Pavlovian Analysis of Interactions Between Hunger and Thirst

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In four experiments we examined the effect of an irrelevant drive on classical conditioning with food and water. In the first experiment the irrelevant drive weakened the conditioned response in extinction. In Experiments 2 and 3, this suppressive effect was found also in acquisition. Furthermore, the presence of an irrelevant drive during nonreinforced presentations of the conditioned stimulus was found to protect the conditioned response from extinction. Experiment 4 showed that the depressive effect of the irrelevant drive is manifested only when the relevant drive is present. Taken together, these results suggest that an irrelevant drive can influence conditioned responding by modulating the representation of the unconditioned stimulus.

A number of authors have observed that instrumental responding for food is suppressed by the simultaneous presence of thirst, and similarly, that responses motivated by thirst are disrupted by hunger. One of the first studies to demonstrate this phenomenon was performed by Kendler (1945). In that experiment, rats were trained to press a bar for food under a 22-hr food deprivation schedule and different levels of superimposed water deprivation. Kendler (1945) found a clear facilitation of extinction in the group with the most severe water deprivation (22 hr) relative to a group that was merely food deprived. Since then, it has been repeatedly found in acquisition that high levels of irrelevant thirst impair instrumental responding for food (Capaldi, Hovancik, & Lamb, 1975) and extinction (e.g., Siegel, 1946) and also that irrelevant hunger is similarly detrimental to water-reinforced responding (e.g., Bolles & Morlock, 1960; Kendler & Law, 1950).

Parallel to these instrumental conditioning studies, other authors have noted decreased feeding when water deprivation is imposed on the animal and decreased drinking when food deprivation is in progress (e.g., Toates, 1980; Verplanck & Hayes, 1953). Thus, there appears to be a reciprocally inhibitory relation between the motivational systems underlying behavior directed toward the acquisition and consumption of food and water. In the present article we attempt to examine the influence of this relation on appetitive classical conditioning. Because responding for an unconditioned stimulus, and its consumption, can be impaired by the presence of an irrelevant drive, we also expect appetitive conditioning to be disrupted by this state. In addition to providing information about the way in which motivational processes influence the vigour of appetitive conditioned responses (CRs), the proposed experiments may also elucidate the nature of the interaction between hunger and thirst.

Experiment 1

In Experiment 1 we examined the influence of an irrelevant drive on the acquisition and extinction of an appetitive CR. Two groups received standard appetitive conditioning: One group, which was thirsty, was reinforced with water, and the other group, which was hungry, was given food. To determine the effect of an added drive, two further groups that were both hungry and thirsty were separately conditioned with either food or water. If the effects found with instrumental conditioning can also be obtained with a Pavlovian procedure, then the presence of an irrelevant drive will impede conditioning and facilitate extinction in the irrelevant-drive groups relative to their single-drive counterparts.

Method

Subjects. The subjects were 32 naïve Sprague-Dawley rats whose mean free-feeding weight was 368 g (range: 302–441 g). The animals were assigned to four groups (ns = 8). Two groups were conditioned with food (F), Group H-F being hungry (H), and Group HT-F being hungry and thirsty (T). The remaining two groups were conditioned with water (W): Group T-W was thirsty, and Group HT-W was both hungry and thirsty. Food deprivation was effected by initially restricting intake to 6 g of Modified Rat and Mouse Breeding Diet (Pilsbury's Ltd.) each day. Group H-F animals were fed this amount until they were reduced to 80% of their free-feeding weights, when they were given a sufficient amount (about 15 g) each day to maintain them at that level. Groups HT-F and HT-W also experienced this schedule of food deprivation, as well as a gradual water deprivation, which was superimposed on the food deprivation schedule starting on the 3rd day. The time allowed for drinking on each of the next 11 days was 8 hr, 4 hr, 2 hr, 1 hr, 30 min/day, 20 min/day (for 4 days), and 15 min/day (for 2 days) before magazine training began. Subjects were thereafter permitted 15-min access to water each day. Group T-W underwent the water-deprivation schedule only. Animals were given food and water immediately after every session.

Apparatus. The apparatus, which was controlled by a microcomputer, consisted of four experimental chambers, stacked in a 2 × 2 matrix, and video-recording equipment. The front and back walls of the chambers were made of clear Perspex. Food was delivered into a rectangular magazine recess (7 cm × 6.7 cm) situated midway along one side wall. The base of this 1.7-cm deep recess was 2 cm above the floor of the chamber. In the center of the floor of the recess was a circular aperture, 1 cm in diameter. The dispenser of the US (unconditioned stimulus) was a Perspex disc, 17 cm in diameter, with 12 regularly placed indentations around the circumference, which contained either a 45-mg food pellet (Campden Instruments) or 0.2 ml of water. This disc was placed immediately below the magazine in such a way that when one of the indentations was touched by the animal, the US was delivered. The two chambers in the top row were designated for conditioning with food, and the two chambers in the bottom row were designated for conditioning with water.
tations on the disc was aligned with the aperture in the magazine, the rat was able to consume the US. During the intertrial interval the disc was rotated by the operation of a stepper motor so that a blank section showed below the hole in the recess.

The conditioned stimulus (CS) was a 2-kHz, 74-dB (Scale C) tone presented through a loudspeaker, the center of which was 7 cm above the top of the magazine recess. Because the operation of the dispenser was virtually noiseless, a 330-ms, 62-dB click was presented simultaneously with the presentation of food or water throughout the experiment. A 60-W bulb was located 2.5 m from the front of the boxes. The behavior of the subjects was recorded on videotape during the CS by a camera placed 2 m away. A 25-cm monitor and video recorder were situated in an adjoining room.

Procedure. All subjects were initially given two 45-min sessions of magazine training, with the appropriate US being presented every 60 s. Two groups were trained with food pellets (H-F and HT-F) and two with water (T-W and HT-W). Then, eight conditioning sessions were conducted. In each 44-min conditioning session, there were six trials with a mean intertrial interval of 5.5 min (range 4-7 min). The 10-s CS overlapped for the final 1 s with the delivery of the US. The US remained in the magazine for 5 s, unless consumed, before the dispenser rotated. After 8 days of conditioning, all subjects received four sessions of extinction training without any change of their deprivation state. Apart from the omission of the US, the procedural details were identical to those during acquisition.

The effects of conditioning were evaluated by observing a magazine response, which was defined as the presence of the subject's snout in the magazine or immediately below it. Observations of this response were made twice during the CS: 4 s and 8 s after onset.

Results

A three-way analysis of variance using the total CRs recorded for each subject in each of the four extinction sessions indicated a significant effect of sessions, $F(3, 84) = 62.35, p < .01$, but not of training US, $F(1, 28) = 2.5, p > .10$. There was a significant interaction between training US and sessions, $F(3, 84) = 3.85, p < .05$. Analysis of simple main effects revealed that on the 3rd day of extinction Groups T-W and HT-W combined responded significantly more than Groups H-F and HT-F combined, $F(1, 28) = 5.15, p < .05$. The remaining days showed no differences in this respect, $F$s(1, 28) < 3.03, $p$s > .09. Most important, there was now a significant effect of the presence of the irrelevant drive, $F(1, 28) = 9.06, p < .01$. The animals with the irrelevant drive showed poorer responding in extinction relative to animals with only the relevant drive. The Training US × Drive State interaction ($F < 1$), the Sessions × Drive State interaction, $F(3, 84) = 1.32, p > .25$, and the triple interaction ($F < 1$) were not significant.

Discussion

The addition of an irrelevant drive had no effect on the acquisition of appetitive conditioned responding. There was, however, a significant effect in extinction: Conditioned responding declined faster in the groups where an irrelevant drive was superimposed on the relevant drive state. One explanation for the failure to observe a similar effect in acquisition is that ceiling effects masked the influence of the irrelevant drive. Had conditioning been less rapid or reached a lower asymptote, there may have been more scope for the differences between the groups to become evident. The effect of the irrelevant drive during acquisition may be enhanced either by increasing the severity of the irrelevant drive or by decreasing the severity of the relevant drive. In the following experiments appropriate changes will be made in the deprivation schedules to look for the effect of an irrelevant drive during acquisition.

Another result of interest in Experiment 1 was that the water-reinforced groups showed better conditioning. This effect was significant in some acquisition and extinction sessions. The fact that the water was able to support better conditioning than food suggests that the animals were slightly more thirsty than hungry or that in our procedure water was a more effective US than food for conditioning. This difference did not in any way interact with the effect of the irrelevant drive as described above.

Experiment 2

Two general classes of explanations are possible for the effect of the irrelevant drive observed in Experiment 1. One possibility is that the motivation to perform the CR is reduced in the presence of an irrelevant drive. To test this account, Experiment 2 focused specifically on the effect of thirst on conditioning with food. Two groups were treated in much the same way as in Experiment 1 except that an attempt was made to enhance the level of the irrelevant drive. Thus Group HT-HT was maintained both hungry and thirsty during acquisition and extinction, and Group H-H was maintained hungry throughout. On the basis of the previous result, Group HT-HT was expected to show faster extinction and perhaps slower acquisition than Group H-H. Two further groups were included. Group HT-H was hungry and thirsty during acquisition but was satiated with
water for the extinction stage. If an irrelevant drive can dampen the vigor with which a CR is performed, then the elimination of this drive should remove this effect and so boost extinction performance in this group to the level of Group H-H. The second additional group (H-HT) was hungry for both stages of the experiment and deprived of water for the extinction stage. Once again, if the irrelevant drive influences conditioning solely by reducing the vigor of the CR, then its imposition in Group H-HT should hasten extinction relative to Group H-H.

The second class of explanation assumes that an irrelevant drive can influence associative learning. Classical conditioning is commonly considered to result in the growth of an association between the CS and US. The strength of this association is said to govern the vigor of the CR and to be determined in part by the magnitude of the US. Because thirst may reduce the palatability of food (Bolles, 1975; Capaldi et al., 1975), it is possible that the presence of this irrelevant drive will reduce the effectiveness of food as a reinforcer for Pavlovian conditioning. This will result in the growth of a weaker CS-US association in animals with the irrelevant drive than in animals that are only hungry. Such an account makes predictions for Experiment 2 that are opposite to those made by the first explanation. For Group H-HT the induction of thirst during extinction should not influence the previously formed CS-food association, and the strength of the CR in this stage of the experiment should be same as that for Group H-H. On the other hand, a rather weak CS-US association will develop for Group HT-H, and in spite of the removal of thirst in extinction the CR in this group should be of a relatively low magnitude.

To test these accounts further, all subjects received a final stage in the experiment for which they were food but not water deprived. The rationale for this treatment will be made clear in the Discussion.

Method

Subjects. Thirty-two naive male Sprague-Dawley rats of mean free-feeding weight 327 g (range: 291-366 g) were used. All subjects were food deprived using the schedule described in Experiment 1 but with one slight alteration. We attempted to make the irrelevant thirst more severe by utilizing a drier food in the home cages (Diet TR 2, Pilsbury's Ltd.) than the pellets used in the previous experiment. This new diet
has the effect of increasing the daily consumption of water when freely available. Half of the animals also underwent a water deprivation schedule that followed the sequence described in Experiment 1. When the schedule was completed, these animals were given 12-min access to water on each of 2 further days before the beginning of magazine training. They were maintained on 12-min access to water each day during acquisition. All animals were given sufficient food to maintain them at 80% of their free-feeding weights throughout the experiment.

**Apparatus and procedure** The details of magazine training and of conditioning and extinction did not change from the previous experiment. During acquisition, the US for all animals was food. Half of the subjects were maintained hungry and thirsty, and the other half were maintained merely hungry. Acquisition was continued for 6 days. After the sixth session, the 16 rats that were both hungry and thirsty were assigned to two groups of equal size: One was given continuous access to water immediately after the final conditioning session (Group HT-H), and the other was maintained hungry and thirsty (Group HT-HT). Similarly, the 16 animals that were only food deprived were assigned to two groups of equal size. The freely available water supply was removed from one of these groups immediately after the final conditioning session (Group H-HT), and the animals were allowed 12-min access to water after each of the following three extinction sessions. The final group was maintained merely hungry (Group H-H). Extinction began 24 hr after the final acquisition session and continued for four daily sessions.

For the final stage of the experiment, in which all subjects were hungry but not thirsty, Groups HT-HT and H-HT were given a continuous supply of water immediately after the fourth extinction session. Twenty-four hr later all subjects were given a single test session that was identical to the extinction sessions. The method of recording the results was the same as for Experiment 1.

**Results**

The acquisition data are presented in the left-hand side of Figure 2. The graph depicts the mean number of CRs observed for each group for every conditioning session. Conditioning progressed at a slower rate and reached a lower asymptote for the groups that were food and water deprived than those that were just food deprived. A two-way analysis of variance was performed on these data. There was a significant effect of thirst, $F(1, 30) = 11.94, p < .01$, and of sessions, $F(5, 150) = 61.3, p < .01$, and there was also an interaction between these factors, $F(5, 150) = 4.92, p < .01$. A series of simple main effects tests showed that Groups HT-HT and HT-H combined differed significantly from Groups H-HT and H-H combined on every acquisition day. Analysis of the interaction by testing for each group of animals. The elimination of thirst on Day 1 of extinction Groups H-HT and H-H together responded significantly more than did Groups HT-H and HT-HT.

For the final test session conducted when all the animals were hungry but not thirsty are presented on the right-hand side of Figure 2. The histograms represent the mean number of CRs observed for each group of animals. The elimination of thirst resulted in an increase in responding relative to the last extinction session for Group HT-HT and, to a lesser extent, in Group H-HT. The remaining two groups showed no such recovery. A two-way analysis of variance of the total CRs recorded for each subject on the last session of extinction and for the subsequent test day revealed no significant effect of groups, $F(3, 28) = 2.74, p > .05$, but a significant effect of days, $F(1, 28) = 7.90, p < .01$, and a significant interaction between these factors, $F(3, 28) = 10.4, p < .01$. Analysis of the interaction revealed a significantly higher level of responding on the test day than in the final extinction session for Groups HT-HT and H-HT, $F(1, 28) = 6.56, p < .05$. No significant difference in this respect was found for Group H-H ($F < 1$), and Group HT-H showed a significant decrease in responding, $F(1, 28) = 4.33, p < .05$.

**Discussion**

Appetitive conditioning with food progressed more slowly and reached a lower asymptote for rats that were both hungry and thirsty than those that were just hungry. Eliminating thirst for extinction, after it was present during conditioning, enhanced the strength of the CR relative to the group trained hungry and thirsty throughout. Similarly, for groups trained while only hungry, the imposition of thirst induced more rapid extinction relative to the group that remained only hungry. Because the presence of thirst depressed responding during both acquisition and extinction, it might be concluded that the irrelevant drive merely impairs the performance of the conditioned response, perhaps by reducing the relevant drive. The results from the test day, however, are inconsistent with this simple analysis. In this stage, all animals were under the same drive state, hunger, and therefore would be expected to show the same level of conditioned responding. But Groups HT-HT and H-HT, both of which experienced extinction under the irrelevant drive, showed a recovery of responding, whereas the CR of Group H-H continued to weaken and that of Group HT-H was no different from the final day of extinction.

The results cannot be explained to any greater extent by the assumption that a weaker CS-US association is formed in the presence of the irrelevant drive than in its absence. If this were
the case, removing thirst before extinction in Group HT-H should not enhance the strength of the CR relative to Group HT-HT. Conversely, the imposition of thirst for extinction in Group H-HT could not be expected to influence the strength of the previously formed CS–US association and should not weaken the CR relative to Group H-H. As we have seen, neither of these claims was supported.

The vigor of a CR is normally considered to reflect the strength of the CS–US association, but it has occasionally proved useful to assume that the CR can also be affected by the strength of the US representation (e.g., Rescorla & Heth, 1975). Authors such as Konorski (1967) have suggested that variations in the strength of appetitive conditioned responding due to a change in deprivation occur because they influence the extent to which the US representation is activated (see also Bindra, 1976; Morgan, 1979). A further account for the above findings can be developed by assuming that one important effect of thirst is to suppress the representation of food associated with the CS. The presence of such a motivational state would then weaken responding during conditioning, not because the CS is weakly associated with the US but because it can activate only a weak representation of the US. Removal of this inhibitory influence for extinction would permit a temporary enhancement of the CR relative to that observed during acquisition. Conversely, the sudden imposition of thirst for rats that were trained while hungry should weaken the US representation and facilitate extinction.

One implication of this interpretation is that throughout extinction, responding in Groups H-HT and HT-HT was partially suppressed by thirst inhibiting the representation of food. As a consequence, the presence of this motivational state is predicted to protect the CR from extinction to some degree (Chorazyna, 1962). If this is correct, then eliminating thirst should produce a transient restoration of responding. The results from the final test session were consistent with this analysis.

Experiment 3

Experiment 3 was conducted to examine whether the results that have just been reported can also be obtained when hunger is the irrelevant motivational state and water is the US. In this experiment we hoped to enhance the effects of the irrelevant drive during conditioning, relative to those observed in Experiment 1, by decreasing the severity of the relevant drive, thirst.
Hence, subjects were allowed a longer period of access to water than in previous experiments.

Method

Subjects. Thirty-two naive male Sprague-Dawley rats whose mean free-feeding weight was 332 g (range: 289–400 g) were used. Half the subjects were food deprived to 80% of their free-feeding weights and restricted to 1 hr of access to water each day. Water deprivation was accomplished over 4 days by gradually decreasing the time allowed for drinking (8 hr, 4 hr, 2 hr, and 1 hr/day). The remaining subjects underwent this water deprivation schedule only.

Apparatus and procedure. The details of magazine training and composition of the six conditioning sessions, the four extinction sessions, and the single test session did not change from the previous experiment, except that water rather than food was the US.

During acquisition Groups T-HT and T-T were water deprived, and Groups HT-T and HT-HT were food and water deprived. For the extinction stage Groups T-T and HT-T were water deprived while Groups HT-HT and T-HT experienced both deprivation schedules. The transfer to food deprivation for Group T-HT was effected by giving each subject only 5 g of food immediately after the final acquisition session and after each of the first three sessions of extinction. The change in deprivation conditions for Group HT-T was achieved by placing unrestricted amounts of food in the subjects’ home cages. Following the fourth extinction session, all subjects were maintained on the water-deprivation schedule, but they were allowed unrestricted access to food.

Results

The left-hand side of Figure 3 shows the mean number of CRs recorded for the four groups on each conditioning session. The groups that were only thirsty conditioned more rapidly and reached a higher asymptote of responding than those that were hungry and thirsty. A two-way analysis of variance was performed on individual subjects’ total CRs for every session, with the factors of hunger and sessions. The effect of hunger, $F(1, 30) = 29.7, p < .01$, the effect of sessions, $F(5, 150) = 88.22, p < .01$, and the Hunger × Session interaction, $F(5, 150) = 2.45, p < .05$, were all significant. Simple main effects analyses on each day indicated that responding by the two groups with the irrelevant drive (Groups HT-T and HT-HT) was not different from the responding by those without the irrelevant drive (Groups T-T and T-HT) on the first day, $F(1, 42) = 1.6, p > .20$, but they were significantly different thereafter, $F(1, 42) > 9.70, ps < .01$.

The middle section of Figure 3 displays the mean number of CRs observed for each group for every extinction session. It can be seen that hunger accelerated extinction in Groups HT-HT and T-HT compared with groups satiated with food for this stage, T-T and HT-T. A three-way analysis of variance (with the factors of hunger in acquisition, hunger in extinction, and sessions) was performed on these data. There was an effect of hunger in extinction, $F(1, 28) = 43.30, p < .01$, and one of sessions, $F(3, 84) = 74.54, p < .01$. The main effect of hunger in acquisition was not significant ($F < 1$). None of the interactions was significant—Hunger in Acquisition × Hunger in Extinction, $F(1, 28) = 3.96, p > .05$; Hunger in Extinction × Sessions, $F(3, 84) = 1.75, p > .15$; Hunger in Acquisition × Sessions, $F(3, 84) = 1.64, p > .15$; and the triple interaction, $F(3, 84) = 1.49, p > .20$.

The histograms on the right-hand side of Figure 3 represent the mean number of CRs observed for each group on the test day. Groups HT-HT and T-HT showed recovery of responding relative to the level on the last day of extinction, whereas Group HT-T responded at the same level, and responding in Group T-T continued to weaken. A two-way analysis of variance for the 4th day of extinction and the subsequent test day indicated no effect of groups, $F(3, 28) = 2.29, p > .05$, but there was a significant effect of sessions, $F(1, 28) = 6.47, p < .05$, and a significant interaction, $F(3, 28) = 7.86, p < .01$. Simple main effects analyses for each group across days confirmed that there was a significant increase in responding in Group HT-HT and in Group T-HT, $F(1, 28) > 4.80, ps < .05$. There was no difference between the level of responding across these 2 days in Group HT-T, $F(1, 28) = 2.29, p > .10$, and Group T-T ($F < 1$).

Discussion

The pattern of results in Experiment 3 was remarkably similar to that found in Experiment 2. There was a significant effect of the irrelevant drive in acquisition. The presence of this drive also accelerated extinction, regardless of its presence or absence in acquisition. Test day data indicated that satiation with food restored conditioned responding in Groups T-HT and HT-H. Both of these groups experienced extinction under the irrelevant drive. As was the case for the preceding experiment, these results can be understood if it is accepted that one effect of an irrelevant drive is to suppress the representation of the US that is associated with the CS.

Experiment 4

Experiments 2 and 3 provide support for the claim that the effect of the irrelevant drive is mediated by central changes involving the US representation. The question now arises as to whether the representation of the relevant US is directly or indirectly affected by the irrelevant drive. In all of the above experiments, the decremental effect of the irrelevant drive has been revealed when the relevant drive is also present. It is therefore possible that the irrelevant drive weakens the relevant drive and thus diminishes the extent to which the latter can activate the US representation. The implication of this possibility is that in the absence of the relevant drive, the irrelevant drive will have no suppressive effect on the CR. On the other hand, the irrelevant drive may be able to influence the US representation directly, without the mediation of the relevant drive. This alternative implies that the irrelevant drive should depress the CR even when the relevant drive is absent. The purpose of Experiment 4 was to choose between these alternative accounts.

In a pilot study we conditioned hungry and thirsty rats with either food or water for a number of sessions. They were then given unrestricted access to both food and water before an extinction test session. In spite of being satiated for this session, a relatively strong CR was recorded during the CS, which suggests that the US representation can be activated and elicit a CR in the absence of the relevant drive. This “residual CR” provides us with a tool with which to test the account that the irrelevant drive inhibits the US representation directly. As we have said, animals satiated for their relevant drive still show a small degree of responding; if the presence of the irrelevant drive inhibits the US representation directly, then its presence might further suppress the residual CR, relative to animals without the irrelevant drive.
We chose to look at the influence of irrelevant hunger on conditioning with water for the practical reason that the appropriate drive states can be more easily manipulated. The experiment consisted of an acquisition and an extinction stage. All animals were trained thirsty with water as the US. Group T-T remained thirsty throughout; Group T-HT was further deprived of food in extinction. The results of Experiment 3 suggest that Group T-HT will respond at a slower rate during extinction than Group T-T. The crucial question in Experiment 4 was whether a similar difference would occur in the absence of the relevant drive. Group T-H was thirsty during acquisition but water satiated and food deprived at the start of extinction. If irrelevant hunger suppresses the representation of water directly, this group should show very little responding in extinction compared with Group T-0, which was satiated with both food and water before extinction.

**Method**

**Subjects.** The subjects were 32 naive male Sprague-Dawley rats (mean free-feeding weight: 349 g; range: 303–399 g). All were given unrestricted access to food during the first stage of the experiment, but they underwent a water-deprivation schedule during which the time allowed for drinking each day was gradually decreased (8 hr, 4 hr, 2 hr, and 1 hr/day) over 4 days. On the next day they were allowed to drink for 50 min, which was chosen to be the level of water deprivation for Experiment 4.

**Apparatus and procedure.** The apparatus was the same as for Experiment 1. All subjects were magazine trained in one 45-min session. Water was presented every 60 s. For the first half of the session the US remained in the magazine throughout the 60-s period unless it was consumed. For the second half, it was presented for only 5 s. Subjects were then given six conditioning sessions: Each of these was composed of six presentations of a 10-s tone immediately followed by the water US, presented for 5 s. All animals were thirsty in acquisition, but for extinction they were assigned to four groups (ns = 8). One group (Group T-T) remained thirsty. The second group was also thirsty, and in addition its supply of food was removed after the final acquisition session (Group T-HT). The third group (Group T-H) was similarly food deprived but given free access to water for the extinction stage. Groups T-HT and T-H received 5 g of food after each extinction session. Group T-0 was given unrestricted food and water after its final acquisition session. Twenty-four hr after the final conditioning session, the first extinction session was given. The extinction stage lasted 4 days. Procedural details, where omitted, were the same as for Experiment 1.

**Results**

The left-hand section of Figure 4 shows the mean number of CRs recorded for each group for each of the six sessions of

![Figure 3](image-url). Mean number of conditioned responses observed for the four groups in each session of acquisition (left-hand section), extinction (right-hand section), and test day (histograms) in Experiment 3.
acquisition. All groups conditioned at the same rate. A two-way analysis of variance was performed on these data. The effect of groups was not significant ($F < 1$). The days effect was highly significant, $F(5, 140) = 178.95, p < .01$, but the Groups × Days interaction was not significant ($F < 1$).

The data for the extinction stage are displayed in the right-hand side of Figure 4. Groups T-HT, T-H, and T-0 showed a faster decline in responding than Group T-T but did not differ substantially among themselves. A three-way analysis of variance was performed on these data. The factors were the presence or absence of the relevant drive (thirst), the presence or absence of hunger, and days. The main effect of days was significant, $F(3, 84) = 68.47, p < .01$, but none of the interactions involving this factor reached significance. The highest $F$ ratio was obtained for the triple interaction, $F(3, 84) = 2.03, p > .10$. The presence of thirst produced a significant effect, $F(1, 28) = 26.94, p < .01$, but the presence of hunger did not, $F(1, 28) = 3.19, p > .05$. The interaction between these two factors reached significance, $F(1, 28) = 11.01, p < .01$. Further analyses in the form of simple main effects tests indicated that Group T-T responded significantly more than Group T-0, $F(1, 28) = 70.89, p < .01$, but Group T-HT was not different from Group T-H, $F(1, 28) = 2.45, p > .10$. In examining the effect of the irrelevant drive, it was found that Group T-T responded at a significantly greater rate than Group T-HT and that Group T-H responded significantly more than Group T-0, $F(1, 28) > 10.55, p < .01$. The presence of the irrelevant drive produced the expected inferiority of performance in Group T-HT relative to Group T-T, but in the absence of the relevant drive, the induction of the irrelevant drive improved conditioned responding in Group T-H compared with Group T-0.

**Discussion**

After the rats were conditioned with water while thirsty, the rate of extinction depended upon the motivational state. The results for Groups T-HT and T-T replicate our previous findings that the rate of extinction is faster if the irrelevant drive is pres-
ent compared with animals that had only the relevant drive. Of more importance, however, are the findings from Groups T-0 and T-H. These groups showed a substantial CR on the initial extinction session in spite of being satiated with water, although their responding was somewhat weaker than for subjects that were just thirsty (Group T-T). Moreover, there was no evidence that hunger inhibits this responding. Indeed, the presence of the irrelevant drive served to augment responding in Group T-H relative to Group T-0. Thus, the principal conclusion to be drawn from these studies is that the presence of an irrelevant drive, hunger, can only weaken the CR if the relevant drive, thirst, is also present. This suggests that the effect of the irrelevant drive is to inhibit the relevant drive and thus indirectly suppress the US representation. The observed facilitatory effect of the irrelevant drive when it is substituted for the relevant drive will be discussed in more detail below.

General Discussion

This article has investigated the interaction between thirst and hunger within a framework of Pavlovian conditioning. First, it has been established that there is an effect of an added irrelevant drive in appetitive classical conditioning. This effect of the irrelevant drive is to depress the CR, both in acquisition and extinction. Second, Experiments 2 and 3 also showed that the irrelevant drive may protect the CR from extinction if it is present during the extinction stage. Finally, the results of Experiment 4 indicated that the influence of an irrelevant drive in extinction cannot be manifested in the absence of the relevant drive. To explain this pattern of results, we have suggested that the presence of an irrelevant drive in Pavlovian conditioning may inhibit the relevant drive and thus depress the representation of the US that is associated with the CS.

Some objections can be raised concerning this conclusion and the experimental procedures employed. We will first consider a criticism concerning the method of deprivation used in these experiments. The deprivation schedule required that animals be food deprived to 80% of their free-feeding weights, and water deprived by limiting access to water to a short period each day. Considering Groups H-F and HT-F of Experiment 1, animals in both groups were maintained at 80% of their weights. But one group, HT-F, was also water deprived—a manipulation that by itself can cause a drop in weight (Kutscher, 1972). If water deprivation causes some weight loss, it is likely that food deprivation need not be so severe in order to bring animals down to 80% of their original weights. Animals in Group HT-F may have shown faster extinction, therefore, because they were less severely food deprived than Group H-F, rather than because of any effect of the irrelevant thirst. This possibility is addressed by Groups HT-HT and HT-H in Experiment 2. In acquisition both of these groups were food and water deprived, but Group HT-H was given unrestricted access to water before extinction. On the first session of extinction the level of food deprivation for these groups was identical, and if the above criticism is correct, then the strength of the CR should have been the same for both groups. But the CR was weaker in Group HT-HT than in Group HT-H.

Other accounts to explain the effect of the irrelevant drive are also possible. The simplest of these is that it affects merely the motivation to respond. One source of evidence against this account is in the test stages of Experiments 2 and 3, in which all groups were under the relevant drive only. It was found that the vigor of responding during this session was greater for groups that had received extinction training under both the relevant and irrelevant drive than for those under only the relevant drive. If the irrelevant drive during extinction merely reduced the motivation to respond, then as a result of its removal all animals should have responded at the same level in the test session. Another counterargument is suggested by the results of Experiment 4. The notion that the irrelevant drive suppresses the motivation to perform the CR predicts that its presence should be more disruptive than no drive at all. This prediction is not supported by the results. The CR in the irrelevant drive group, Group T-H, extinguished at a slower rate than in the satiated animals of Group T-0.

Our suggestion that the presence of an irrelevant drive weakens the representation of the US implies that this state should also reduce the attractiveness of the US itself. According to most theories of conditioning, therefore, the presence of an irrelevant drive will result in a weaker CS-US association than when conditioning is conducted in its absence (Mackintosh, 1975; Pearce & Hall, 1980; Rescorla & Wagner, 1972). Our results provide no support for this prediction. In Experiments 2 and 3 the levels of responding during extinction, for groups in which only the relevant drive was present, was either the same or numerically less for subjects that had been conditioned under the relevant drive than for those trained under both drives. On the basis of these results, we must conclude that the imposition of an irrelevant drive during conditioning does not result in a weaker CS-US link. To reconcile this conclusion with our claim that an irrelevant drive weakens the US representation, we reject the notion that the magnitude of the US influences associative strength. Instead, it is possible, as Hull (1952) has suggested, that this strength is determined simply by the number of CS-US pairings. The influence of the properties of the US on conditioned responding would then be mediated by the nature of its representation that is associated with the CS.

Some authors have appealed to the stimulus properties of deprivation states to explain changes in responding with changes in drive (e.g., Estes, 1958), and it could be argued that the results for the final test session Experiments 2 and 3 were due to this mechanism. That is, for Groups H-HT and T-HT induction of the irrelevant drive during extinction might have created a different stimulus context from that of acquisition, and therefore may have facilitated extinction relative to Groups H-H or T-T, respectively, because of generalization decrement. Restoring the original stimulus context by removing the irrelevant drive for the test session would then lead to some recovery of responding. But the groups that were both hungry and thirsty in acquisition and extinction experienced the test day under a totally new drive state, and these animals showed the greatest recovery of all. We suggest, then, that the degree of CR recovery is dependent principally upon the status of the US representation. This is the conclusion also reached by Rescorla and Holland (1975), for different reasons.

Apart from the theoretical conclusions outlined above, a few further points arise from our study. Our results, although within a restricted framework of Pavlovian conditioning of magazine approach, reveal a remarkable degree of symmetry between the effects of irrelevant hunger and thirst on the CR. This, however,
need not imply that irrelevant hunger and thirst both suppress the CR by the same mechanism. Although there is some work indicating that the effect of thirst on hunger is centrally mediated (Rolls & McFarland, 1973; Van Hemel & Myer, 1970), a similar claim has not been made for the effect of hunger on thirst. Indeed, it is conceivable that the effect of hunger on conditioning with water did not depend at all on an inhibitory influence of hunger on thirst. The consumption of the dry food supplied in the home cages may heighten the level of thirst, so that animals with food freely available would be more thirsty than those that were deprived of food. Thus the lower level of responding by subjects that were both hungry and thirsty, relative to those that were just thirsty, may have occurred not because hunger diminished thirst for the former but because continuous access to food enhanced thirst in the latter. Unfortunately, we are unable to think of any method for distinguishing empirically between these alternatives.

Experiments 2 and 3 also have implications for theories of extinction. We found a recovery of the CR by satiating animals with the irrelevant US after the extinction stage. This recovery of responding on the test day cannot be explained by theories such as that of Rescorla and Wagner (1972), which account for extinction as the breaking of the association between the CS and US. If extinction causes the severing of the associative link, it is difficult to see how any recovery of the CR can occur. These data are more in support of another type of theory that has been proposed by Konorski (1967; see also Pearce & Hall, 1980). This suggests that extinction is a process whereby the CS-US association is opposed by the construction of another association signaling the absence of the US. Artificially reducing the US representation by the induction of an irrelevant drive will then result in a weak representation of the omitted-US event. When the US representation is enhanced on the test day by removing the irrelevant drive, the CS-no US association will be unable to counteract it completely, and a recovery of the CR will be recorded.

Finally, some implications of the results can be best discussed within the framework of Konorski's account for the representation of unconditioned stimuli. Konorski (1967) distinguished between a general representation, which encoded only the motivational properties of the US, and a more specific representation encoding unique aspects of the US. There is evidence for both types of US representation in our experiments. First, the evidence for the general aspect of the US representation is in the finding that the irrelevant drive is not always detrimental to the CR. In Experiment 4, prior to extinction, Group T-H underwent a substitution of the relevant thirst drive by hunger. Although performance was markedly impaired in this group compared with Group T-T, where the acquisition drive state was maintained, extinction was slower relative to the group (T-O) that was satiated for both drives. This indicates a small facilitative effect of the irrelevant drive. Similar drive substitution effects have been found by Miller (1948) and Jenkins and Moore (1973). Our tentative explanation for this is that food and water, as appetitive unconditioned stimuli, share a common affective representation. Pairing a CS with water will presumably result in an association between the CS and this affective representation, and its arousal will be partly responsible for the CR. The induction of hunger rather than thirst will still allow the CS to activate this general representation and elicit a stronger CR than for animals that are neither hungry nor thirsty. Presumably this facilitative effect of the irrelevant drive is always present, but it is masked in the presence of the relevant drive for the reasons discussed above.

The findings from our studies suggest, however, that an appetitive CS does not excite just a general representation of the US. We have found that the CR can be influenced in different ways by the relevant and irrelevant drives. For this to be possible, the CS must also excite a specific representation of the US that is activated solely by the relevant drive. The conclusion that unique representations for food and water exist has also been reached by other authors who have either explored the influence of an irrelevant drive on instrumental responding (e.g., Capaldi, Smith, & Hovancik, 1977) or have shown that food and water can serve as discriminative stimuli for different responses (Sperch, Wilkie, & Skelton, 1981). Our results also resemble those of Holland (1981) in demonstrating that the CS is capable of retrieving a relatively precise representation of the US with which it is associated.

References


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# Articles Published in the Most Recent Issue of *Journal of Comparative Psychology*

**March 1987**

Vol. 101, No. 1

**3** Social Variables Influence Female Sexual Behavior in the Musk Shrew (*Suncus murinus*) *Emille F. Rissman*

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**47** Behavioral Responses of Juvenile Rats (*Rattus norvegicus*) to Neonates After Infusion of Maternal Blood Plasma *Susan A. Brunelli, Richard D. Shindledecker, and Myron A. Hofer*

**60** Development of the Auditory Orientation Response in the Albino Rat (*Rattus norvegicus*) *Jack B. Kelly, Peter W. Judge, and Ian H. Fraser*

**67** The Acoustic Startle Threshold of the Albino Rat (*Rattus norvegicus*) *Peter K. D. Pilz, Hans-Ulrich Schnitzler, and Dieter Menne*

**73** Role of the Ultrasonic Vocalization of the Female Rat (*Rattus norvegicus*) in Sexual Behavior *Nicholas R. White and Ronald J. Barfield*

**82** Simian Scribbles: A Reappraisal of Drawing in the Chimpanzee (*Pan troglodytes*) *Sarah T. Boysen, Gary G. Berntson, and James Prentice*

**90** Experience Mediated Reduction in Courtship of *Drosophila melanogaster* in Large and Small Chambers *Stephen Zawistowski and Rollin C. Richmond*

**94** Experience-Dependent Changes in Exploratory Behavior in the Adult Rat (*Rattus norvegicus*): Overall Activity Level and Interactions With Objects *Michael J. Renner*

**Brief Communication**

**101** Time Course of Postpartum Aggression in Rats (*Rattus norvegicus*) *Kevin J. Flannelly and Laura Flannelly*