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Extinction and renewal of cue-elicited reward-seeking

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ABSTRACT

Reward cues can contribute to overconsumption of food and drugs and can relapse. The failure of exposure therapies to reduce overconsumption and relapse is generally attributed to the context-specificity of extinction. However, no previous study has examined whether cue-elicited reward-seeking (as opposed to cue-reactivity) is sensitive to context renewal. We tested this possibility in 160 healthy volunteers using a Pavlovian-instrumental transfer (PIT) design involving voluntary responding for a high value natural reward (chocolate). One reward cue underwent Pavlovian extinction in the same (Group AAA) or different context (Group ABA) to all other phases. This cue was compared with a second non-extinguished reward cue and an unpaired control cue. There was a significant overall PIT effect with both reward cues eliciting reward-seeking on test relative to the unpaired cue. Pavlovian extinction substantially reduced this effect, with the extinguished reward cue eliciting less reward-seeking than the non-extinguished reward cue. Most interestingly, extinction of cue-elicited reward-seeking was sensitive to renewal, with extinction less effective for reducing PIT when conducted in a different context. These findings have important implications for extinction-based interventions for reducing maladaptive reward-seeking in practice.

1. Extinction and renewal of cue-elicited reward-seeking

Reward cues can influence behaviour aimed at obtaining both natural (e.g. food) and artificial rewards (e.g. drugs). This can lead to maladaptive reward-seeking such as overeating and drug abuse, where reward cues may pose a significant threat to self-regulatory behaviour and lead to relapse in those attempting to abstain or moderate their intake (Niaura et al., 1988). Understanding how to reduce the impact of reward cues on reward-seeking is therefore critical to reducing maladaptive reward-seeking.

The majority of reward-related cues are learned. For example, a child may learn that particular music signals the arrival of an ice cream truck. Once learned, such reward cues can have a variety of effects on the individual. For instance, reward cues can induce significant physiological responses, such as changes in heart rate, sweat gland activity, and skin temperature – particularly in individuals addicted to drugs of abuse (see Carter & Tiffany, 1999 for a review). Such 'cue reactivity' may produce a withdrawal-like source of motivation whereby the reward is sought to provide relief from the aversive affective state induced by the cue (e.g. opponent process models of addiction: Solomon & Corbit, 1974). However, there is also evidence that reward cues can directly influence motivation to obtain rewards. This process is known as Pavlovian-to-instrumental transfer (PIT). PIT is an associative learning process that occurs when a Pavlovian cue that predicts a reward elicits instrumental responses (actions) to obtain that and other rewards, despite the Pavlovian and instrumental relationships being acquired separately (Estes, 1943).

PIT has been documented in a range of animal (see Holmes, Marchand, & Coutureau, 2010 for a review) and human studies (Allman, DeLeon, Cataldo, Holland, & Johnson, 2010; Bray, Rangel, Shimojo, Balleine, & O'Doherty, 2008; Hogarth, Dickinson, Wright, Kouvaraki, & Duka, 2007). As shown in Fig. 1, the standard procedure for testing PIT involves three phases: Pavlovian acquisition, instrumental acquisition, and a transfer test (Colwill & Rescorla, 1988; Estes, 1943; Holland, 2004). In Pavlovian acquisition, a cue (e.g. a tone) is paired with the delivery of a reward (e.g. food). In a separate instrumental acquisition phase, the same reward can be obtained by making an instrumental response (e.g. pressing a lever). In the transfer test, instrumental responding is measured in the presence of the reward cue and an unpaired cue. PIT occurs when the reward cue elicits increased responding

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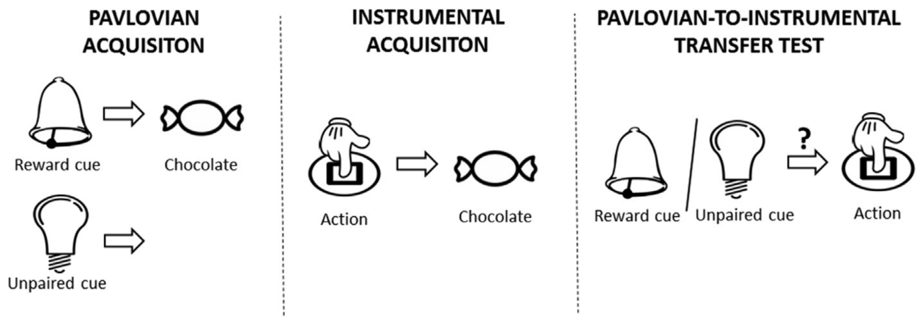

Fig. 1. Typical PIT design involving three phases: Pavlovian acquisition, instrumental acquisition, and transfer test. PIT occurs when the reward cue triggers instrumental responding aimed at obtaining the reward in the transfer test, despite the reward cue and the instrumental response being trained separately.

relative to the unpaired cue.

One of the most concerning features about PIT is its apparent insensitivity to devaluation manipulations. In rodents, for example, numerous studies indicate that reward cues can continue to facilitate reward-seeking via PIT even when the animal has had a taste aversion conditioned to the relevant reward (Corbit, Janak, & Balleine, 2007; Holland, 2004; Rescorla, 1994). This insensitivity to devaluation extends to humans, with a number of studies demonstrating that PIT is insensitive to devaluation manipulations for symbolic rewards such as money (Allman et al., 2010), drug-related symbols (Hogarth & Chase, 2011; Hogarth, 2012) and natural food rewards (Colagiuri & Lovibond, 2015; Eder & Dignath, 2016; Watson, Wiers, Hommel, & de Wit, 2014). The insensitivity of PIT to devaluation is concerning in terms of maladaptive reward-seeking, because it suggests a way in which biological feedback systems intended to regulate reward-seeking, e.g. satiety, can be overridden by reward cues. Further, insensitivity to devaluation may suggest that PIT is beyond cognitive control, which would render cognitive strategies, e.g. self-regulation, futile for reducing maladaptive reward-seeking. As such, reducing the ability of reward cues to directly facilitate reward-seeking via PIT appears critical for the treatment and reduction of potentially harmful reward-seeking behaviours.

Extinction is one of the most obvious methods of attempting to reduce PIT. Extinction refers to presenting a cue in the absence of its prior reinforcer, with this procedure typically reducing conditioned responding (Bouton, 2002; Pavlov, Petrovich, & Anrep, 1927). Only a handful of studies have tested the extent to which extinction can reduce PIT. One study using rats (Delamater, 1996) found that extinction was ineffective for reducing PIT. Two human studies have also found evidence that extinction is ineffective for reducing PIT (Hogarth et al., 2014; Rosas, Paredes-Olay, Garcia-Gutierrez, Espinosa, & Abad, 2010), both of which used symbolic rewards (e.g. points). In contrast, we recently found that extinction successfully reduced PIT in humans when they were responding for a natural high value reward, i.e. chocolate (Lovibond, Satkunarajah, & Colagiuri, 2015).

Apart from the qualitative differences in rewards across the human studies testing for extinction of PIT, i.e. symbolic versus natural, one potentially critical difference between the human studies demonstrating effects of extinction and our own study demonstrating that extinction attenuated PIT, is that the former involved strong experimental incentives to respond during the transfer test (e.g. forced choice responding) whereas in the latter, participants were entirely free to respond or not respond. For example, in Hogarth et al. (2014) participants were forced to choose between two response options when the reward cues were presented during the transfer test. In contrast, in our previous study (Lovibond et al., 2015), during the transfer test participants were explicitly told that they could respond as much or as little as they liked. One could imagine that in situations in which an individual is forced to select a response, a cue with even the slightest association with a reward could bias responding towards a response also associated with that reward. On the other hand, when participants are free to respond or not respond, there is likely some absolute (rather than relative) criterion for the strength of association between the cue and the reward needed to induce the relevant instrumental response. Therefore, if extinction does reduce the strength of the association between a reward cue and the relevant reward (either directly or via competing inhibitory learning) but does not fully eradicate the association, then designs with forced choice or high incentives to respond may substantially underestimate the ability of extinction to reduce PIT. Further, as we have argued previously (Colagiuri & Lovibond, 2015; Lovibond & Colagiuri, 2013; Lovibond et al., 2015), models of PIT that involve voluntary responding, i.e. including the option not to respond, are likely to better reflect real world settings in which individuals have the option not to engage in any action. Therefore, the evidence that extinction can attenuate PIT when responding is voluntary may generalise better to non-laboratory settings.

However, one *a priori* limitation to the possibility of using extinction to reduce cue-induced reward-seeking is renewal. Renewal refers to the recovery of conditioned responding following extinction when the extinguished cue is encountered in a context different to the one in which extinction was conducted (Bouton, 2002). Renewal and related effects (e.g. spontaneous recovery, reinstatement) have led most researchers to adopt the view that extinction involves new inhibitory learning (cue → no outcome), which co-exists with the prior excitatory learning (cue → reward), rather than extinction actually erasing the excitatory learning (Bouton & Bolles, 1979; Bouton, 2002; Konorski, 1967). Renewal effects suggest that extinction may only be effective for reducing reward-seeking in the specific context in which extinction is conducted. If, for example, a therapist extinguishes drug cues with an addicted patient in her clinic, the drug cues will likely still elicit responses (i.e. renew) when they are encountered outside of the clinic. Renewal is often proposed as the main reason that cue-exposure therapy fails to reduce actual relapse rates despite reducing cue-reactivity in the clinic (Conklin & Tiffany, 2002; Rachman, 1989).

Renewal has been demonstrated in terms of reactivity to fear cues (Bouton & Bolles, 1979), drug reward cues (Collins & Brandon, 2002), and food reward cues (Van Gucht, Vansteenwegen, Beckers, & Van den Bergh, 2008). For example, in a study by Van Gucht et al. (2008), human participants had the opportunity to learn the association between the colour of a tray (cue) and chocolate (reward) before undergoing extinction in either the same or a different context to training. Participants' expectancies and cravings were then tested in the original training context. While there was no apparent evidence of extinction of cravings at all, likely due to a floor effect, there was clear evidence of extinction and renewal of expectancy. Participants who received extinction in a different context reported substantially higher expectancies for chocolate to the chocolate-paired cue than those who received extinction in the same context. Importantly, however, these studies are distinct from PIT in that they concern cue-reactivity, rather than cue-induced reward-seeking.

It is also interesting to note that the role of awareness of the cue-reward relationships is not typically investigated in human PIT research. In most human PIT studies, participants who fail to demonstrate sufficient awareness of the cue-reward relationships are simply excluded from further analysis (e.g. Hogarth et al., 2007; Hogarth et al., 2014). Thus, while there is evidence that participants with awareness of the cue-reward relationships do typically demonstrate PIT effects, whether this type of knowledge if actually *required* to produce the PIT effect is not usually examined. The only two studies that examined the relationship between PIT and awareness found that PIT was only present in participants who could report the relationships between the cues and their paired outcomes (Lovibond et al., 2015; Talmi, Seymour, Dayan, & Dolan, 2008). This is interesting in terms of the requirements for obtaining an overall PIT effect, but in both cases the test of awareness only involved reporting the contingencies between a non-extinguished reward cue and an unpaired cue. As such, those studies do not provide information about whether awareness is also necessary for extinction of a reward cue or its subsequent renewal.

To address these issues, the current study tested the extent to which extinction can reduce PIT in humans, whether any such effect was sensitive to context change (i.e. renewal), and whether these effects required knowledge of the cue-reward relationships (i.e. awareness). To maximise ecological validity, we used a natural high value reward (i.e. chocolate) with participants free to respond or not respond throughout the entire instrumental acquisition and test phases, similar to our previous study demonstrating that extinction can reduce cue-induced reward-seeking (Lovibond et al., 2015). The new critical manipulation was that one group of participants received Pavlovian extinction in the same context as all other phases (Group AAA), whereas the other group received Pavlovian extinction in a different context to all other phases (Group ABA) to test whether the effect of extinction of PIT was context-specific. To investigate the role of awareness, we compared the presence of PIT, extinction, and renewal in sub-groups of participants demonstrating no awareness, partial awareness, or full awareness of the cue-reward relationships. In order to make these sub-group comparisons meaningful, we recruited a large sample ($n > 150$) to ensure sufficient numbers of participants within each awareness group. To the best of our knowledge, no previous study has tested whether PIT is sensitive to renewal and whether awareness is required for extinction and renewal of PIT.

2. Method

2.1. Participants

A total of 246 (157 female, mean age = 20.0, SD = 4.0) students from the University of Sydney participated and received either partial course credit or AUD$15 reimbursement. The study was advertised as investigating responses to food and food-related stimuli on an internal website. Consistent with Lovibond et al. (2015), participants were eligible for the study if they liked and regularly consumed chocolate, were not dieting, and were not allergic to ingredients in chocolate. Participants were asked to refrain from eating chocolate for 24 h, and food for 3 h, prior to the experiment. Ethical approval for all study procedures was obtained from the University of New South Wales Human Research Ethics Committee (Project no HC13026) and ratified by the University of Sydney Human Research Ethics Committee.

2.2. Design

The study employed a 2 × (3) mixed design as shown in Table 1. The within-subjects factor was cue, where one cue was a non-extinguished reward cue (X), one an extinguished reward cue (Y), and one was never paired with reward (unpaired cue; Z). The between-subjects factor was the context of extinction. Participants were randomly allocated to two groups. One group was given the extinction phase in the same context (context A) as the acquisition and transfer test phase (Group AAA). A second group was given the extinction phase in a different context (context B) to the acquisition and transfer test phase (Group ABA). The dependent variable was the number of button presses (instrumental responses) in the transfer test phase.

2.3. Apparatus and materials

Setting Participants were tested individually in a small booth, with the experimenter monitoring the experiment from the adjacent room. Using a similar procedure to Lovibond and Colagiuri (2013), participants were seated at a desk in a 2 m × 2.15 m room facing a 51 cm × 29 cm computer monitor. A webcam (Logitech HD Pro Webcam, Model C920) was set up in the back corner of the room so the experimenter could ensure participants were following instructions throughout the experiment, including consuming the chocolates. On the desk was a Med Associates M&M dispenser model ENV-702 on a pedestal mount, inside a 210-mm x 170-mm x 330-mm, plywood sound attenuating box. A clear 20-mm diameter plastic tube delivered M&M chocolates through a hole in the plywood box into a plastic container within reach of the participant's left hand. In front of the computer was a keyboard which had every key removed except for the spacebar – which was the instrumental response. The experiment was programmed using PsychToolbox for Matlab (Brainard, 1997; Pelli, 1997). Presentation of all stimuli, instructions, and chocolate rewards was controlled by Matlab.

Pre-experimental questionnaire Participants completed questionnaire items to ensure they met the eligibility criteria of the study. Participants were asked about their allergies, whether they were dieting, the time since they last consumed food/chocolate, and were asked to rate their current desire for chocolate on a scale from 0 "*Do not want chocolate*" to 10 "*Want chocolate a lot*". If participants had eaten food within the last 3 h, or chocolate within 24 h, they were asked by the experimenter if they still wanted to consume chocolate and if so, they were included.

Cues Three cues served as the conditioned sitmuli (CSs): a clicker, light, and tone. To the left of the computer was a 20 mm × 25 mm × 30 mm re-configured relay box that, when activated, made 8 clicks per second and was used as the clicker. In front of the computer was a box (80 × 50 × 30 mm) containing a red LED light (11 mm diameter), which flashed when activated. To the right of the computer were two stereo speakers (Logitech, Model Labtec S-120) which emitted a 440 Hz Matlab generated tone when activated. These speakers were also used to deliver verbal instructions throughout the experiment. To ensure these physical cues did not have a differential impact on responding they were randomly allocated as X, Y and Z for each participant.

Context manipulation The lighting and background noise in the room was manipulated to create two different contexts. In the *light + sound* context, a fluorescent white light strip (measuring

Table 1
Study design.

Pavlovian acquisition	Pavlovian extinction	Instrumental acquisition	Transfer test
CONTEXT A	*CONTEXT A or B*	*CONTEXT A*	*CONTEXT A*
X+	X+	R+	X-; Y-; Z-
Y+	Y-		R-
Z-	Z-		

5050 mm × 200 mm × 140 mm, 60 LED) attached to the ceiling was illuminated and two stereo speakers placed under the desk played continuous ocean sounds. In the *dark + no sound* context all lighting in the room was turned off (except the participant monitor) and no background sounds were played. A similar context change manipulation has been used in previous human studies on renewal of cravings (Van Gucht, Baeyens, Hermans, & Beckers, 2013; Van Gucht, Baeyens, Vansteenwegen, Hermans, & Beckers, 2010; Van Gucht et al., 2008; Vansteenwegen et al., 2005). The two contexts served as context A and context B, counterbalanced across participants.

Contingency awareness questionnaire Computerised questions were used to assess contingency awareness. Specifically, participants were instructed "*You will now see/hear the LIGHT/TONE/CLICKER"* and were then asked to rate how likely each cue was to be paired with chocolate on a visual analogue scale (VAS) from 0 *"Never"* to 100 *"Always"*.

Post-experimental questionnaire Participants rated how much they wanted chocolate on a VAS ranging from 0 "Do not feel like chocolate" to 100 "*Feel like chocolate a lot*". Participants also provided demographic information and their weight and height.

2.4. Procedure

Participants were tested individually in a single 1 hr session. On arrival they were given the participant information statement and asked to provide informed consent if they wished to participate. Those consenting completed the pre-experimental questionnaire and were seated in the test room. All instructions were presented on the computer monitor and accompanied with pre-recorded voice instruction. The experiment included four phases described below and shown in Table 1.

2.4.1. Phase 1

Pavlovian acquisition (Context A) During this phase, participants had the opportunity to learn the cue-chocolate relationships. Participants were informed that they would see and hear different cues, some of which would be followed by chocolate, and that they should consume each chocolate as soon as it was delivered. A differential conditioning procedure was implemented such that cue X was presented with chocolate for 4 trials, cue Y was presented with chocolate for 6 trials, and cue Z was presented with no outcome for 4 trials. The order of trials was randomised over two blocks of two X, three Y and two Z trials. Each cue was presented for 10 s. On X and Y trials, the chocolate dispenser delivered a chocolate at the end of the 10 s cue presentation. Throughout the experiment, the delivery of a chocolate was accompanied by the text *"chocolate"* appearing on the monitor for 3 s. The inter-trial interval was varied randomly from 30 to 40 s.

2.4.2. Phase 2

Pavlovian extinction (Context A or B) This phase followed on immediately from the end of Pavlovian acquisition without any further instructions. In this phase, cue Y was presented without a chocolate for 6 trials. There were also two reminder trials of cue X followed by chocolate and cue Z not followed by a chocolate. There were two blocks in total, with trials randomised within each block consisting of one X, three Y, and one Z trial/s. Consequently, cues X and Y were equivalent in terms of number of reinforced trials (both receiving a total of 6 reinforced trials) over the course of the experiment, such that any difference on test could not be explained by differences in amount of excitatory learning. For Group AAA, Pavlovian extinction was carried out in the same context as the Pavlovian acquisition phase (context A). For Group ABA, Pavlovian extinction phase was carried out in a different context to the Pavlovian acquisition phase (context B).

2.4.3. Phase 3

Instrumental acquisition (Context A) During this phase participants had the opportunity to learn the response-chocolate relationship. Participants were given instructions that they were able to press the space bar to earn chocolates, and that they may press it as often or as little as they liked. Space bar pressing was rewarded on a variable ratio (VR) 10 schedule in which, on average, 10 presses (range 6–14) were required to receive a chocolate. To shape participant's responses, the VR schedule was phased in over the first three rewards which required a fixed ratio of 2, 4 and 6 responses, progressively. Each time the participant pressed the space bar a small black square (20 × 20 pixels) appeared in the centre of the monitor for 50 ms. Participant had to earn a minimum of 4 chocolates and could earn a maximum of 8 during the instrumental acquisition phase. Note that our previous results suggest that the PIT effect and its extinction are unaffected by the order of the Pavlovian and instrumental phases (Lovibond et al., 2015). In the current study, the instrumental phase was implemented after the Pavlovian phases so that once the button press was introduced it remained available during the remainder of the experiment to allow the transfer test to be implemented without further instructions.

2.4.4. Phase 4

Transfer Test (Context A) The transfer test was conducted under Pavlovian and instrumental extinction, whereby neither the cues nor pressing the space bar led to chocolate. Each of the three cues was presented twice during the transfer test. Order of presentation was randomised within two blocks of three trials (one of each cue). Each trial lasted 60 s with button press responses recorded in 5 s bins throughout. The first 30 s constituted the baseline period, the cues were then presented for a period of 10 s, and the trial continued for 20 s after the end of cue presentation. The inter-trial interval was fixed at 20 s. The first cue in the transfer test was presented after participants had either not responded for 2 min or a total of 10 min of the instrumental extinction had elapsed. Participants who failed to show reasonable instrumental extinction, i.e. who responded at more than 1 response per second during the baseline phases of the transfer test, were excluded (see Colagiuri & Lovibond, 2015).

2.5. Data handling and analyses

Thirty-eight participants were excluded for failing to obtain at least 4 rewards during instrumental training and 37 for failing to demonstrate instrumental extinction prior to the transfer test. A further 8 participants were excluded ad hoc as a result of computer failure (n = 7) or because they were clearly not following instructions (n = 1). This left a sample of 160 participants with analysable data.

Participant characteristics were first compared to ensure that Group AAA and Group ABA participants did not differ on factors that may affect responding. Planned orthogonal contrast analysis implemented via mixed ANCOVA was then used to test PIT effects with the average number of responses made per 5 s bin in the 30 s following cue onset as the dependent variable and average number of responses made per 5 s bin in the 30 s before cue onset as the covariate. The two factors were group (AAA vs ABA) and cue (X, Y, Z). The first contrast tested the overall PIT effect, by comparing responding following the two reward cues (X & Y) with the unpaired cue (Z) averaged over groups. The second contrast tested whether there was evidence of extinction overall, by comparing responding for the non-extinguished reward cue (X) with the extinguished reward cue (Y) averaged over groups. The third and fourth contrasts were interaction contrasts that tested whether the size of the PIT effect (X & Y vs Z) and the effect of extinction (X vs Y) differed as a function of extinction context, respectively.

To investigate the role of awareness, participants were classified as fully aware, partially aware, or unaware of the Pavlovian contingencies. In order to be classified as aware, participants were required to rate the likelihood of receiving chocolate after each cue in the correct order (i.e. X > Y > Z, n = 89). Participants were classified as partially aware (n = 47) if they failed to report the full contingencies but rated the likelihood of receiving chocolate following X as greater than Z, meaning that they were aware of the simple PIT relationship, but not extinction. The remaining participants were classified as unaware (n = 24). To examine whether PIT or its extinction differed as a function of level of awareness, we used a mixed ANCOVA to test the two-way interactions between the PIT and extinction contrasts with level of awareness and the three-way interaction between the PIT and extinction contrasts with level of awareness and renewal group as factors, controlling for baseline responding. The main contrast analysis used for the full sample was then repeated within each of the awareness sub-groups. All analyses were conducted using the Statistical Package for the Social Sciences (SPSS) Version 20 for Windows. A *p*-value of < 0.05 was considered statistically significant.

3. Results

3.1. Participant characteristics

There were no statistically significant differences in mean age, gender, BMI, time since eating chocolate, time since eating any food, and or pre- and post experimental chocolate cravings between groups, highest $t_{158} = 1.34$, $p = 0.18$.

3.2. Cue-elicited reward-seeking (all participants)

Fig. 2 shows mean responding to cues X, Y, and Z during the transfer test for each group separately. Contrast analysis revealed a statically significant overall PIT effect, with participants making an average of 4.5 (SD = 16.0) more button presses following the reward cues (X and Y) than the unpaired cue (Z), controlling for baseline responding, $\eta_p^2 = 0.08$, $F_{1,157} = 12.8$, $p < 0.001$. Extinction significantly attenuated this PIT effect, with button presses following the extinguished reward cue being an average of 3.1 (SD = 18.3) presses lower than those following the non-extinguished reward cue, $\eta_p^2 = 0.03$, $F_{1,157} = 4.63$, $p = 0.03$. Comparing across the two groups, there was no difference in the size of the overall PIT effect, $\eta_p^2 = 0.001$, $F_{1,157} = 0.20$, $p = 0.66$. However, the difference in responding to the extinguished reward cue (Y) relative to the non-extinguished reward cue (X) was significantly smaller in Group ABA (mean $diff_{XY} = 0.08$, SD = 17.7) than in Group AAA (mean $diff_{XY} = 6.10$, SD = 18.5), indicating statistically significant renewal of cue-elicited responding, $\eta_p^2 = 0.03$, $F_{1,157} = 4.43$, $p = 0.04$.

3.3. Cue-elicited reward-seeking by awareness

Fig. 3 shows mean cue-elicited responding by level of awareness for each group separately. There were no significant differences in the proportion of aware, partially aware, and unaware participants between the Groups AAA and ABA, $\chi^2 = 0.18$, df = 2, $p = 0.92$. A mixed ANCOVA indicated that both the overall PIT effect and the extinction effect interacted significantly with level of awareness, $\eta_p^2 = 0.11$, $F_{2,153} = 9.02$, $p < 0.001$ and $\eta_p^2 = 0.06$, $F_{2,153} = 5.14$, $p = 0.01$, respectively, indicating differences in PIT and extinction as a function of level of awareness. The three-way interactions indicated that the differing effects of PIT and extinction across levels of awareness did not interact significantly with renewal group, highest $\eta_p^2 = 0.01$, $F_{2,153} = 0.86$, $p = 0.42$. Subgroup analysis revealed that for the fully aware participants, the pattern of responding was very similar to that of the full sample. Specifically, there was a statistically significant PIT effect overall, with the reward cues inducing 7.9 (SD = 14.8) more button presses than the unpaired cue, $\eta_p^2 = 0.23$, $F_{1,86} = 26.0$, $p < 0.001$. Pavlovian extinction significantly reduced this PIT effect, with an average of 8.2 (SD = 19.3) less button presses following extinguished reward cue than the non-extinguished reward cue, $\eta_p^2 = 0.17$, $F_{1,86} = 17.3$, $p < 0.001$. There was no statistically significant difference in the size of the PIT effect across groups, $\eta_p^2 = 0.01$ $F_{1,86} = 1.08$, $p = 0.30$. However, the reduction in button presses to the extinguished reward cue relative to the non-extinguished reward cue was significantly smaller in Group ABA (mean $diff_{XY} = 3.9$, SD = 20.0) than in Group AAA (mean $diff_{XY} = 12.7$, SD = 17.6), indicating a statistically significant renewal effect, $\eta_p^2 = 0.05$, $F_{1,86} = 4.53$, $p = 0.04$.

When analysing responses in the partially aware and unaware subgroups, there was no evidence of statistically significant PIT effects, extinction effects, or interaction by group for any of the contrasts tested, highest $F_{1,21} = 2.08$, $p = 0.16$.

4. Discussion

The current study used a PIT design to test whether Pavlovian extinction reduces cue-induced reward-seeking and whether any effect of extinction was sensitive to renewal. We found clear evidence that extinction attenuates PIT in that an extinguished reward cue elicited less reward-seeking compared with a reward cue that was not extinguished. Further, we found that the effect of extinction was subject to renewal in that reward-seeking induced by the extinguished reward cue was stronger when extinction was conducted in a different context to the initial training and test phase (ABA renewal). These findings have a number of important implications.

In terms of the overall effect of Pavlovian extinction, the current result is consistent with a recent study of ours using a similar design (Lovibond et al., 2015), which also found evidence that extinction can reduce the impact of reward cues on reward-seeking. However, one important improvement over that study is that in the current study, we equated the total number of reinforced trials for the non-extinguished (X) and extinguished cues (Y), whereas in our previous study the non-extinguished cue was reinforced on more trials than the non-extinguished cue (i.e. 9 vs 6 times, respectively). As such, the current study eliminates the possibility that the differences in cue-induced reward-seeking in the transfer test in our previous study may have resulted from differences in total associative strength achieved during Pavlovian acquisition. Thus, the current result provides even stronger evidence that Pavlovian extinction is capable of diminishing cue-induced reward-seeking.

The most interesting finding of the current study was that the attenuation of cue-induced reward-seeking by Pavlovian extinction

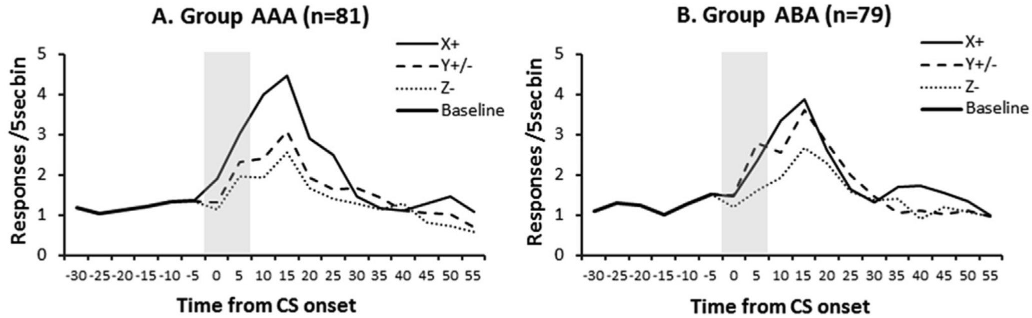

Fig. 2. Mean button presses per 5 s bin for the 30 s before cue onset to 60 s post cue onset for all participants in Group AAA (A) and Group ABA (B).

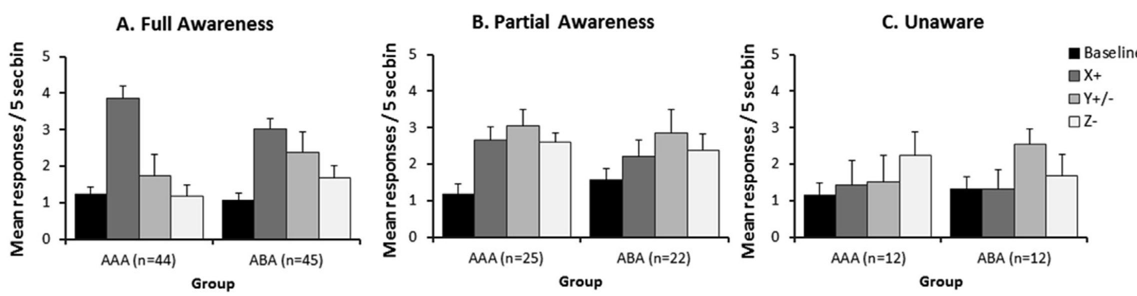

Fig. 3. Mean (+SE) responses per 5 s bin in the 30 s before cue onset (baseline) and the 30 s after cue onset for each cue shown separately for participants with full awareness (A), partial awareness (B), and no awareness (C) by group.

was subject to renewal. Here, the PIT effect to a cue extinguished in a different context re-emerged when participants were tested in the context in which they underwent Pavlovian training. To our knowledge, this is the first demonstration of a renewal effect in both the human and animal PIT literature. This extends the evidence that cue-reactivity is sensitive to context renewal for drug and food rewards (Collins & Brandon, 2002; Van Gucht et al., 2008) by demonstrating that any direct motivational effect of cues on reward-seeking is also subject to renewal. Sensitivity of PIT to renewal suggests a practical limitation to how effective extinction could be for reducing the impact of reward cues on maladaptive reward-seeking. Further, this effect is entirely consistent with clinical studies indicating that cue-exposure therapy typically fails to reduce relapse rates outside of the laboratory (Conklin & Tiffany, 2002; Rachman, 1989).

Two points are important to consider regarding the limited ability of extinction to reduce cue-elicited reward-seeking due to renewal. First, studies showing renewal effects in other areas often find that renewed responding is weaker than if no extinction had taken place (see Bouton, Winterbauer, and Todd, 2012 for examples). This pattern is supported in the current study, particularly for the fully aware participants, whereby responding to the non-extinguished reward cue was numerically stronger than responding to the extinguished cue in Group ABA. As such, extinction training may dampen reward-seeking even with renewal and could serve as part of a multifaceted intervention. Second, both human and animal studies suggest that some techniques may be capable of reducing renewal effects, including multiple context extinction (e.g. Chelonis, Calton, Hart, & Schachtman, 1999; Glautier, Elgueta, & Nelson, 2013; Gunther, Denniston, & Miller, 1998), using retrieval cues to facilitate generalisation of the extinction learning to new contexts (see Schachtman & Reilly, 2011 for a review), and disrupting reconsolidation of the memory of reward-cue pairings (see Torregrossa & Taylor, 2013 for a review). It may therefore be possible to increase the efficacy of extinction interventions through using a variety of these techniques.

Another interesting finding was that the PIT effect was only evident in participants demonstrating full awareness of the Pavlovian contingencies. This is consistent with previous studies that have shown awareness to be important in producing PIT (Lovibond et al., 2015; Talmi et al., 2008). Given that only participants classified as fully aware demonstrated a significant PIT effect, it was not possible to determine whether awareness was necessary for extinction or renewal specifically. The fact that the partially aware participants failed to show an overall PIT effect suggests that quite a high level of awareness may be necessary to induce PIT. However, some caution is required here as participants with no awareness could have been misclassified as partially aware simply by chance. That is, if participants simply guessed the likelihood of X and Y being followed by chocolate, then they would have a 50% chance of being misclassified as partially aware. This is in contrast to only a 17% chance of correctly guessing the contingencies to be classified as fully aware. Thus, responding in participants classified as partially aware may underestimate the effect of knowledge of the simple non-extinguished cue and unpaired cue on PIT. Furthermore, it is important to point out that just because awareness of the Pavlovian contingencies is required for the acquisition of PIT does not mean that expression of PIT is necessarily under voluntary cognitive control. Certainly the evidence that PIT is insensitive to devaluation (Allman et al., 2010; Colagiuri & Lovibond, 2015; Eder & Dignath, 2016; Hogarth & Chase, 2011; Hogarth, 2012; Watson et al., 2014) would suggest that PIT can be driven by non-cognitive factors.

There are some limitations to the study worth mentioning. First, by necessity of design, although we were able to match the number of rewards following X and Y during training, there were temporal differences in exposure to these cues which could influence the rate of learning and hence their associative strength. However, this could only explain differences between the two reward cues within-groups, because the contingencies and timing were identical across the groups. Second, Group ABA was exposed to two contexts while Group AAA was only exposed to a single context (albeit counterbalanced). Therefore we cannot rule out the possibility that exposure to multiple contexts to some extent influenced the difference between (but not within) groups. To rule this possibility out, future studies could consider using within-subjects designs in which testing occurs in both Context A and Context B. Third, we only assessed awareness of the Pavlovian contingencies, not the instrumental contingency. While it seems reasonable to assume a high, if not perfect level of awareness for the instrumental contingency given it involved only a single response and outcome, it would be worth directly testing this in future studies. Fourth, our single reward design likely tests a combination of reward-specific and reward-general effects (see Corbit & Balleine, 2005), so we do not know if extinction and context renewal influence these types of PIT differently. Therefore, it would be interesting to tease apart these effects in future studies with multiple high value rewards and voluntary responding.

In summary, the current study demonstrated that cue-induced reward-seeking assessed via PIT can be reduced by Pavlovian extinction and provides novel evidence that this effect is subject to renewal following a change in context. The sensitivity of extinction of PIT to renewal suggests that extinction may have limited utility in eliminating maladaptive cue-induced reward-seeking – consistent with the general poor efficacy of cue-exposure therapy for reducing relapse. Given that studies investigating renewal in other learning paradigms suggest that techniques such as multiple context extinction, retrieval cues, and reconsolidation manipulation can reduce renewal, it would be interesting for future studies to test whether such techniques reduce renewal for PIT effects. These techniques could form part of a multifaceted intervention for overcoming the effects of renewal on extinction and reducing maladaptive reward-seeking behaviours.

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