this seemingly outdated theory to favor?

On the one hand, the findings furnish evidence that "something" progressively strengthens through repetitions of pairings, and vanishes when CS alone occurs. This phenomenon, which constitutes a cornerstone of the strength model, has been overlooked by most cognitively oriented workers, perhaps because the concept of awareness is not well-suited to the idea of gradual increment or decrement. The present research shows that such a traditional notion deserves further consideration.

On the other hand, however, there is no compelling reason to assert that "something" that gradually strengthens or vanishes is mechanistic and reflexive in nature, as does the conventional strength theory. In the remainder of this paper, findings will be considered tentatively in terms of a so-called cognitive point of view.

As a starting point, the time-locked feature (Sears, Baker, and Frey 1979) of the eyeblink CR requires consideration. Dependency of eyeblink CRs on the strictly defined temporal relation between CS and US has been underscored since the earliest studies on this topic. Further investigations have shown repeatedly that eyeblink CRs track the exact moment of US occurrence (*e.g.*, Martin and Levey 1969). This property of the responses involves an accurate knowledge of the timing of the stimuli. It may be hypothesized that this knowledge is acquired step-by-step through the repetitions of trials. In a first stage, knowledge of the accurate timing would be stored in short-term memory. The short-lived feature of the mnemonic traces would account for the pattern of empirical results reported above: representation of the CS–US interval vanishes through spontaneous decay and/or interference provided by CS-alone occurrence (as does any representation stored in short-term memory), and is revived by a new occurrence of paired stimuli. This model permits the anticipation that, with further repetitions, short-term traces transfer to a more permanent long-term memory store. Consequently, the pattern of increment/decrement with successive reinforcements/nonreinforcements must tend to disappear with prolonged practice. Such was indeed the result reported by Prokasy and Kumpfer (1969) when a very long conditioning phase (15 sessions of 360 trials each) was split into two parts. It may be noted that Prokasy and Kumpfer encountered some difficulties in accounting for their result within the framework of a conventional strength theory of conditioning.

The assumption that the constitution of memory traces bearing on the accurate timing of events is a fundamental requirement of conditioning generates other empirical predictions, the testing of which must await future investigations.

‡ Supporters of the expectancy theory may argue that assessment of expectancy through subjective ratings is not relevant. However, this kind of criticism has little, if any, value, until such time as alternative methods of measurement are proposed.

If the model is correct, the timed representation could be built through specific arrangements, such as a RT task with constant foreperiod, or a time estimation task, and then successfully transferred to conditioning situations. To the best of my knowledge, such a prelearning phase has never been performed.

As a final point, it must be emphasized that this hypothesis only addresses eyeblink, or, at best, skeletal conditioning. Most of the other response systems do not exhibit the same dependency of CRs on strictly defined timing, and input into memory of accurate CS–US intervals is perhaps not a necessary prerequisite for their conditioning.

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