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Extinguishing cue-controlled reward choice: Effects of Pavlovian extinction on outcome-selective Pavlovian-instrumental transfer

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Abstract

Outcome-selective Pavlovian-instrumental transfer (PIT) refers to the finding that presenting Pavlovian predictors of outcomes can enhance the vigour of instrumental responding for those same outcomes. Three experiments examined the sensitivity of outcome-selective PIT to Pavlovian (stimulus-outcome) extinction. In Experiment 1, participants first learned to perform different instrumental responses to earn different outcomes. In a separate Pavlovian training phase, certain stimuli were established as Pavlovian signals of the different outcomes. Some of these Pavlovian stimuli were then extinguished (they were presented alone, without any outcome), while others were not. A final transfer test measured the extent to which these Pavlovian cues biased instrumental response choice. Consistent with previous work, the observed PIT effects were immune to Pavlovian extinction; the non-extinguished and extinguished cues produced PIT effects that did not significantly differ in size. In Experiment 2, response choice was tested in the presence of compound stimuli that included both extinguished and non-extinguished cues. Response choice was highly sensitive to the extinction manipulation under these circumstances. Experiment 3 tested whether this sensitivity to Pavlovian extinction was a direct effect of the associative strength of the Pavlovian cues present, or an indirect effect of cue salience. The results provide unique evidence to suggest that PIT is a direct consequence of the strength of the Pavlovian associations.

Keywords: Pavlovian-instrumental transfer, extinction, cue reactivity.

Cues that signal rewarding outcomes can motivate reward-seeking behaviours (e.g., Hogarth, Dickinson, & Duka, 2010). Such *cue reactivity* is often adaptive, allowing individuals to selectively seek natural rewards (such as food and drink) that are predictable in a given environment. Cue reactivity can also become problematic, however, as seen in the case of drug addiction (Hogarth et al., 2010) and overeating (Ridley-Siegert, Crombag, & Yeomans, 2015; Watson, Wiers, Hommel, Ridderinkhof, & de Wit, 2016).

Cue reactivity is often assessed experimentally using Pavlovian-instrumental transfer (PIT) tasks (e.g., Colwill & Rescorla, 1988; Hogarth, Dickinson, Wright, Kouvaraki, & Duka, 2007; Kruse, Overmier, Konz, & Rokke, 1983). Outcome-selective PIT tasks, for example, typically involve separate instrumental and Pavlovian training phases (the order of which varies), followed by a final transfer test. During instrumental training, participants learn that two instrumental responses (R1 and R2) earn two rewarding outcomes (O1 and O2), such that R1 earns outcome O1 and R2 earns outcome O2 (R1 – O1, R2 – O2). During Pavlovian training, two neutral stimuli (S1 and S2) are consistently paired with outcomes O1 and outcome O2, respectively, to establish S1-O1 and S2-O2 associations. In a final transfer test, the Pavlovian stimuli S1 and S2 are presented on separate trials and instrumental response choice (R1 vs R2) is tested. The critical finding is that the cues typically increase the instrumental response that was paired with the same outcome as the cue. That is, stimulus S1 selectively increases R1 responses (both paired with O1), and stimulus S2 increases R2 responses (both paired with O2). Importantly, the transfer test is usually conducted in extinction (i.e., no outcomes are provided during this test) to ensure that response choice is not driven by new learning about the stimulus-response relationships during the test. Thus, the PIT effects observed are usually thought to reflect an interaction between the Pavlovian (S-O) and instrumental (R-O) associations that formed during the preceding training phases (although see Cohen-Hatton, Haddon, George, and Honey, 2013, for a different interpretation).

A peculiar aspect of outcome-selective PIT effects is that they are often robust against a range of manipulations that one might expect to diminish them. In particular, outcome-selective PIT effects have been reported to be insensitive to both outcome devaluation (Corbit, Janak, & Balleine, 2007; Hogarth, 2012; Hogarth & Chase, 2011; Holland, 2004; Rescorla, 1994; van Steenbergen, Watson, Wiers, Hommel, & de Wit, 2017; Watson, Wiers, Hommel, & de Wit, 2014, although for exceptions see Allman, DeLeon, Cataldo, Holland, & Johnson, 2010; Eder & Dignath, 2016a, 2016b; Seabrooke, Le Pelley, Hogarth, & Mitchell, 2017) and Pavlovian extinction manipulations (Delamater, 1996; Hogarth et al., 2014; Rosas, Paredes-Olay, García-Gutiérrez, Espinosa, & Abad, 2010, but also see Delamater, Schneider, & Derman, 2017). Hogarth et al. (2014) provided a good example of this insensitivity to Pavlovian extinction. They trained participants to perform two instrumental responses (R1 and R2) to earn tobacco and chocolate points (outcomes O1 and O2), to establish R1-O1 and R2-O2 associations. Four Pavlovian stimulus-outcome (S-O) associations were then established in a Pavlovian training phase. Two stimuli, S1 and S2, predicted outcome O1 (S1-O1, S2-O1); the remaining stimuli predicted outcome O2 (S3-O2, S4-O2). Importantly, S2 and S4 stopped predicting the outcomes part way through the Pavlovian training phase, and instead predicted "nothing". Hence, one stimulus that was associated with each outcome was extinguished. On test, each Pavlovian cue (S1-S4) was presented individually and instrumental response choice (R1 vs. R2) was tested. Unsurprisingly, the non-extinguished cues (S1 and S3) produced typical outcome-selective PIT effects (S1 and S3 increased choice of R1 and R2, respectively). Crucially, the extinguished cues produced similar effects (S2 and S4 increased choice of R1 and R2, respectively), and the size of the PIT effects for the extinguished and non-extinguished stimuli did not significantly differ. Such findings (also observed in studies with rats; Delamater, 1996), have led to a prevailing view that appetitive, outcome-selective PIT effects are largely insensitive to Pavlovian extinction.

The insensitivity to Pavlovian extinction described above is particularly intriguing from a theoretical perspective, because it arguably speaks against the most widely advocated model of PIT: S-O-R theory (e.g., Alarcón & Bonardi, 2016; Alarcón, Bonardi, & Delamater, 2017; de Wit & Dickinson, 2009; Watson et al., 2014, 2016). S-O-R theory assumes that Pavlovian conditioning produces excitatory stimulus-outcome (S-O) links between the Pavlovian cues and the rewarding outcomes. Instrumental conditioning is also suggested to foster a link between the instrumental response R and the outcome O, either as a bidirectional R-O/O-R link (Asratyan, 1974; Elsner & Hommel, 2001; Pavlov, 1932), or an indirect outcome-response O-R link (de Wit & Dickinson, 2009; Trapold & Overmier, 1972). In the transfer test, the Pavlovian stimulus is then suggested to activate the outcome representation (through the S-O link), which in turn activates and triggers the associated instrumental response through the instrumental O-R link. Thus, S-O-R theory suggests that Pavlovian cues increase instrumental responses via a chain of Pavlovian and instrumental links that are mediated by a common outcome.

S-O-R theory assumes that PIT effects depend on the Pavlovian stimulus S activating the associated outcome O. It therefore predicts that, as long as Pavlovian extinction weakens the S-O association effectively, it should also reduce the ability of the Pavlovian stimulus S to elicit a PIT effect (Hogarth et al., 2014). Of course, S-O-R theory is non-committal about whether extinction should actually degrade S-O associations in the first place. If the extinction procedure fails to weaken the relevant underlying associations, then S-O-R theory would naturally predict a strong PIT effect despite the extinction procedure (Delamater, 1996). Delamater and Westbrook (2014), for example, suggested that extinction might weaken the association between the Pavlovian stimulus S and the motivational properties of the outcome O, without necessarily affecting the association between the stimulus and the sensory properties of the outcome. S-O-R theory assumes that PIT effects depend on the stimulus S activating only the sensory properties (not the motivational value) of the outcome (e.g., Hogarth & Chase, 2011; Rescorla, 1994; van Steenbergen et al., 2017). Hence, if extinction fails to weaken the association between the stimulus and the sensory properties of the outcome then S-O-R theory would not predict a weakening of the PIT effect following extinction.

It is important to note at this point that, while the majority of studies have failed to detect effects of Pavlovian extinction on PIT, there are a few recent exceptions. Bezzina, Lee, Lovibond, and

Colagiuri (2016) and Lovibond, Satkunarajah, and Colagiuri (2015) first reported attenuated PIT effects in two recent publications with human participants. We shall return to these experiments in the General Discussion, since they employed rather different procedures to the outcome-selective PIT procedures discussed thus far. More recently, Delamater et al. (2017) reported that extinction weakened outcome-selective PIT effects in rats using a Pavlovian conditioning procedure that was expected to produce relatively weak Pavlovian conditioning. These studies suggest that outcome-selective PIT effects can be sensitive to extinction manipulations under certain circumstances.

The present experiments aimed to shed further light on the conditions that promote sensitivity to Pavlovian extinction in outcome-selective PIT experiments with human subjects. To anticipate, Experiment 1 replicated Hogarth et al.'s (2014) demonstration of an outcome-selective PIT effect that was insensitive to Pavlovian extinction. Experiment 2 explored whether a more sensitive transfer test procedure would produce evidence of sensitivity to extinction. This procedural difference will be expanded on following presentation of the data from Experiment 1.

Experiment 1

Experiment 1 aimed to replicate Hogarth et al.'s (2014) demonstration of insensitivity to Pavlovian extinction in a typical outcome-selective PIT task. Table 1 shows the design. In an initial instrumental training phase, participants first learnt to perform two instrumental responses (R1 and R2) to earn points towards either outcome O1 or O2 (R1-O1, R2-O2). In a separate Pavlovian acquisition phase, six neutral cues (A-F) were established as predictors of either outcome O1 or O2. Cues A and C served as non-extinguished cues, B and D as extinguished cues, and E and F as filler cues. During Pavlovian acquisition, cues A, B, and E were repeatedly presented (one at a time) and were followed by outcome O1. Cues C, D and F were similarly presented and were followed by outcome O2. In the extinction phase, B and D were then presented and were followed by “nothing”. The non-extinguished cues (A and C) were not presented here, so that they did not undergo extinction or additional training. The filler cues (E and F) were presented and reinforced during the extinction phase, so that the participants learnt that both outcomes were still available. In the final transfer test, the extinguished and non-extinguished cues (A-D) were presented on separate trials and instrumental response choice (R1 vs. R2) was tested. The outcomes were not presented during the transfer test so that they did not affect response choice.

We expected the non-extinguished A and C to produce outcome-selective PIT effects by biasing response choice towards the response that predicted the same outcome (R1 and R2, respectively). The question was whether the extinguished B and D would produce the same pattern. If outcome-selective PIT effects are insensitive to Pavlovian extinction, then the extinguished cues should bias response choice to the same extent as the non-extinguished cues. This pattern would replicate Hogarth et al.'s (2014) results. Sensitivity to Pavlovian extinction, by contrast, would be revealed if the extinguished cues produced smaller PIT effects than the non-extinguished cues.

Method

Participants. Twenty-four participants (12 males, aged between 20 and 69, *M* = 35.96 years, *SEM* = 3.78 years) were recruited from Plymouth University in exchange for £4. The Plymouth University Ethics Committee approved the study.

Apparatus and materials. The experiment was programmed in E-Prime 2.0 (Psychology Software Tools, Inc) and was presented on a 22-inch computer monitor. The text and Pavlovian cues were presented on a white background, and responses were made using a standard keyboard. The participants wore headphones throughout the experiment. Tyrell's Lightly Sea Salted Crisps and Tyrell's Sea Salted Popcorn were decanted into separate, transparent containers to serve as props. Assignment of crisps and popcorn to the roles of outcomes O1 and O2 was counterbalanced over participants. The six Pavlovian cues (A-F; see Table 1) were coloured squares. The colours blue, green, pink, purple, red and yellow were randomly assigned to cues A-F for each participant.

Procedure. Participants were shown the food containers and were told that they could win crisps and popcorn points throughout the experiment. They then sampled the crisps and popcorn in a random order and rated how much they would like to eat them (1 = Not at all, 7 = Very much). The containers were then removed and the experimenter read aloud the instrumental training instructions: "You can now earn [O1] and [O2] points by pressing the left and right arrow keys. Your task is to learn which keys earn each reward". The text in brackets was replaced by the appropriate outcome ("CRISPS" or "POPCORN"). A choice symbol ("← or →") was presented on each instrumental training trial until either the left or right arrow key (R1/R2) was selected on the computer keyboard. The left arrow key (R1) earned points towards outcome O1, and the right arrow key (R2) earned points towards outcome O2. The outcomes were available on alternate trials. The participants were free to perform either response on each trial, but only one response would be rewarded on each trial. We used a forced-choice procedure (see e.g., Hogarth, 2012; Hogarth & Chase, 2011), where the participants were required to make one response per trial. After a response was made, the choice symbol was replaced by the statement, "You earn one [CRISPS/POPCORN] point" as appropriate if the participant responded for the available outcome, or "You earn NOTHING" if the unavailable outcome was chosen. Rewards were presented as points rather than real food outcomes to be consistent with Hogarth et al. (2014), and to avoid a generalised devaluation of the outcomes through satiation (see Colagiuri & Lovibond, 2015). Feedback was presented centrally for 3000ms. There were 48 instrumental training trials, which were separated by random intervals of 750-1250ms.

Pavlovian training followed the instrumental training phase. The instructions stated: "You will now see some different colours. These colours will predict either CRISPS or POPCORN points. Your task is to learn which colours predict each reward. To help you learn, you will be asked to predict which reward you think the colours predict. At first you will need to guess, but with feedback you should be able to learn the relationships between the colours and the rewards."

Each trial began with the central presentation of a Pavlovian stimulus. The text, "Which reward will follow?", was superimposed on the stimulus. Beneath the question appeared the reward options ("CRISPS", "POPCORN", "NOTHING" and "DON'T KNOW"), arranged vertically. The "DON'T KNOW" option was always presented last; the other options were ordered randomly on each trial. Options were selected using the mouse. Regardless of the participant's answer, the outcome text read, "[STIMULUS] earns one [OUTCOME] point" or "[STIMULUS] earns NOTHING", as appropriate (see Table 1). The text in brackets was replaced by correct stimulus (e.g., "BLUE") and outcome (e.g., "CRISPS"). Outcome-selective PIT effects are thought to depend on the Pavlovian cues and instrumental responses sharing a common outcome. We therefore attempted to keep the language relating to the outcomes as similar as possible between the two training phases. Thus, participants were presented with the statement that either they or the stimulus "earned" the relevant outcome (along with a corresponding picture) in both phases. Incorrect responses (not including "DON'T KNOW" responses) produced an error noise. Outcome text was presented for 3000ms.

The Pavlovian training phase consisted of 72 acquisition trials, followed by 48 extinction trials. The acquisition and extinction phases consisted of six blocks each, with each stimulus presented twice per block in a random order. The transition from acquisition to extinction appeared seamless to participants. Trial types were as in Table 1. The trials were separated by random intervals of 750-1250ms.

After Pavlovian extinction, the transfer test instructions were presented: "You can now continue to earn the crisps and popcorn points by pressing the left or right arrow key in the same way as before. You will now only be told how many of each reward you have earned at the end of the experiment. The colours from the previous stage will also be presented before you choose the left or right arrow key." Each trial began with a Pavlovian cue (A, B, C or D), presented at the top of the screen. After 3000ms, the instrumental choice symbol (← or →) appeared beneath the Pavlovian stimulus, until R1 or R2 was performed. No feedback was provided. There were eight blocks of eight trials, with each cue presented twice per block in a random order. The trials were separated by random intervals of 750-1250ms.

After the transfer test, the participants completed Pavlovian and instrumental contingency knowledge tests. In the Pavlovian knowledge test, four questions were presented in a random order. For each question, one Pavlovian stimulus (A, B, C or D) was presented, along with the question, “Which reward did [STIMULUS COLOUR] produce?” Participants chose one of three options (CRISPS, POPCORN and NOTHING) using the mouse, and then rated their confidence in this choice (1 = Not at all confident, 7 = Very confident). In the instrumental knowledge test, two questions were presented in a random order: “Which key earned [CRISPS/POPCORN], the left or right arrow key?” Participants selected a response using the keyboard, and again rated their confidence. Finally, participants completed four expectancy ratings in a random order. A stimulus (A, B, C or D) was presented on each trial, along with the question, “When the colour [STIMULUS COLOUR] was presented, to what extent did you think you were more likely to earn [CRISPS/POPCORN]?” The outcome in this question (crisps/popcorn) was always the correct outcome for that stimulus. For example, if the blue square had predicted crisps points, then expectancy ratings were recorded for crisps rather than popcorn (even if the blue-crisps contingency had been extinguished). Expectancy ratings were on a scale from one (Not at all) to seven (Very much).

Reward points were not translated into real rewards, but the participants were offered chocolate at the end of the experiment (regardless of their points tally).

Results

Liking ratings for outcomes O1 (M = 4.71, SEM = 0.30) and O2 (M = 4.42, SEM = 0.24) did not significantly differ, $t < 1$. During instrumental training, choice of the R1 (M = 49.13%, SEM = 2.15%) versus R2 response did not significantly differ from 50%, $t < 1$. Furthermore, 87.50% of participants reported perfect instrumental contingency knowledge. Confidence ratings for O1 (M = 5.71, SEM = 0.28) and O2 (M = 5.75, SEM = 0.26) did not significantly differ, $t < 1$.

Figure 1a shows the percentage of correct predictions made during Pavlovian training. During acquisition, the correct prediction for cue B and D was O1 and O2, respectively, and these changed to 'nothing' in extinction. Prediction accuracy for the non-extinguished (A and C), extinguished (B and D), and filler (E and F) cues did not significantly differ (*t*s < 1.25, *p*s > .22). The cues within each cue type were therefore collapsed for presentation. Most importantly, the participants learnt to correctly predict that B and D earned 'nothing' during extinction. Accuracy on the final block did not significantly differ on B/D and E/F trials, t (23) = 1.37, p = .19, Cohen's d_z = 0.28. Furthermore, 83.33% of the sample reported perfect knowledge of the Pavlovian contingencies (cues A-D) in the final Pavlovian knowledge test[1]. Unsurprisingly, the participants were more confident in their knowledge of the non-extinguished contingencies (M = 6.31, SEM = 0.16) than the extinguished contingencies (M = 5.40, SEM = 0.21), t (47) = 4.65, p < .001, d_z = 0.79. Similarly, expectancy ratings were higher for the non-extinguished cues (M = 6.25, SEM = 0.24) than the extinguished cues (M = 5.06, SEM = 0.32), t (23) = 3.07, p = .005, d_z = 0.63.

The results of most interest are from the transfer test, shown in Figure 1b. We used a balanced design, where outcomes paired with each instrumental response were counterbalanced between-subjects. Across participants, baseline response choice in the absence of any cues must, therefore, logically sit at 50%. The graph suggests that each stimulus biased response choice away from this 50% indifference point and towards the associated outcome, regardless of whether that stimulus was extinguished or not. Since there were an equal number of male and female participants, gender was also included as a between-subjects factor in the analysis. A stimulus (A/B vs C/D) × extinction (A/C vs B/D) × gender (male vs female) mixed ANOVA revealed a main effect of stimulus, F (1, 22) = 39.22, p < .001, generalised eta squared (η_G^2) = .58, with A and B producing more R1 responses than C and D. There was no significant main effect of extinction or gender, *Fs* < 1,

[1] Both "O1" and "Nothing" were regarded as correct responses for cue B. Likewise, both "O2" and "Nothing" were considered correct for cue D.

nor were there any significant interactions, (*F*s < 2.99, *p*s > .10). The non-significant stimulus × extinction interaction was supported by a Bayes Factor (BF_{10}) of 0.35, which favours the null hypothesis (JASP Team, 2018).

Discussion

In Experiment 1 we observed an outcome-selective PIT effect: the Pavlovian cues selectively biased instrumental response choice towards the response that predicted the same outcome in the transfer test. The magnitude of this PIT effect was not significantly diminished by the extinction procedure; there was no significant difference in the extent to which the extinguished and non-extinguished cues biased response choice, despite the extinguished cues producing no outcomes during the extinction phase. The participants learned to accurately predict “no outcome” to the extinguished cues very well during the extinction phase, so the strong PIT effect despite extinction of cues B and D cannot readily be attributed to poor learning during the extinction phase. The results replicate Hogarth et al.'s (2014) findings and are consistent with the claim that outcome-selective PIT effects are robust against Pavlovian extinction treatments.

Experiment 2

In Experiment 1, Pavlovian extinction had little impact on the ability of the Pavlovian cues to drive outcome-selective PIT. This is consistent with previous studies with both rats (Delamater, 1996) and humans (Hogarth et al., 2014; Rosas et al., 2010). A common feature of these studies is that the Pavlovian cues were presented individually during the transfer test. This is one potential reason for the observed insensitivity to extinction; perhaps PIT transfer tests are especially sensitive to the presence of cues that signal outcomes, even if those signals are relatively weak. Even an extinguished cue might elicit a PIT effect when it is the only cue present and only one outcome is signalled. It has been argued that PIT effects reflect a tendency for participants to infer that the Pavlovian cues signal which outcomes are available on any given trial during the transfer test, and which ones are not (Cartoni, Moretta, Puglisi-Allegra, Cabib, & Baldassarre, 2015; Hogarth et al., 2014; Seabrooke, Hogarth, & Mitchell, 2016; Seabrooke et al., 2017). When only one stimulus (which signals a single outcome) is presented on each trial during the transfer test, participants might infer that the cued outcome is the only available outcome. Hence, responding during the transfer test may be particularly sensitive to Pavlovian cues (even those with low associative strength) during typical transfer tests, because participants choose to respond for what they consider to be the only available outcome. As a consequence, typical PIT transfer tests (such as that used in Experiment 1) may be commensurately *insensitive* to differences between the associative strengths of extinguished and non-extinguished cues.

The implication of the above argument is that a more sensitive transfer test might reveal evidence for an effect of extinction on outcome-selective PIT. Experiment 2 investigated this possibility, using a transfer test that was based on a procedure originally used with rats by Rescorla (1994). The design, shown in Table 1, was the same as in Experiment 1, except that compound rather than single cues were presented during the transfer test. Thus, response choice during the transfer test was tested in the presence of one of two stimulus compounds: AD or BC. These stimulus compounds both contain one element that was earlier paired with the outcome (O1) produced by response R1, and one element that was paired with the outcome (O2) produced by R2. In each compound, one of these elements has previously undergone Pavlovian extinction, and the other has not. If outcome-selective PIT is truly insensitive to extinction, then the stimulus compounds should not bias response choice in either direction. Consider compound AD: if A (non-extinguished) promotes choice of R1 just as strongly as D (extinguished) promotes choice of R2, then participants should be equally likely to make response R1 as response R2. In contrast, if S-O extinction weakens the PIT effect, then instrumental responding should be biased towards the outcome signalled by the non-extinguished cues A and C. For example, the non-extinguished cue A in the compound AD will produce a bias towards R1 responding due to the shared outcome O1. Likewise, BC will produce a bias towards R2. The side-by-side presentation of one extinguished and one non-extinguished stimulus, which are associated with different responses (via different mediating outcomes), might promote comparison and contrast of the two response options, thereby increasing the sensitivity of the test.

Method

The method was the same as Experiment 1, except in the following respects.

Participants. Twenty-four Plymouth University psychology undergraduates (20 females, aged between 18 and 44, *M* = 22.25 years, *SEM* = 1.48 years) took part for course credit.

Procedure. The transfer test instructions were the same as those given in Experiment 1, except that the participants were also told that the coloured squares would appear at the top and bottom of the screen, and that the location of the colours (top or bottom) was not important. Cues A and D were presented on half of the trials; B and C were presented on the remaining trials. The location of the cues (top/bottom) was counterbalanced, thereby creating four trial types (AD and BC, with counterbalanced cue location). Each trial type was presented once per block in a random order, and there were eight blocks. The transfer test was preceded by one practice block.

Results

Liking ratings for outcomes O1 (*M* = 4.50, *SEM* = 0.29) and O2 (*M* = 4.42, *SEM* = 0.35) did not significantly differ, $t < 1$. During instrumental training, choice of the R1 (*M* = 51.65%, *SEM* = 1.56%) versus R2 response did not significantly differ from 50%, t (23) = 1.06, $p = .30$. Furthermore, 87.50% of the sample reported perfect instrumental contingency knowledge. Confidence ratings for O1 (*M* = 5.42, *SEM* = 0.29) and O2 (*M* = 5.38, *SEM* = 0.29) did not significantly differ, $t < 1$.

Figure 2a shows the percentage of correct predictions made during Pavlovian training. During acquisition, the correct prediction for cues B and D was O1 and O2, respectively, and these changed to ‘nothing’ in extinction. Prediction accuracy for the non-extinguished (A and C), extinguished (B and D), and filler (E and F) cues did not significantly differ (*t*s < 1). The cues within each cue type were therefore collapsed for presentation. Most importantly, the participants learnt to correctly predict that B and D earned 'nothing' during extinction. Accuracy on the final block did not significantly differ on B/D and E/F trials, $t < 1$. Furthermore, 83.33% of participants reported perfect knowledge of the Pavlovian contingencies in the Pavlovian knowledge test (scored as in Experiment 1). Participants were more confident in their knowledge of the non-extinguished contingencies (*M* = 5.88, *SEM* = 0.20) than the extinguished contingencies (*M* = 4.98, *SEM* = 0.16), t (47) = 4.01, $p < .001$, $d_z = 0.70$. Expectancy ratings were also higher for non-extinguished stimuli (*M* = 5.83, *SEM* = 0.27) than extinguished stimuli (*M* = 4.15, *SEM* = 0.25), t (23) = 4.92, $p < .001$, $d_z = 1.00$.

The results of greatest importance are those from the transfer test (Figure 2b). Most importantly, the stimulus compounds selectively biased response choice toward the response that was associated with the same outcome as the non-extinguished stimulus. That is, AD produced more R1 responses than BC, t (23) = 4.75, $p < .001$, $d_z = 0.97$. Furthermore, the AD compound increased R1 responses relative to the 50% indifference point, t (23) = 4.79, $p < .001$, Cohen's $d = 0.98$. Conversely, the BC compound increased R2 responses relative to the 50% indifference point, t (23) = 3.76, $p = .001$, $d = 0.77$.

Discussion

When both extinguished and non-extinguished cues were presented together during the transfer test, instrumental response choice was biased towards the response that earned the same outcome as the non-extinguished stimulus. To the best of our knowledge, this is the first demonstration of an outcome-selective, appetitive PIT effect that was sensitive to Pavlovian extinction in human subjects. Furthermore, the results compliment and extend Delamater et al.'s (2017) studies with rats, by demonstrating another condition in which outcome-selective PIT effects are sensitive to Pavlovian extinction treatments.

The only difference between Experiments 1 and 2 was the nature of the transfer test. In Experiment 1, instrumental response choice was tested in the presence of a single Pavlovian stimulus that either had or had not undergone Pavlovian extinction. Experiment 2, by contrast, used a more sensitive test procedure in which instrumental response choice was assessed in the presence of compound stimuli that included both extinguished and non-extinguished cues. The results of Experiment 2 suggest that PIT effects are sensitive to Pavlovian extinction when this more sensitive test procedure is used.

There is a question, however, as to *why* response choice was sensitive to Pavlovian extinction in Experiment 2. One possibility is that response choice was driven by the associative strength of the stimuli presented on test. The extinction manipulation would be expected to reduce the associative strength of the extinguished stimuli relative to the non-extinguished stimuli. This difference in associative strength might then have produced the observed response bias, with the non-extinguished stimuli dominating instrumental response choice. This account would be consistent with the S-O-R theory, since the extinguished cues should activate the associated outcomes less than the non-extinguished cues.

Another possibility is that instrumental response choice was indirectly driven by the *salience* of the Pavlovian cues in each compound. Following Mackintosh (1975), extinction might be expected to reduce the salience of the extinguished cues by reducing their predictiveness with respect to the outcomes (see Le Pelley, Mitchell, Beesley, George, & Wills, 2016, for a review), thus reducing the extent to which these cues were able to control responding on test. Hence, the results of Experiment 2 could have been driven by an attentional bias towards the more salient, non-extinguished cues during the transfer test. Experiment 3 tested this possibility.

Experiment 3

The concept for Experiment 3 runs as follows. As in Experiments 1 and 2, participants first learn to perform two instrumental responses to earn different rewarding outcomes (R1 – O1, R2 – O2). In a separate Pavlovian acquisition phase, participants learn that cue A predicts *both* outcomes O1 and O2 (A-O1 and A-O2). Suppose that, in a subsequent Pavlovian extinction phase, we can extinguish the A-O2 relationship while keeping the A-O1 relationship intact. In a final transfer test, we then measure the influence of cue A on instrumental choice of response R1 or R2. If outcome-selective PIT is sensitive to extinction, then we should observe a bias towards R1, because cue A signals O1 more strongly than O2 (since the A-O2 relationship was extinguished) and R1 earns the more strongly predicted O1. Critically, such an effect could not be due to an attentional bias because the same stimulus, cue A, is part of both the non-extinguished and the extinguished relationship (A-O1 and A-O2, respectively).

Of course, extinguishing one A-outcome relationship but not the other is not straightforward. One option would be to present both outcomes O1 and O2 following cue A during acquisition (A-O1 and A-O2 trials), and then follow cue A with only O1 during extinction (A-O1 trials). This would certainly maintain the A-O1 relationship and extinguish the A-O2 relationship. However, any response bias during the transfer test might be due to the additional A-O1 pairings rather than the extinction of A-O2. We opted for a different approach. During training, only one outcome was potentially available on each trial. This was indicated by a closed box with the outcome written on the lid. On each trial, a cue (e.g., cue A) and a box with an outcome (e.g., O1) indicated on the lid was presented. Participants were asked to predict whether the box actually contained the specified outcome. Once that prediction was made, the lid would open and the contents were revealed (O1 could be either present or absent). Hence, each trial was specific to each outcome, which meant that the A-O1 and A-O2 contingencies could be trained separately. Most importantly, the A-O2 contingency could be extinguished without affecting the A-O1 contingency. That is, when cue A appeared with the empty O2 box, it should weaken the A-O2 relationship. The A-O1 relationship, by contrast, should be unaffected because O1 was not available on that trial.

Table 3 shows the full design of Experiment 3. Pavlovian trials shown in bold implement the design described above for both cue A and B. The A-O2 and B-O1 contingencies were extinguished, so we would expect an R1 and R2 bias on transfer trials with A and B, respectively. The rationale for cues C and D and outcome O3 is as follows. Cues A and B were paired with outcome O3 (A-O3 and B-

O3) across both Pavlovian acquisition and extinction to prevent participants from learning, in the extinction phase, that A and B no longer signalled outcomes in general. The C-O1 and C-O2 contingencies, which were also consistent throughout both Pavlovian acquisition and extinction, signalled that outcomes O1 and O2 could still occur during the extinction phase (though they were never available on A or B trials). The remaining trials (C-no O3, D-no O1, D-no O2, and D-no O3) were included so that participants did not simply answer "yes" to every question in the acquisition phase. In the transfer test, instrumental response choice (R1 vs. R2) was tested in the presence of cue A or B[2].

As noted above, sensitivity to the Pavlovian extinction manipulation would be revealed if cues A and B selectively increased the instrumental response with which they shared a non-extinguished outcome. That is, sensitivity to the extinction manipulation would be revealed if A increased choice of the R1 response relative to B. This effect could not be ascribed to an attentional bias. Insensitivity to extinction, by contrast, would be revealed if A and B failed to bias response choice in either direction.

Method

Participants. Twenty-four UNSW Sydney students (20 females, aged between 18 and 21, *M* = 18.67 years, *SEM* = 0.19 years) took part for course credit. The experiment was approved by the UNSW Sydney Human Research Ethics Advisory Panel (Psychology).

Apparatus and materials. Stimuli were presented on a 23-inch monitor. Bags of Kettle Sea Salt Crisps, Cobs Sea Salt Popcorn, and Nobby's Salted Cashews served as props during the initial liking ratings. The three food rewards (crisps, popcorn, and cashews) were randomly allocated to the

[2] Cue C was also presented on filler trials during the transfer test. We did not expect C to bias response choice, because it predicted both O1 and O2 equally during Pavlovian training. As expected, C did not significantly bias responding in either direction (mean percent choice of R1: 50.78%, *SEM*: 7.94%).

three outcomes for each participant. The four colours of the coloured squares used for Pavlovian cues (A-D; see Table 2) were blue, pink, red and yellow; these were randomly assigned to the roles of cues A-D for each participant. Other aspects were as for Experiments 1 and 2.

Procedure. The participants were first shown the three food rewards that were available to win, and provided liking ratings for each. The experimenter then removed the food props and read aloud the instrumental training instructions: "You can now earn [O1] and [O2] points by pressing the left and right arrow keys. You will see two closed boxes on each trial, one for each reward. After you choose a response, the contents of your chosen box will be revealed. Your task is to learn which keys earn each reward." The text in brackets was replaced by the appropriate outcome ("CRISPS", "POPCORN" or "CASHEWS"). There were 24 trials of instrumental training. Each trial began with two grey, closed boxes that were presented on either side of a choice symbol (← or →). The name of outcome O1 (e.g., "CRISPS") was superimposed on the left-hand box; the name of O2 was shown on the right-hand box. After either the left or right arrow key (R1/R2) was selected, the corresponding box "opened" (i.e., it turned white) to reveal the contents. The other box remained closed. The left and right arrow keys served as R1 and R2, respectively. The R1 and R2 responses were selectively paired with outcomes O1 and O2, respectively. Each outcome was available on a randomly distributed half of the trials each. Thus, there was a 50% probability that a given response would produce the corresponding outcome on any given trial. When the participant responded for an available outcome, a picture of that outcome was presented "inside" the corresponding box, and the text, "You earn one [CRISPS/POPCORN/CASHEWS] point" appeared. When the participant responded for an unavailable outcome, the corresponding box appeared to be empty and the text read, "You earn NOTHING". The outcomes were presented for 1500ms.

Pavlovian training followed instrumental training. Figure 3 shows an example training trial. The instructions were similar to the previous experiments; the participants were told that they would see different colours, which would predict points towards crisps, popcorn and cashew nuts.

The participants were told that their task was to learn which colour predicted each reward, and that they would be asked to predict whether the outcome shown would be received on each trial. There were 144 trials of Pavlovian training, which consisted of 96 acquisition trials, followed by 48 extinction trials.

Each Pavlovian trial began with the central presentation of one of the Pavlovian cues (coloured squares). A closed box (which was identical to those used during instrumental training) was superimposed on the stimulus. Below the box appeared the question, “Will [COLOUR] earn [OUTCOME]?” The text in brackets was replaced by the appropriate colour or outcome. The corresponding outcome was also written on top of the box, as in the instrumental training phase. “YES”, “NO” and “DON’T KNOW” options were superimposed on the stimulus, arranged vertically. After a response was made using the mouse, the correct outcome was revealed. An “open” box replaced the closed box. If the outcome was available, a corresponding picture was also presented within the box. Finally, the outcome was confirmed with the text, “[COLOUR] earns one [OUTCOME] point”, or “[COLOUR] earns NO [OUTCOME] points” if the stimulus did not predict the outcome. The text in brackets was replaced by the appropriate colour and outcome, and the outcome was presented in bold. Incorrect predictions (not including “DON’T KNOW” responses) were followed by error noises. Visual feedback was presented for 1500ms.

The Pavlovian acquisition phase consisted of four blocks of 12 trial types (see Table 2). Each trial type was presented twice per block (96 trials total). The Pavlovian extinction phase consisted of four blocks of six trial types. The six trial types were presented twice per block (48 trials total).

To minimise the possibility of participants forgetting the instrumental contingencies, a booster instrumental training session was administered immediately after the Pavlovian training phase (see Allman et al., 2010 and Eder and Dignath, 2016a, 2016b for similar procedures). The booster session was identical to the first instrumental training phase. Critically, no Pavlovian cues were presented during this phase; participants never performed the instrumental responses in the presence of the cues before the transfer test.

The transfer test followed the booster instrumental session. It followed a similar format to the previous experiments; the participants were told that they could continue earning outcomes O1 and O2 by pressing the left and right arrow keys, and that they would be told how many of each reward they had earned at the end of the experiment. Each trial began with either cue A, B or C being presented alone for 1000ms. The choice symbol (← or →) then appeared until a response was selected. The cues were presented twice per block in random order, and there were eight blocks. The participants completed one practice block before the real transfer test.

The participants completed a Pavlovian knowledge test after the transfer test. A Pavlovian cue (A or B) was presented on each trial, along with the question, "Did [COLOUR] earn [O1/O2]?" The text in brackets was replaced by the appropriate colour and outcome. The participants chose either "Yes" or "No", and then rated their confidence (1 = Not at all confident; 7 = Very confident). Knowledge of the A-O1, A-O2, B-O1 and B-O2 relationships was tested in a random order.

We then administered an instrumental knowledge test. Two questions were presented in a random order: "Which key earned [O1/O2], the left or right arrow key?" The outcome was replaced by the appropriate food (crisps, popcorn or cashews) for each question. Confidence ratings were taken after each question (1 = Not at all confident; 7 = Very confident).

Finally, expectancy ratings were recorded for the A-O1, A-O2, B-O1, and B-O2 contingencies. Four questions were presented in a random order: "When the colour [COLOUR] was presented, to what extent did you think that you were more likely to earn [OUTCOME]?" Expectancies were rated between one ("Not at all") and seven ("Very much").

Throughout the experiment, the trials were separated by random intervals of 350-750ms.

Results

Liking ratings for the three outcomes (M = 4.69, SEM = 0.17) did not significantly differ, $F < 1$.

During instrumental training, choice of the R1 (M = 50.52%, SEM = 3.31%) versus R2 response did not significantly differ from 50%, $t < 1$. Furthermore, 87.50% of the sample reported perfect instrumental contingency knowledge. Confidence ratings for O1 (M = 4.83, SEM = 0.45) and O2 (M = 4.75, SEM = 0.46) did not significantly differ, $t < 1$.

Figure 4a shows the percentage of correct predictions made during Pavlovian training. The filler trials involving cues C and D are omitted for clarity. Most importantly, the participants learnt to accurately predict that cues A and B did not predict outcomes O2 and O1, respectively, during the extinction phase. Accuracy on the final block did not significantly differ between trial types, F (2, 46) = 1.26, p = .29, η_G^2 = .03. Furthermore, 87.50% of participants reported perfect knowledge of the non-extinguished contingencies (A-O1 and B-O2) in the Pavlovian knowledge test. With respect to the extinguished contingencies, 62.50% of participants thought that cues A and B did not predict O2 and O1, respectively. A stimulus (A vs. B) × outcome (O1 vs. O2) repeated measures ANOVA on the confidence ratings revealed no significant main effects or interactions (Fs < 2.45, ps > .13).

Figure 4b shows the percent choice of R1 versus R2 on A and B trials during the transfer test. Most importantly, cue A increased choice of response R1 relative to cue B, t (23) = 5.46, p < .001, d_z = 1.11. Furthermore, cue A increased choice of R1 relative to the 50% indifference point, t (23) = 2.33, p = .03, d = 0.48. Conversely, cue B increased choice of R2 relative to 50%, t (23) = 8.64, p < .001, d = 1.76.

Figure 4c shows the mean expectancy ratings for the critical Pavlovian contingencies. The graph suggests that participants gave higher ratings for the non-extinguished (A-O1 and B-O2) contingencies than the extinguished (A-O2, B-O1) contingencies. To confirm, a repeated-measures ANOVA on the stimulus (A and B) and outcome (O1 and O2) factors revealed a stimulus × outcome interaction, F (1, 23) = 13.70, p = .001, η_G^2 = .20. In the presence of cue A, participants expected to earn outcome O1 more than O2, t (23) = 2.33, p = .03, d_z = 0.48. Conversely, higher expectancy ratings were given to O2 than O1 in the presence of cue B, t (23) = 4.30, p < .001, d_z = 0.88.

Discussion

In Experiment 3, two instrumental responses were trained to predict different rewarding outcomes (R1-O1, R2-O2). The critical Pavlovian cues (A and B) also predicted *both* of these outcomes (A-O1, A-O2, B-O1, B-O2). During the Pavlovian extinction phase, one contingency involving each Pavlovian cue was extinguished, such that A and B no longer predicted O2 and O1, respectively. On test, instrumental response choice was sensitive to the extinction manipulation; cue A increased R1 responding relative to cue B. This sensitivity to Pavlovian extinction is consistent with the results of Experiment 2, and it cannot be readily explained by cue salience[3]. Rather, the PIT effect appears to be a direct effect of the associative strength of the Pavlovian cues.

General Discussion

Three experiments examined the effect of Pavlovian extinction on human outcome-selective PIT. Experiment 1 employed a traditional PIT procedure and replicated previous demonstrations that PIT is insensitive to Pavlovian extinction (Hogarth et al., 2014; Rosas et al., 2010). It also highlighted the parallel between human and animal PIT studies; insensitivity to extinction has been seen across different species, with different testing methodologies. We speculated that the typical PIT procedure, in which a single Pavlovian cue is presented per trial, might be insufficiently sensitive to detect effects of Pavlovian extinction. One way to increase the sensitivity of a test to the difference between two cues is to force a choice between those cues. This is exactly the approach Rescorla (1994) adopted to test for effects of outcome devaluation on PIT. In Experiments 2 and 3 here, therefore, we used an analogous forced-choice approach to examine the effect of Pavlovian

[3] We do not wish to imply here that reward-predictive cues do not preferentially capture attention. Indeed, there is very good evidence to suggest that such cues *do* command attention (Le Pelley et al., 2016), and these attentional biases may well play an important role in some extinction effects (e.g., Robbins, 1990). Nevertheless, the PIT effect observed in Experiment 3 appears to be independent of any effects of cue salience, because each cue was part of both an extinguished and a non-extinguished relationship.

extinction on PIT. These two experiments revealed clear evidence of outcome-selective PIT effects that were sensitive to Pavlovian extinction. We therefore suggest that human outcome-selective PIT effects are influenced by Pavlovian extinction, but that the test used in Experiment 1 was not sensitive enough to detect an effect. This conclusion is consistent with both Delamater et al.'s (2017) results and the predictions of S-O-R theory.

Of course, we are not the first to demonstrate that cue-elicited instrumental responding can be weakened by extinction. Notably, Lovibond and colleagues reported PIT effects that were attenuated by Pavlovian extinction treatments in two recent publications (Bezzina et al., 2016; Lovibond et al., 2015). However, these studies both employed "single-lever" designs that measured the extent to which extinguished and non-extinguished cues boosted the rate of a single instrumental response. These procedures were therefore not designed to measure *outcome-selective* PIT, in which a Pavlovian stimulus boosts instrumental responding for the outcome with which it was previously associated, but not responding for other outcomes. The single-lever designs could, in principle, operate through an entirely different mechanism from that responsible for outcome-selective PIT, one that does not rely on the specific outcome with which the stimulus and response are associated. For example, the effect observed by Lovibond and his colleagues might be the consequence of the stimulus activating a general motivational state (e.g., Rescorla & Solomon, 1967). Hence, any effects of S-O extinction on this motivational state would not necessarily have implications for the effects of extinction in outcome-selective PIT. S-O-R theory is specifically a model of outcome-selective PIT (Trapold & Overmier, 1972), because it assumes that Pavlovian cues will activate only associated outcome representations. The current findings, that outcome-selective PIT is sensitive to Pavlovian extinction, therefore provide novel support for S-O-R theory.

We mentioned in the Introduction that S-O-R theory could be reconciled with the previous demonstrations of insensitivity to Pavlovian extinction by assuming that Pavlovian extinction fails to weaken the association between the Pavlovian stimulus S and the sensory properties of the outcome O (Delamater & Westbrook, 2014). In the current Experiments 2 and 3, we observed outcome-selective PIT effects that were sensitive to the Pavlovian extinction procedures. These results are therefore consistent with a simple version of S-O-R theory, in which Pavlovian extinction would be expected to weaken PIT effects by degrading the association between the Pavlovian stimulus S and both the sensory and motivational properties of the outcome O.

To what extent do our results affect the interpretation of other accounts of PIT? Hierarchical S:R-O theory is one such account (Cartoni et al., 2015; Colwill & Rescorla, 1990; Hardy, Mitchell, Seabrooke, & Hogarth, 2017; Hogarth et al., 2014; Hogarth & Troisi, 2015; Rescorla, 1991), and it differs from S-O-R theory in two key ways. First, the hierarchical account of PIT suggests that instrumental responding is the consequence of the response-outcome (R-O) relationship rather than the O-R link postulated by S-O-R theory. Second, the Pavlovian S-O pairings allow the stimulus S to act as a discriminative stimulus or “occasion setter” for the instrumental response (as opposed to the S activating the outcome representation, as in S-O-R theory). This means that the Pavlovian stimuli signal which response will produce an outcome (S:R-O) in PIT transfer tests. Hierarchical theory originates from studies on non-human animals (e.g., Colwill & Rescorla, 1990; Rescorla, 1991) and, as a consequence, is often suggested to be “associative” in nature. The associative mechanism by which S-O pairings allow the stimulus S to serve as an occasion setter (that is, how the S:R-O structure emerges from S-O and R-O training) is not well specified. Whatever the precise mechanism, the Pavlovian stimuli are thought to gain control over the instrumental contingencies that share an outcome (Balleine & O’Doherty, 2010). Occasion setters are known to be unaffected by simple extinction (Holland, 1989). The hierarchical model of PIT therefore suggests that simply extinguishing a Pavlovian S-O relation should not alter the extent to which the stimulus S produces a PIT effect (Hogarth et al., 2014). Hierarchical S:R-O theory would, therefore, require further modification (perhaps in terms of specifying the way in which S-O and R-O training results in the S:R-O structure) to account for the sensitivity to Pavlovian extinction observed in Experiments 2 and 3.

A third theory of PIT is our goal-directed, propositional model (Hogarth et al., 2014; Seabrooke et al., 2016, 2017). Similar to hierarchical theory, participants are assumed to infer that the Pavlovian stimuli signal which outcomes are more available, and therefore which instrumental response is more likely to be reinforced on any given test trial. Thus, human PIT effects are suggested to reflect a controlled decision-making process rather than an automatic priming mechanism. In contrast to hierarchical theory, the propositional approach expects that S-O extinction would weaken PIT effects, because it should weaken the belief that the stimulus signals that the associated outcome is available. The sensitivity to Pavlovian extinction that was seen in Experiments 2 and 3 is therefore consistent with the propositional model of PIT.

The issue remaining for proponents of the propositional account of PIT is to more tightly specify the meaning of "outcome availability". Availability relates to the ease with which an outcome can be earned. A cue that signals increased outcome availability in a transfer test is not a pure Pavlovian cue because the outcome is not simply delivered; an action is also required. Such a cue is not a discriminative stimulus (in the usual sense) either, however, because its relationship is with the outcome rather than a specific response. One way to characterise this approach is as a combination of both the S-O-R and hierarchical accounts of PIT. The first component is similar to the idea in S-O-R theory, that the stimulus activates the associated outcome representation. Hence, participants have an increased expectancy that the cued outcome is close by, or can be earned more easily than a non-cued outcome. Unlike in S-O-R theory, however, the outcome expectancy does not trigger the response directly. Rather, and this is the second component, instrumental responses (actions) are the consequence of participants acting in a goal-directed, intentional manner to obtain the outcome (similar to the R-O relationship postulated in S:R-O theory). Responses will then be based on (some function of) the probability of obtaining the outcome and the value of that outcome. This approach allows us to account for both the sensitivity of outcome-selective PIT to extinction (in the current experiments) and outcome devaluation (in our previous work: Seabrooke et al., 2017). Extinction decreases the perceived probability of the outcome being earned (i.e., its availability) and devaluation decreases the perceived value of the outcome. According to our propositional model of PIT, both manipulations should decrease the likelihood that participants will respond to earn that outcome.

Of the three theories outlined above, our feeling is that the propositional model of PIT fairs best in the face of the data. First, although S-O-R theory predicts the current extinction result, it does not readily account for the effects of outcome devaluation seen by Seabrooke et al. (2017), because the Pavlovian stimuli are assumed to activate only the sensory properties (not the current incentive value) of the associated outcome (e.g., Hogarth & Chase, 2011; Rescorla, 1994; van Steenbergen et al., 2017). Second, hierarchical S:R-O theory provides no obvious mechanism by which S-O extinction might weaken PIT effects (or indeed why S-O pairings should result in S:R-O knowledge in the first place). The propositional model of PIT appears to be consistent with the effects of both extinction and outcome devaluation. It suggests that participants infer that a Pavlovian stimulus signals that the associated outcome is now more available and therefore more likely to be earned. So long as the outcome is valued, then participants should act to obtain that outcome. Both extinction and outcome devaluation should, therefore, weaken PIT effects (as observed) via reductions in perceived availability and value, respectively.

It might be questioned whether the propositional theory of PIT is also relevant to non-human PIT effects. In truth, we have few data that speak to this issue at present. However, if researchers are interested in determining whether human and non-human PIT effects are mediated by a common mechanism, we suggest that the focus should be on Rescorla's (1994) results. Here, Rescorla demonstrated insensitivity to outcome devaluation in rats, whereas we saw sensitivity to devaluation in a similar experiment with human participants (Seabrooke et al., 2017). On the face of it, these studies therefore suggest that human and non-human PIT effects might reflect different mechanisms. It would be worth exploring the parameters of these effects further. For example, more sensitive test procedures might reveal evidence of sensitivity to devaluation in rats. Likewise, certain conditions (e.g., stress; Pritchard, Weidemann, & Hogarth, 2017) might reveal *insensitivity* to outcome devaluation in human PIT tasks.

At least with respect to human PIT effects, the propositional model outlined above opens up the associative effect of PIT to more mainstream cognitive analysis. This seems appropriate, as the choices made in outcome-selective PIT procedures seem very similar to those made in studies of judgement and decision making. Bringing concepts from the judgement and decision making literature to bear on “associative” effects would be a potentially fruitful development for the future. Of course, this cross-talk can work both ways. To the extent that PIT is found to be automatic, it might represent a domain in which associative theorists can contribute to the dual-systems debate in decision-making (Evans, 2008). We would suggest that this depends on future research strengthening the argument for an “associative” or non-propositional component of PIT.

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Tables

Table 1

Design of Experiments 1 and 2

Instrumental training	Pavlovian acquisition		Pavlovian extinction	Transfer test	
	Experiments 1 and 2			**Experiment 1**	**Experiment 2**
R1 – O1	A – O1	D – O2	B – Ø	A: R1 vs R2?	AD: R1 vs R2?
R2 – O2	B – O1	E – O1	D – Ø	B: R1 vs R2?	BC: R1 vs R2?
	C – O2	F – O2	E – O1	C: R1 vs R2?	
			F – O2	D: R1 vs R2?	

Note: R1 and R2 represent instrumental responses (left and right arrow key presses), O1 to O2 represent outcomes (crisps and popcorn points), and A to F represent Pavlovian stimuli (coloured squares). Ø represents that the stimulus predicted 'nothing'.

Table 2

Design of Experiment 3

Instrumental training	Pavlovian acquisition		Pavlovian extinction	Instrumental training	Transfer test
R1 – O1	**A – O1**	C – O1	**A – No O2**	R1 – O1	A: R1 vs R2?
R2 – O2	**A – O2**	C – O2	A – O3	R2 – O2	B: R1 vs R2?
	A – O3	C – No O3	**B – No O1**		
	B – O1	D – No O1	B – O3		
	B – O2	D – No O2	C – O1		
	B – O3	D – No O3	C – O2		

Note: R1 and R2 represent instrumental responses (left and right arrow key presses), O1 to O3 represent outcomes (crisps, popcorn and cashew nuts points), and A to D represent Pavlovian stimuli (coloured squares). The experimental Pavlovian contingencies are presented in bold.

Figures

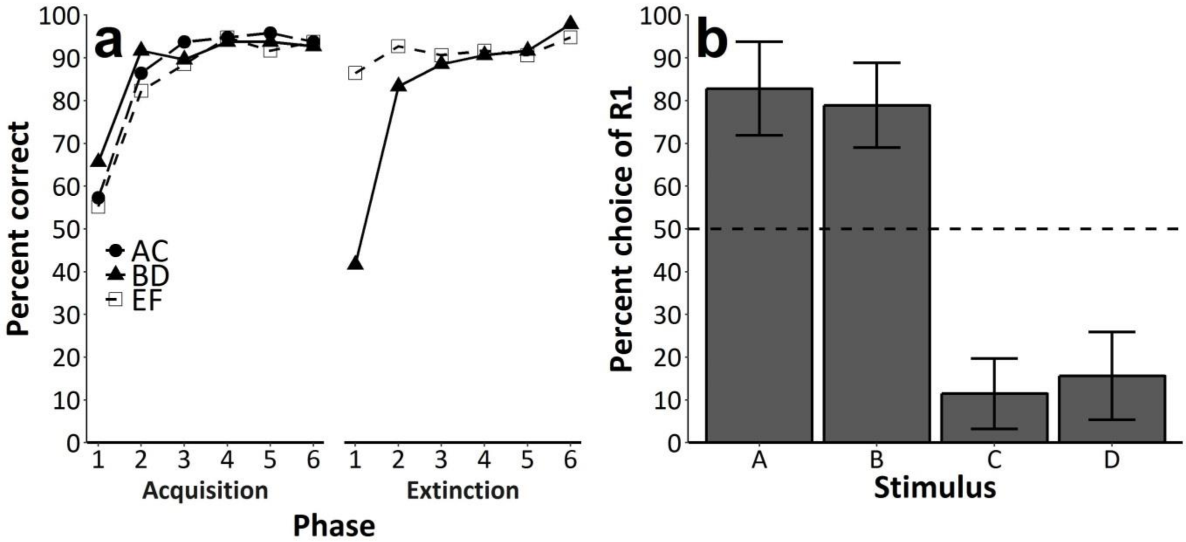

Figure 1. Results of Experiment 1. A and C were non-extinguished stimuli that were paired with O1 and O2, respectively, during Pavlovian acquisition. B and D were stimuli that were paired with O1 and O2, respectively, during Pavlovian acquisition. Stimulus B and D were then extinguished. Stimulus E and F were control stimuli that were paired with O1 and O2, respectively, during both the Pavlovian acquisition and extinction phase. **(a)** Percentage of correct predictions to each of the six stimuli presented during the Pavlovian acquisition and extinction phases. **(b)** The percent choice of the R1 versus R2 response to each of the four stimuli presented during the transfer test. Scores above 50% represent a bias towards R1; scores below 50% reflect a bias towards R2. Error bars are difference-adjusted within-subject 95% confidence intervals (Baguley, 2012).

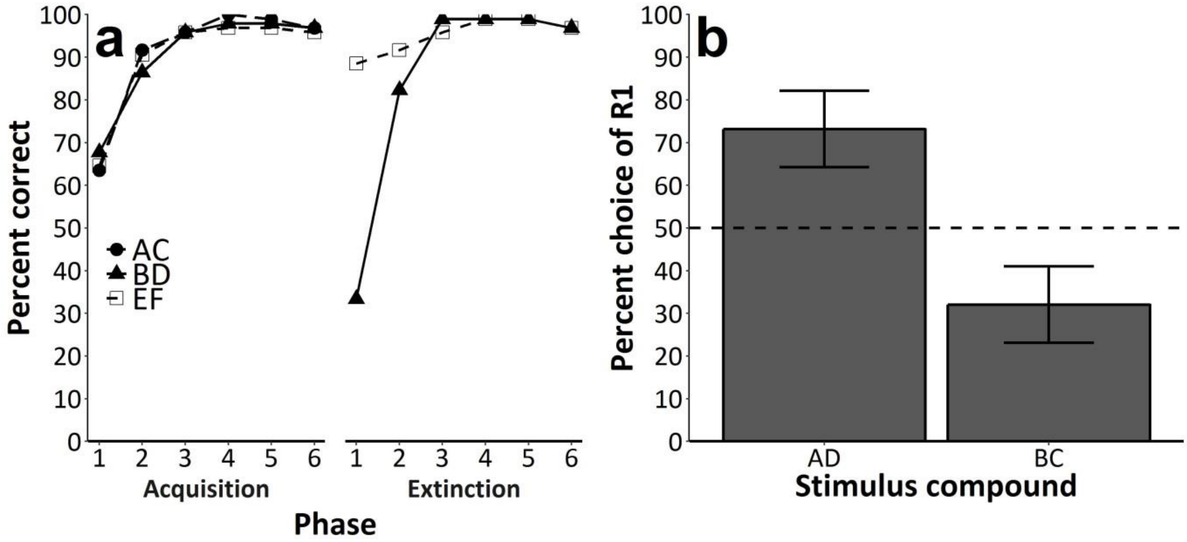

Figure 2. Results of Experiment 2. A and C were non-extinguished stimuli that were paired with O1 and O2, respectively, during Pavlovian acquisition. B and D were stimuli that were paired with O1 and O2, respectively, during Pavlovian acquisition. Stimulus B and D were then extinguished. Stimulus E and F were control stimuli that were paired with O1 and O2, respectively, during both the Pavlovian acquisition and extinction phase. **(a)** Percentage of correct predictions to each of the six stimuli presented during the Pavlovian training phase. **(b)** The percent choice of the R1 versus R2 response to the two stimulus compounds that were presented during the transfer test. Scores above 50% represent a bias towards R1; scores below 50% reflect a bias towards R2. Error bars are difference-adjusted within-subject 95% confidence intervals (Baguley, 2012).

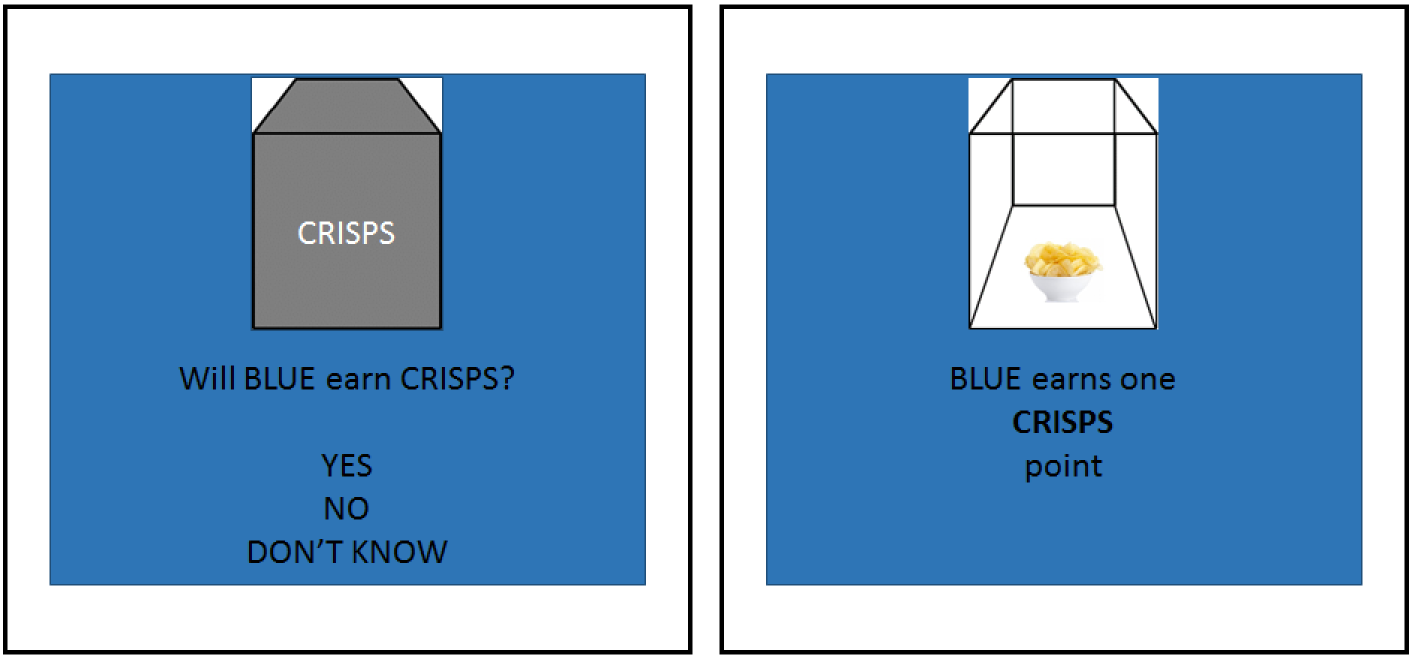

Figure 3. An example Pavlovian training trial. At the start of each trial (left), a grey box with a written outcome was superimposed on a coloured square, along with a question and response options. Predictions were made using the mouse. Once a prediction was made, the outcome was presented (right).

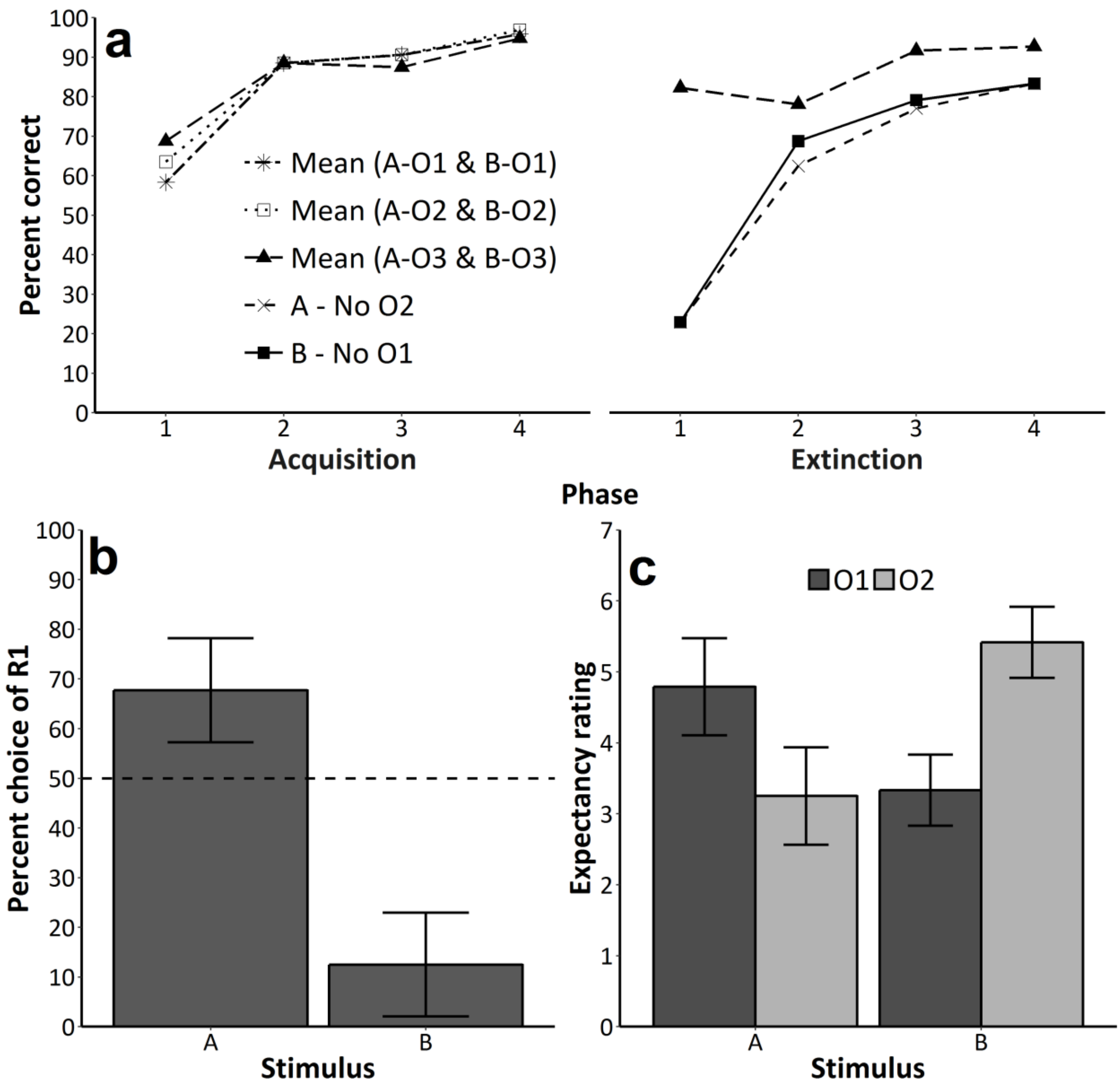

Figure 4. Results of Experiment 3. **(a)** Percentage of correct predictions to the critical cues on each block in the acquisition and extinction phases of Pavlovian training. **(b)** The percent choice of the R1 versus R2 response to cues A and B during the transfer test. Scores above 50% represent a bias towards R1; scores below 50% reflect a bias towards R2. **(c)** Mean expectancies for outcomes O1 and O2 in the presence of cues A and B during the expectancy ratings. Ratings of 1 and 7 represent expecting the outcome “very much” and “not at all”, respectively. Error bars are difference-adjusted within-subject 95% confidence intervals (Baguley, 2012).