

# Effects of response-independent stimuli on fixed-interval and fixed-ratio performance of rats: a model for stressful disruption of cyclical eating patterns

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**Abstract** Binge eating is often associated with stress-induced disruption of typical eating patterns. Three experiments were performed with the aim of developing a potential model for this effect by investigating the effect of presenting response-independent stimuli on rats' lever-pressing for food reinforcement during both fixed-interval (FI) and fixed-ratio (FR) schedules of reinforcement. In Experiment 1, a response-independent brief tone (500-ms, 105-dB, broadband, noisy signal, ranging up to 16 kHz, with spectral peaks at 3 and 500 Hz) disrupted the performance on an FI 60-s schedule. Responding with the response-independent tone was more vigorous than in the absence of the tone. This effect was replicated in Experiment 2 using a within-subject design, but no such effect was noted when a light was employed as a disrupter. In Experiment 3, a 500-ms tone, but not a light, had a similar effect on rats' performance on FR schedules. This tone-induced effect may represent a release from response-inhibition produced by an aversive event. The implications of these results for modeling binge eating are discussed.

**Keywords** Binge eating · Response-independent stimuli · Reinforcement · Response-inhibition · Fixed-interval schedule · Fixed-ratio schedule · Performance

Binge eating is associated with numerous eating disorders, such as bulimia nervosa, binge eating disorder (BED), and anorexia nervosa (DSM IV). Two factors have been highlighted as important to the development and occurrence of BEDs: (1) a history of food restriction and (2) environmental stress (see Crowther, Sanftner, Bonifazi, &

Shepherd, 2001; Polivy & Herman, 1985). A number of animal models have been developed to explore the relationship between these variables. For example, Hagan, Wauford, Chandler, Jarrett, Rybak and Blackburn (2002) explored the relationship between food restriction and stress in young female rats. The rats were submitted to a 4-day period of food restriction, then 6 days of free feeding, before being stressed by foot shock. Those rats exposed only to food restriction or only to stress did not differ from the controls in their food intake. However, the rats that were restricted and then stressed displayed hyperphagia. Thus, stress appears critical in the development of 'binge' eating in food-restricted rats.

In discussing this model, Hagan et al. (2002) note that studies of the effect of other stressors would further help to explore such models of binge eating. In particular, they suggest that shock may release endogenous opioids, which may mimic exogenous opioid agonist administration. The generality of this model may possibly be extended were a similar effect to be observed with stimuli that are functionally similar to shock, but which may have a much reduced impact in terms of pain. This generality is especially important, as stress, as related to human binge eating, is often not defined in terms of pain (see Crowther et al., 2001). One potential stimulus that has been shown to exert similar punishing properties to shock is a loud tone (Reed & Yoshino, 2001, 2008). Therefore, one of the aims of the study reported here was to address the question of whether the application of such a 'stressor' to food-deprived rats would alter their performance. In addition to exploring an alternative stimulus to shock, finding an alternative response to feeding in order to mimic the binge-inducing effect of a stressor may also go some way to removing the mediating effects of opioids that are directly released when eating and which appear to add some confounding dimensions to this model (see Adam &

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Epel, 2007, for a discussion of the effects of stress on the reward system in the context of eating behavior). To this end, a lever-press response was used in the present study as the model for eating behavior.

A further feature of non-disordered eating that has not been previously considered in animal models of BED is disruption to the typical eating pattern (Nicklas, Baranowski, Cullen, & Berenson, 2001). Eating is typically noted to occur in bouts, followed by refractory periods, and disruptions to this pattern result *inter alia* in BED (Nicklas et al., 2001). It might then be expected that a stressor would not only increase the rates of responding/feeding (Hagan et al., 2002), but would also alter the pattern of such responding/feeding. In particular, it may make responding much more likely to occur earlier in the pause-respond cycle, before it would typically occur otherwise (i.e., in terms of BED, eating would resume earlier, and the refractory period would be decreased). An attempt is made to model such an effect in this study.

Rats' performance on schedules of reinforcement is orderly and predictable (Ferster & Skinner, 1957). On fixed-interval (FI) and fixed-ratio (FR) schedules, there is a period of little responding after reinforcement, which is followed by a period of relatively rapid responding until the delivery of the next reinforcement. The precise description of this response pattern varies between different reports (e.g., Baron & Leinenweber, 1994; Dews, 1978), but it is clear that both FI and FR schedules generate a substantial pause that commences immediately following the delivery of reinforcement (i.e., a long post-reinforcement pause is produced). This pattern may well serve as a useful model of the eat-pause cycle, and its stability in normal circumstances will allow the effects of a stressor stimulus on its disruption to be explored.

There has been some interest in documenting the effects of presenting stimuli during performance on FI schedules. Harrison and Isaac (1984) describe the effect of presenting response-independent auditory stimuli on the FI performance of monkeys. Such stimuli were presented randomly during the FI schedule and were observed to disrupt the typical response pattern noted on that schedule, especially in older subjects who seemed to be more sensitive to the presentation of the auditory stimulus than the younger ones.

There are many possible causes of the disruption in behavior noted by Harrison and Isaac (1984). Their preferred explanation was that the cue served to disrupt the timing of the schedule. However, it could also be said that the S-delta properties (see Dews, 1978) had been disrupted by these random stimuli. The presentation of disruptive cues that are not related to either the subjects' behavior or the contingency may well disrupt the development of inhibitory control by the reinforcer. If it is assumed that S-delta stimuli are learned about in the same way as

other discriminative stimuli, that is, by virtue of their relationship to the delivery of outcomes, then events that serve to interfere with this process may disrupt the acquisition of S-delta properties by a stimulus. It has been noted that the presentation of post-trial events can disrupt the preceding learning if the disrupting stimulus is not response-dependent (see Reed, 1998; Reed & Adams, 1996) or if the addition of a 'surprising event' causes generalization decrement (Colwill & Dickinson, 1980). However, it should be noted that much of this evidence comes from the study of discrete-trial procedures, such as learning in a radial maze (Reed & Adams, 1996), or delayed conditional discrimination procedures (Colwill & Dickinson, 1980), and it remains to be seen if such effects are also noted in free-operant procedures.

The initial aim of the current series of studies was to address the issue of whether or not the presentation of response-independent stimuli during the performance of both FI and FR schedules disrupts behavior. The importance of these studies to the development of a model of stress-induced BED is to establish whether or not a stressor impacts not only the quantity of behavior, but also the distribution of responding over time.

## Experiment 1

The aim of the first experiment was to investigate the influence of a randomly presented response-independent stimulus on rats' performance on an FI schedule. To this end, rats were trained to respond on a FI 60-s schedule. Half of the rats received a small reinforcer (one food pellet) and the other half received a large reinforcer (four pellets). This manipulation was included as there has been some suggestion that larger reinforcers produce more delineated post-reinforcement pauses (see Baron, Mikorski, & Schlund, 1992; Harzem & Harzem, 1981). In addition to allowing further investigation of this under-investigated schedule effect, if large reinforcers produce clearer scalloping, then the use of a larger reinforcer may allow easier investigation of the impact of a response-independent cue. One set of rats receiving each of the different reinforcers had response-independent presentation of a brief tone superimposed during the schedule, whereas the remaining rats had no tone presentations.

## Method

*Subjects* Sixteen male, Lister hooded rats were used in this experiment. The subjects were 10–11 months old at the start of training, had a free-feeding body-weight range of 450–550 g, and were maintained at 85% of this weight throughout the experiment. The subjects had previously

served in a classical conditioning experiment in which they had experienced light stimuli, but they were naive with respect to the auditory stimuli and lever-pressing. The animals were housed in groups of four, and water constantly available in the home cage.

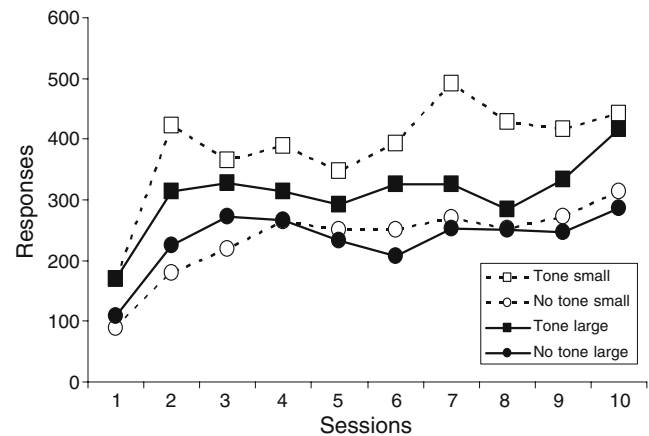
**Apparatus** Four identical operant conditioning chambers (Campden Instruments, Loughborough, UK) were used. Each chamber measured 23.5×23.5×20.5 cm and was housed in a light- and sound-attenuating case, ventilated by a fan that provided background masking noise [65 dB (A)]. Each chamber had two levers, both of which were permanently inserted into the chamber, but only one lever (the left) was operative during the experiment. Reinforcement consisted of 45-mg standard Noyes food pellets and was delivered to a centrally located, recessed food tray that was covered by a clear Perspex hinged flap. A speaker mounted on the outside of the ceiling of the chamber could provide a 105-dB(A) tone (40 dB above background). The tone was a broadband, noisy signal (ranging up to 16 kHz), with spectral peaks at 3 and 500 Hz. A jeweled house-light was located in the center of the ceiling. The chamber was not illuminated during the course of the experiment.

**Procedure** The subjects were given two 20-min sessions of lever-press training on a continuous reinforcement (CRF) schedule. The subjects were then given one 30-min session on a FI 30-s schedule, followed by two 30-min sessions on a FI 60-s schedule. The subjects were then divided into four groups ( $n = 4$ ) that were matched for response rate over the two FI 60-s schedule sessions.

For the experimental contingencies, all four groups responded on a FI 60-s schedule. Two groups of rats responded for one reinforcement pellet (i.e., a small reinforcer), the other two groups received four reinforcement pellets (i.e., a large reinforcer). One of each of these groups was presented with a 500-ms tone according to a random time (RT) 60-s schedule (i.e., tone groups). This schedule operated independently of the FI schedule that determined food presentation and scheduled the presentation of the stimulus with a probability of 1/60 each second. The other two groups did not receive the response-independent tone (i.e., no tone groups). Thus, there were four groups: Tone–small, Tone–large, No tone–small, and No tone–large. There were ten 30-min sessions of training.

## Results and discussion

Figure 1 shows the group-mean number of responses emitted during each session. Inspection of this figure shows that there was little difference between the rates of response for the large and small reinforcers. If anything, the small reinforcer groups, particularly the tone-small group,

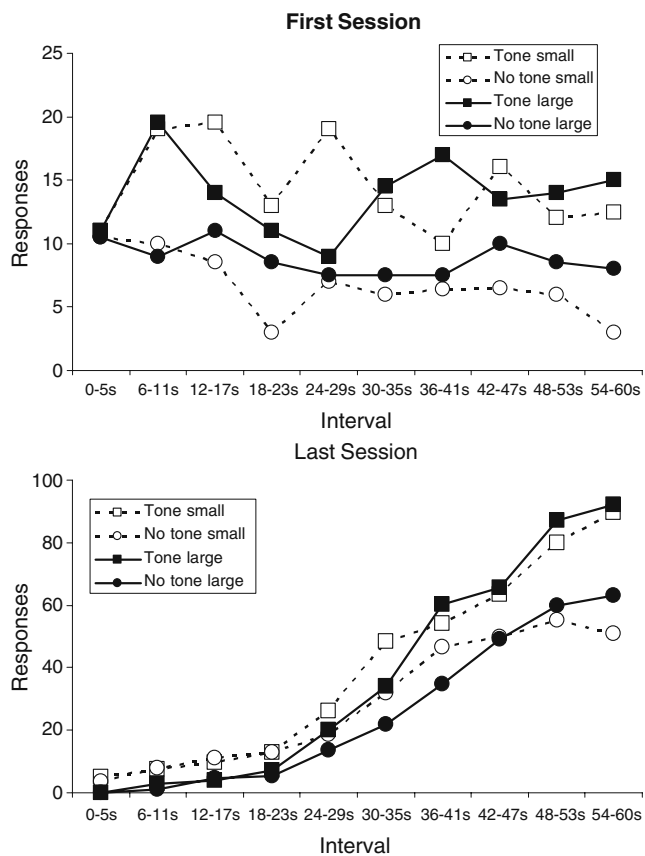


**Fig. 1** Results from Experiment 1. Group-mean number of responses emitted during each session

responded slightly faster than the large reward groups. This finding is in line with previous demonstrations of the effects of greater levels of reward (e.g., Baron et al., 1992). Comparison of the groups with a tone to those groups without a tone revealed that, at both reward magnitudes, the tone groups responded faster than the no-tone groups. This difference was more pronounced for the small reward groups.

A three-factor mixed-model analysis of variance (ANOVA) was performed on these data. The between-subject factors were stimulus (tone vs. no tone) and reward (large vs. small), and session was the within-subject factor. A rejection criterion of  $p < 0.05$  was adopted for this and all subsequent analyses. This analysis revealed that both stimulus and session had a statistically significant main effect [ $F(1, 12) = 5.07$  and  $F(9, 108) = 15.86$ , respectively]. There were no other statistically significant main effects or interactions (all  $p > 0.30$ ).

Figure 2 shows the number of responses emitted in each successive 6-s bin during the FI 60-s interval, both during the first (top panel) and the last (bottom panel) sessions of training. For the purposes of this analysis, the first two FI 60-s intervals during the session were discarded (as responding at the start of a session may not be completely under schedule control at this early point in the session), as were any incomplete intervals at the end of the session. Inspection of these data from the first session of training (top panel) reveals that responding was relatively undifferentiated across the interval. However, the two groups with a tone appeared to respond more vigorously earlier in the interval than the two no-tone groups. During the last session (bottom panel), a pattern of responding resembling a more typical scallop across the bins emerged in all groups. The two tone groups appeared to display an increased rate of responding at a slightly earlier point during the scallop than the two groups without the tone;



**Fig. 2** Results from Experiment 1. Number of responses in each successive 6-s bin occurring in the fixed-interval (FI) 60-s interval during the first (*top panel*) and last (*bottom panel*) sessions of training

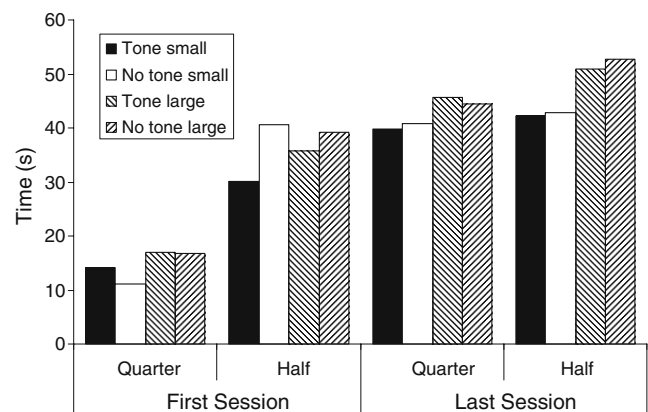
that is, the low level of responding following reinforcement appeared to continue for longer in the two groups lacking the tone.

A four-factor mixed-model ANOVA (stimulus  $\times$  reward  $\times$  session  $\times$  bin) conducted on these data revealed statistically significant main effects of session [ $F(1, 12) = 40.53$ ] and bin [ $F(9, 108) = 41.40$ ]. There were statistically significant interactions between session and bin [ $F(9, 108) = 49.44$ ] and between session, bin, and stimulus [ $F(9, 108) = 2.07$ ]. No other main effects or interactions were statistically significant (all  $p > 0.30$ ). To analyze further the three-way interaction, separate two-way ANOVAs (stimulus  $\times$  bin) were conducted on each session, as recommended by Howell (1997). The ANOVA on the first session revealed no statistically significant main effects or interactions (all  $p > 0.20$ ). The ANOVA conducted on the last session revealed no statistically significant main effect of stimulus ( $p > 0.09$ ), but there was a statistically significant main effect of bin [ $F(9, 126) = 54.50$ ] and a statistically significant interaction between the two factors [ $F(9, 126) = 2.51$ ]. Simple effects analysis of stimulus at each bin revealed statistically significantly higher rates of responding in the tone groups than in the no-tone groups over each of the last four bins [smallest  $F(1, 126) = 4.96$ ].

To further examine the impact of the groups on responding, the ‘quarter point’ and the ‘half point’ for responding (i.e., the point at which either a quarter or a half of the responses had been emitted between each reinforcer) were calculated for the first and last sessions. These data are shown in Fig. 3, and inspection of these data reveals that both the quarter point and the half point became longer over the course of training, as scalloping developed. These data also show that, generally, both the quarter and the half points were shorter for the groups with a smaller magnitude of reinforcement, suggesting that this manipulation led to responding being more vigorous earlier in the trial. The pattern of data for the tone versus no-tone groups was less clear. Inspection of the quarter point data suggests little consistent difference between the groups with or without a tone, whereas the half point data suggest that the groups with a tone reached this point earlier than those without the tone.

A four-factor mixed-model ANOVA (stimulus  $\times$  reward  $\times$  point  $\times$  session) conducted on these data revealed statistically significant main effects of reward [ $F(1, 12) = 17.75$ ], session [ $F(1, 12) = 168.45$ ], and point [ $F(1, 12) = 216.60$ ]. There were statistically significant interactions between point and stimulus [ $F(1, 12) = 5.07$ ], between point and session [ $F(1, 12) = 50.5$ ], and between point, session, and stimulus [ $F(1, 12) = 3.70$ ]. No other interactions were statistically significant (all  $p > 0.09$ ). To investigate the three-way interaction, separate two-factor ANOVAs (stimulus  $\times$  session) were conducted for the quarter and half point data. The ANOVA conducted on the quarter point data revealed only a statistically significant main effect of session [ $F(1, 14) = 570.09$ ], while that conducted on the half point data revealed a statistically significant main effect of sessions [ $F(1, 14) = 21.87$ ] and tone [ $F(1, 14) = 3.72$ ].

Overall, these results show that, despite relatively few sessions of training, a typical scalloping pattern of the FI



**Fig. 3** Results from Experiment 1. Mean time taken to emit a quarter and a half of the responses in an FI 60-s trial during the first and last sessions of training

schedule developed over the course of training. From responding in a relatively undifferentiated manner in the first session, the rats came to pause following reinforcement, and then increase their rate of response as the time of the next reinforcement approached. The effect of reinforcement magnitude on this performance was in the direction previously noted (Baron et al., 1992; Harzem & Harzem, 1981). That is, greater magnitudes of reinforcement produced fewer responses and a greater period of time with relatively little responding after reinforcement.

These results also show that presentation of a response-independent stimulus altered the responding seen during performance on such an FI schedule. Overall, the stimulus increased the overall rate of responding. The impact on the pattern of responding was less clear, namely, while the rats experiencing the tone showed no clear tendency to emit responses earlier when the quarter time measure was used, they did reach the half-point earlier than the rats without the tone. This result demonstrates that the alteration of responding is not necessarily a product of response contingency, but that it can be produced by a randomly presented non-contingent tone.

## Experiment 2

There are many potential explanations for the effect noted in Experiment 1. It is possible that the stimuli served to disrupt the temporal processing of the interval by the subjects. Alternatively, it may be that the tone served to release the subjects from the inhibitory S-delta effects of the reinforcer—possibly due to the potentially aversive properties of auditory stimuli for rats (Reed, Mitchell, & Nokes, 1996; Reed & Yoshino, 2001, 2008).

The second experiment attempted to replicate the results of Experiment 1, but with the additional aim of to see whether they could also be obtained with another type of stimulus. Light stimuli can have positive hedonic properties in rats (Reed et al., 1996). If the stimulus served merely to disrupt timing behavior or the development of S-Delta properties, then both the tone and the light stimuli may be expected, to some extent, to disrupt responding. However, if it were something unique to the tone, perhaps because of its aversive properties, then the tone, but not the light, should be expected to produce this pattern of behavior.

To this end, a within-subjects design was employed, in which each subject was trained on an FI schedule and then experienced three conditions; one with a superimposed tone stimulus, one with a superimposed light stimulus, and one with no stimulus presentations. This procedure may also allow the effect of the superimposition of a stimulus on a well-developed FI scallop to be observed, in contrast to the

previous study that demonstrated the effect of such a superimposition on a developing FI pattern of responding.

## Method

*Subjects and apparatus* Ten male, Lister hooded rats were used in the present experiment. The subjects were 7–8 months old at the start of training and had a free-feeding body-weight range of 405–475 g. The rats had a similar history and were housed and maintained as described in Experiment 1. The apparatus was that described in Experiment 1.

*Procedure* The subjects were given two 20-min sessions of CRF training, followed by one 30-min session of FI 30-s training. All rats then received a further twenty 30-min sessions of FI 60-s training. For the subsequent three experimental contingencies, all rats continued to respond on a FI 60-s schedule, and each session lasted 30 min.

For the first ten sessions, five rats received a 500-ms tone (105 dB), presented on a RT 60-s schedule. The other five rats received a 500-ms light presentation from the overhead jeweled house-light on a RT 60-s schedule. In both cases, the RT schedule ran independently of the FI schedules and programmed the presentation of the stimulus with a probability of 1/60 for each second.

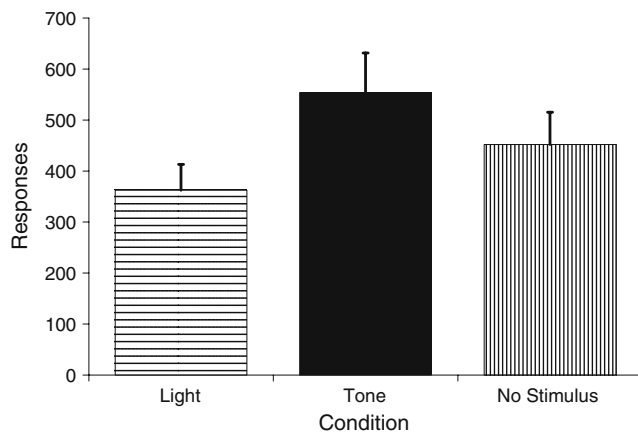
During the next ten sessions, all rats were returned to the FI 60-s schedule without any stimulus presentations.

For the final ten sessions, the five rats who had received the tone stimulus received the response-independent light, and the rats who had received the light stimulus received the response-independent tone.

## Results and discussion

The mean number of responses during the last four sessions, in each of the three conditions, are displayed in Fig. 4. Inspection of these data reveals that more responses were emitted in the tone condition and that there were a similar number of responses in the no stimulus and light conditions. An ANOVA conducted on these data revealed a statistically significant effect of condition [ $F(2, 18) = 3.41$ ]. Planned comparisons revealed that the tone condition differed from both the light and no-stimulus conditions [ $t(9) = 7.76$ ] but that the light and no-stimulus conditions did not differ from one another ( $p > 0.10$ ).

Figure 5 shows the number of responses in each successive 6-s bin occurring in the FI 60-s interval during the last four sessions of training under each condition. For the purposes of analysis, as in Experiment 1, the first two FI 60-s intervals during the session were discarded, as were any incomplete intervals at the end of the session. Inspection of these data reveals that a typical scalloped pattern of responding emerged in all groups. However, the

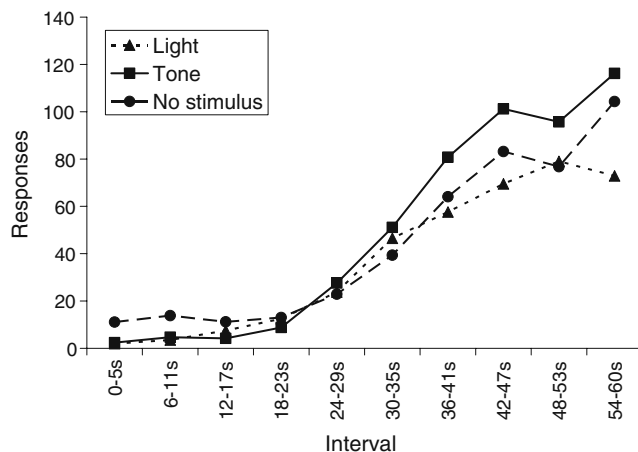


**Fig. 4** Results from Experiment 2. The mean numbers of responses during the last four sessions under each of the three conditions

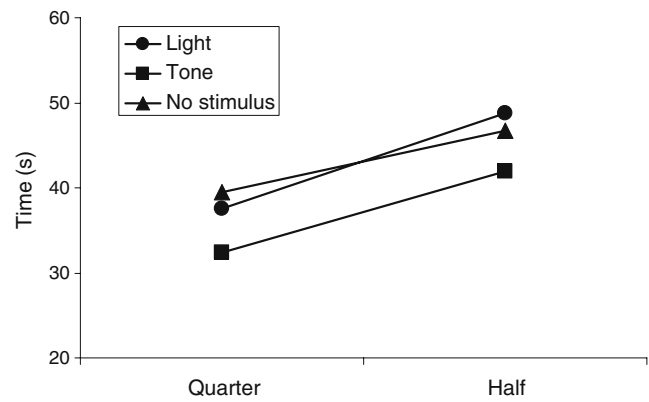
tone group came to respond more vigorously earlier in the trials than the other two groups (light, no stimulus).

A two-factor ANOVA (condition  $\times$  bin) conducted on these data revealed statistically significant main effects of session [ $F(2, 18) = 3.47$ ] and bin [ $F(9, 81) = 32.11$ ] and a statistically significant interaction between the two factors [ $F(18, 162) = 2.54$ ]. Simple effects analysis of stimulus at each bin revealed statistically significantly higher responding in the tone groups over each of the last four bins [smallest  $F(2, 162) = 3.97$ ].

Figure 6 shows the quarter and half points for responding (i.e., the point at which a quarter and a half of the responses had been emitted between each reinforcer). These data also show that both the quarter and the half points were shorter in the condition with the tone than in the other two conditions, suggesting that the former manipulation led to responding being more vigorous earlier in the trial. A two-factor repeated-measures ANOVA (stimulus  $\times$  point)



**Fig. 5** Results from Experiment 2. The number of responses in each successive 6-s bin occurring in the FI 60-s interval during the last four sessions of training under each condition



**Fig. 6** Results from Experiment 2. Mean time taken to emit a quarter and a half of the responses in an FI 60-s trial in each of the three conditions

conducted on these data revealed a statistically significant effect of point [ $F(1, 9) = 357.88$ ] and a marginally statistically significant effect of stimulus [ $F(2, 18) = 2.91$ ;  $p < 0.07$ ]. There was no statistically significant interaction ( $p > 0.10$ ).

This experiment confirmed the effect of a tone on rats' FI responding noted in Experiment 1, although they did so with longer FI training. Response rates were higher in the tone condition, and responding started marginally earlier in the interval under the tone condition. However, this is unlikely to be the result of general disruption, as a light stimulus failed to produce a similar type of disruption. In fact, if anything, the light tended to suppress responding. One possibility is that the light was not as salient as the tone. However, there are two reasons to doubt this supposition. Firstly, the light was salient enough to produce the opposite effect to that noted by the tone; secondly, in numerous other studies, the same stimuli have been found to be equally effective in producing signaled reinforcement (Reed, Schachtman, & Hall, 1988) and conditioned reinforcement (Reed et al., 1988).

### Experiment 3

In both Experiment 1 and Experiment 2, the effect of the tone could have been due to either the disruption of timing or to the disruption of the S-delta properties of the contingencies. However, if the same disrupting effect of the stimulus occurs on an FR schedule, the effect would be unlikely to be due to a disruption of timing behavior. The aim of Experiment 3 was to investigate the effect of a disrupting stimulus on FR performance.

### Method

**Subjects and apparatus** Twenty-four male, Lister hooded rats were used in this experiment. The rats were 10–

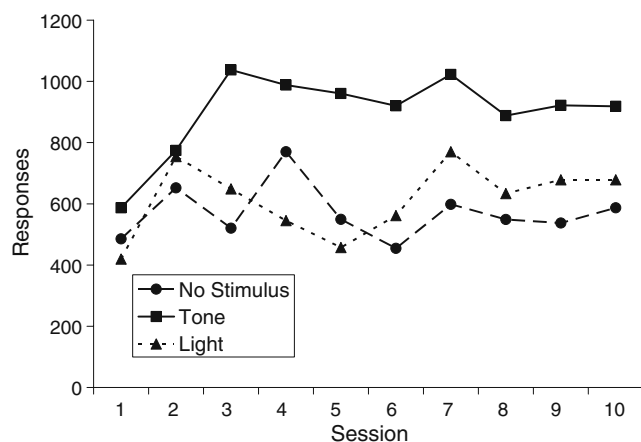
11 months old at the start of the study and had a free-feeding body weight range of 410–465 g. The subjects had a similar history to those described in Experiment 1, and they were maintained as described in Experiment 1. The apparatus was that described in Experiment 1.

**Procedure** The subjects were given two 20-min sessions of lever-press training on a CRF schedule. The subjects then received one session on a FR-5 schedule, one session on a FR-10 schedule, followed by two sessions on a FR-25 schedule. All sessions lasted 30 min. The subjects were then divided into three groups ( $n = 8$ ) that were matched for response rate over the two FI 60-s schedule sessions. Unfortunately, four rats became ill and died during the course of the experiment, leaving seven rats in Group No stimulus, seven rats in Group Tone, and six rats in Group Light.

For the experimental contingencies, all groups responded on a FR-25 schedule. For one group (Group No stimulus), these were the only contingencies in operation. A second group of rats (Group Tone) were also presented with a 500-ms tone according to a RT 60-s schedule. The final group (Group Light) was also presented with a 500-ms light (the jeweled house-light) according to a RT 60-s schedule. There were ten 30-min sessions of training.

## Results and discussion

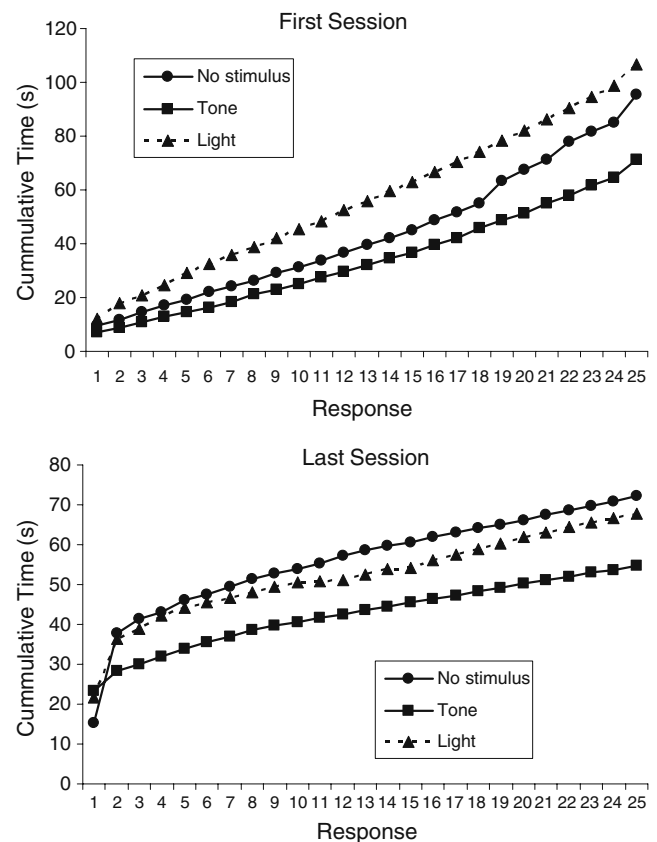
Figure 7 displays the group-mean number of responses emitted during each session. Inspection of this figure shows that all groups increased their rate of responding over the first few sessions of training, but that thereafter responding was relatively constant. Rats in Group Tone had a numerically slightly higher rate of response than those in the other two groups. However, a two-factor ANOVA (group  $\times$  session) found neither of the main effects nor the interaction to be statistically significant (all  $p > 0.10$ ).



**Fig. 7** Results from Experiment 3. Group-mean number of responses emitted during each session

Figure 8 shows the mean cumulative time to emit each of the responses required by the FR-25 schedule on the first and last session of training. These data show that there was a relatively even rate of response during the first session in all three groups. However, by the last session, the post-reinforcement pause had become more pronounced prior to a relatively even rate of responding once initiated. In general, responding was faster earlier in the FR ‘trial’ in Group Tone, although this was not true for the first response emitted.

A three-factor ANOVA (group  $\times$  session  $\times$  response) conducted on these data revealed a statistically significant main effect of response [ $F(24, 408) = 66.00$ ] and a statistically significant interaction between session and response [ $F(24, 408) = 25.16$ ]. No other main effects or interactions were statistically significant (all,  $F < 1$ ). Separate analyses were conducted on each session. On the first session, this analysis revealed a statistically significant main effect of response [ $F(24, 408) = 62.44$ ] but no statistically significant main effect of group or interaction (all  $p > 0.10$ ). On the last session, this analysis revealed statistically significant main effects of response [ $F(24, 408) = 38.25$ ] and group [ $F(2, 17) = 6.98$ ] but no interaction ( $p > 0.20$ ).



**Fig. 8** Results from Experiment 3. Mean cumulative time to emit each of the responses required by the FR-25 schedule on the first (*top panel*) and last (*bottom panel*) session of training

These data show that the addition of a tone, but not a light, served to alter the pattern of responding emitted by the groups. The group with a tone showed faster responding than the other two groups and also tended to respond faster earlier in the FR ‘trial’ than the other groups. However, this latter finding is made more difficult to interpret by the fact that the group with a tone emitted their first response after reinforcement sooner than the other groups. This result is similar to that observed in the previous two experiments reported here that used FI schedules. The fact that similar effects occurred on both FI and FR schedules suggests that the effect is not limited to schedules in which there is the scope for the temporal disruption of responding. Rather, it suggests that the tone may be affecting the signaling properties of the schedule.

### General discussion

The results of the series of experiments reported here demonstrate that the presentation of a brief loud tone stimulus, non-contingently upon responding, disrupts the responding that would otherwise occur on FI and FR schedules of reinforcement. In particular, the subjects receiving a response-independent tone responded more quickly than subjects not receiving this stimulus and, generally, began to respond sooner after reinforcement when the tone was presented than when the tone was not presented. However, this last finding was only found using some measures of early responding and cannot be taken to be certain. In no case did a visual stimulus produce this pattern of results.

Prior to a theoretical discussion of these results, and of their possible implications for the development of a model of BED, some attention should be given to one aspect of these data, that is, the length of the training given to the subjects. In the experiments described here, the length of the FI and FR training sessions (at least in Experiments 1 and 3) was relatively short compared to those reported in previous studies that have investigated pausing on these schedules (e.g., Baron & Leinenweber, 1994). Of course, there are studies that have investigated FI and FR performance using similar numbers of sessions of training to those in the current series of experiments, and which have found similar schedule-typical behavior (Tarpy, Roberts, Lea, & Midgley, 1984). Moreover, the current Experiment 2 did employ substantially longer training—and found similar results to Experiment 1. However, this length of training may explain the relatively less pronounced scalloped pattern of responding noted in the current studies compared to that of these previous studies. Notwithstanding the results of Experiment 2, the short length of training may also be a factor in enhancing the impact of the tone. A disruptive stimulus may have a

greater impact on less well-trained schedule performance than on well-established schedule performance (cf. Reed & Yoshino, 2001, 2008). These are issues that should be further investigated. However, the reason for the small number of sessions being selected was a concern over the possible habituation to the aversive properties of the tone if training had continued for a longer period (see Rudell, 1983).

It is possible that the stimulus disrupted the timing behavior and that this factor may underlie performance on FI schedules. There are demonstrations of response-contingent stimuli appearing to disrupt such performance. Thus, the subjects may start responding more quickly and, to some extent, sooner after the delivery of the last reinforcer due to the timing mechanism having been disrupted. However, two findings from the present studies seem to make this an unlikely scenario. Firstly, the same pattern of disruption was not found with visual stimuli. Such visual stimuli have been found to be effective in altering behavior, both in this study and also in previous studies on the effects of such cues on FI performance (Harrison & Isaac, 1984). Given this, the lack of similarity of the visual and auditory stimuli in disrupting behavior may not be due to the lack of salience of the visual stimuli. Secondly, the same pattern of disruption was noted with auditory (but not visual) stimuli on FR schedules. Again, rats started responding earlier after food with the tone was presented, but not with light stimulus.

One alternative explanation for this effect is that the auditory stimulus served to increase the subjects’ arousal in a manner that made them respond more vigorously. Why this should not occur with the light stimulus, and why such evoked behavior should be directed to the lever is not clear from this account. Moreover, it is known that the auditory cue used in the current experiment, when it is made contingent on responding, will suppress rather than enhance responding (Reed & Yoshino, 2001, 2008).

Another plausible view of these results that can accommodate both studies suggests that the auditory stimulus interferes with the inhibitory properties of the reinforcer. Removal of the S-delta would allow responding to occur more vigorously across the session, and more readily after reinforcement, and enhance overall response rates. This release-from-inhibition view also may offer an explanation for the failure of the visual stimulus to influence responding in the same manner. It has been noted that periods of inhibition, especially those induced by food, can be removed by the experience of a stressful or aversive event (Crowther et al., 2001). As noted above, the tone used in the present experiments has been found to be aversive to rats (Reed et al., 1996; Reed & Yoshino, 2008). In contrast, the light has not been shown to possess these properties. Rather, the light has been shown to be reinforcing to rats.



Of course, such a view is speculative and would require more evidence regarding patterns of responding early in the trial than was obtained in these studies, but it does accommodate the data presented here, and it also offers an opportunity to link the present results to models of binge eating disorder. While such a link requires much greater development, a brief discussion of the potential links may be worthwhile. A typical (non-disordered) eating pattern may be thought of as consisting of a refractory period followed by a consummatory episode. The subsequent refractory period may, perhaps, be induced by inhibition to engage in the consummatory process for a period of time. Disruptions to this typical (eat-pause) pattern may be considered as disordered eating (Nicklas et al., 2001). If such a view of eating is accepted, and it seems a reasonable description, then the current fixed schedules may be thought of as mimicking this behavior, at least to the extent of allowing a well-defined pause-response pattern to be established and the factors which impact on it to be examined. Of course, this requires that a link is made between the responses of eating and lever-pressing, but should they be considered as operants, within the context of a model, this may be appropriate. The potential of the lever-press as maintained by a fixed schedule to stand as a model for eating is enhanced by the current findings that a known stressor will disrupt the fixed schedule pattern in much the same way as stressors disrupt eating. It is known that stressful events will remove potential inhibition for eating and promote earlier eating (see Crowther et al., 2001; Hagan et al., 2002). However, it should also be noted that such stress in humans tends to be chronic in nature and that given the length of time over which the studies were conducted, it is a matter for debate as to whether the unpredictable tone in the current study would also be classed as chronic or acute, which may limit the generality of this model. However, the unpredictable auditory stimulus in the current study appears to provide a start for mimicking this process using a fixed schedule model, and this may deserve further investigation.

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