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Research report

Mechanisms of attention for appetitive and aversive outcomes in Pavlovian conditioning

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ABSTRACT

Different mechanisms of attention controlling learning have been proposed in appetitive and aversive conditioning. The aim of the present study was to compare attention and learning in a Pavlovian conditioning paradigm using visual stimuli of varying predictive value of either monetary reward (appetitive conditioning; 10p or 50p) or blast of white noise (aversive conditioning; 97 dB or 102 dB). Outcome values were matched across the two conditions with regard to their emotional significance. Sixty-four participants were allocated to one of the four conditions matched for age and gender. All participants underwent a discriminative learning task using pairs of visual stimuli that signalled a 100%, 50%, or 0% probability of receiving an outcome. Learning was measured using a 9-point Likert scale of expectancy of the outcome, while attention using an eyetracker device. Arousal and emotional conditioning were also evaluated. Dwell time was greatest for the full predictor in the noise groups, while in the money groups attention was greatest for the partial predictor over the other two predictors. The progression of learning was the same for both groups. These findings suggest that in aversive conditioning attention is driven by the predictive salience of the stimulus while in appetitive conditioning attention is error-driven, when emotional value of the outcome is comparable.

1. Introduction

Attentional models of conditioning state that learning parameters such as prediction error (the difference between the occurrence and the prediction of an event) and stimulus salience (the acquired motivational properties of a stimulus) drive learning via increased attention to the conditioned stimulus [23,29]. There is to date substantial evidence that overt attention to stimuli predictive of certain outcomes is crucial in order for learning to occur [6,7].

Although both prediction error [29] and stimulus salience [23] theories of conditioning postulate a role for attention in learning, they make differing predictions concerning the parameters that are controlling it. Prediction error theories claim that attention is allocated to a stimulus on a given trial if during a previous episode it was paired with an unpredicted event, and less attention is allocated if it was paired with a predicted event [29]. Theories of stimulus salience, on the other hand, state that a stimulus that predicts an important event acquires salience as learning progresses and captures attention; this in turn leads to further increases in stimulus salience [1,23,33]. Subsequently the two theories make differing predictions about the progression and control of attention during learning. There is evidence in support of both theories. Studies which have employed EEG and eye tracking procedures to measure attentional processes have provided evidence that prediction error is related to increased attention [37,38]. However, it was also acknowledged in some of these studies that attention could be due to the salience of a stimulus acquired by its predictability of an outcome [38].

In addition, the study of transfer effects along intradimensional shifts provides strong support for the stimulus salience model of attention. In this paradigm participants originally learn to discriminate stimuli according to certain features that belong to a particular stimulus dimension (e.g. colour). Participants in an intradimensional group are then transferred to a new discrimination in which new features belonging to this same dimension provide the basis for discrimination. For participants in an extradimensional group, the relevant features for the transfer discrimination were irrelevant during the prior original training discrimination. Learning of the transfer discrimination typically proceeds more rapidly in the intradimensional group than in the extradimensional group [2]. The Mackintosh (1975) theory argues that the facilitation of performance in the intradimensional group is due to the prior training to attend to the intradimensional qualities of the stimuli. Studies where the transfer effect has been demonstrated using an emotionally relevant outcome have led to disagreements over the mechanisms of attentional control [21]. According to one interpretation of the Mackintosh model attention is determined by the correlation of the stimulus with the significant outcome,

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while another interpretation states that attention is determined by whether or not the stimulus is relevant to the solution of the discrimination [19]. Indeed, some studies have attempted to discern which of these two theories is correct [9]. Regardless of the interpretation, prediction error theories of attention fail to account for these transfer effects.

Incentive salience models of attention [1,33] on the other hand state that stimuli associated with reward will become emotionally significant and will attract attention. Thus, incentive models of attention are consistent with the Mackintosh model, as both state that attention for a conditioned stimulus should be related to its correlation with the affective outcome. In contrast, incentive salience models are inconsistent with prediction error theories, which state that if an affective outcome was fully predicted, the conditioned stimulus would not be attended to.

One possible way of uniting these theories may be through locating some variable, which could account for the different findings. One such variable could be the valence of the stimulus. Indeed the valence of a stimulus differentially controls the maintenance of attention, with aversive stimuli commanding less maintenance of attention than appetitive stimuli e.g. [30].

Furthermore according to Gray's theory [11], behavioural systems are separated according to positive or negative valence. One system regulates aversive motivation (behavioural inhibition system – BIS) and the other appetitive motivation (behavioural activation system – BAS). The BIS responds to stimuli which signal punishment, non-reward, and novelty, while the BAS is sensitive to signals of reward, non-punishment, and escape from punishment. As these differences are postulated to exist at all levels of processing it follows that there may be differing attentional mechanisms involved in learning about rewarding and aversive outcomes. Indeed, there is evidence from animal studies of differences in prediction error systems and in anatomical areas involved in attention when BIS or BAS are activated [36]. Furthermore, there is evidence that these systems are mediated by different neural substrates. For example, novelty seeking (a component of BAS) was found to be negatively associated with dopamine (DA) function, while harm avoidance (a component of BIS) was positively correlated with serotonin (5HT) in a non-opiate dependent control group [10].

According to findings from investigations using primates, areas of the brain implicated in production of a prediction error signal are well defined and include the ventral tegmental area, substantia nigra, anterior cingulate cortex, dorsolateral prefrontal cortex, orbitofrontal cortex, and striatum [34]. Dopamine neurons within these structures have been implicated as the neural substrate of prediction error signals. For instance responses recorded from a single dopamine neuron in a monkey decrease as a rewarding event becomes predicted, and increase again when the reward is unexpectedly omitted [15]. However, while dopamine neurons in the aforementioned structures play a role in appetitive learning, they seem to be insignificant in aversive learning: In primates, rewards such as sweet juice activate dopamine neurons according to associative learning prediction error rules whereas aversive outcomes such as air puffs fail to elicit responses in these same neurons [26]. Based on such findings it is reasonable to suggest that the prediction error model, which postulates that learning is supported by error-driven attentional mechanisms, may be applicable for appetitive outcomes and not for aversive outcomes, which may govern attention to stimuli that predict the outcome via their acquired salience. Animal behavioural data, on the other hand, are not consistent, with studies supporting error-driven theories of learning as shown in both, appetitive [18] and aversive conditioning [9]. However, it must be noted that behavioural data from animal studies are based on indirect measures of attention (rate of learning). The use of eye gaze, a more direct measure of attention in the present experiment, may therefore shed light on the contradictory predictions derived from the electrophysiology data [15,34] on the one hand, and the behavioural data [9,18] on the other hand.

In humans, studies on attentional mechanisms have also proven controversial. One study has found attention to be greater for a partial predictor over a full predictor for an aversive outcome [12], suggesting that allocation of attention to the conditioned stimulus is driven by the requirements of learning. In this study the duration of stimulus presentation was contingent to the length of time taken for the participant to make a response, allowing more time for the least predictive stimulus (partial predictor) to be attended to. Also, in an appetitive conditioning paradigm (using a rewarding cigarette outcome in smokers) attention diminished over time for a full predictor CS+ when the length of time a stimulus was viewed for was controlled by the participant, while when the stimulus length was for a fixed length of time, attention was maintained by the full significant predictor (CS+) [13]. It is possible that being able to control the stimulus duration led to an added motivation to complete the trials as quickly as possible in order to obtain the reward. In the present study the length of stimulus presentation was fixed to eliminate such a confound.

In addition to these methodological issues, the effect of negative and positive valence on the maintenance of attention also needs to be addressed. The maintenance of attention has been found to differ according to valence with aversive stimuli commanding less attention [39], and appetitive stimuli more [5], than neutrally valenced stimuli. Furthermore, the biological value of the stimulus may play a role in determining attention such that only sufficiently aversive stimuli may induce attentional avoidance, and sufficiently appetitive stimuli may induce maintenance of attention (for a detailed analysis on these issues see [14]). Consequently, the effects of valence may mask the effects of prediction error on this aspect of attention. A direct comparison of attention allocation on stimuli predicting an appetitive and an aversive event of comparable biological value should clarify some of the discrepancies between the predictions of models of learning [29] and the behavioural data discussed above.

To our knowledge there is no study in the literature which has compared attention to aversive and appetitive conditioned stimuli using similar conditions of learning and comparable values of outcomes. Thus, the present study set out to examine under comparable conditions differences in attention to conditioned stimuli during aversive (the outcome was a blast of noise) and during appetitive conditioning (the outcome was money). It was predicted that attention to the stimulus will increase as its salience increases in aversive learning [23], while in appetitive learning attention will be more driven by the prediction error effect [29]. The predictions were derived from the electrophysiological studies [26,34] as these studies used comparable procedures between appetitive and aversive outcomes to study the prediction error effect. In addition electrophysiological recordings represent a more direct measurement of prediction error effects than rate of learning, which is used in behavioural studies. Two levels of money (10p, 50p) and two levels of an aversive blast of noise (97 dB, 102 dB) were used as outcomes to evaluate further the effect of emotional intensity that stimuli evoke on attention.

The paradigm itself compared the two theories of attention by using stimuli of varying predictive value of the outcome – 100% (A), 50% (B), and 0% (C). Stimuli were presented in a pair with the same stimulus X, which provided a control stimulus to measure attentional bias towards the informative stimuli (A, B and C) over the common uninformative control stimulus X. Attention was measured using an eye tracker device while learning was assessed through expectancy ratings for the outcome, and emotional reactions (ratings of pleasantness and anxiety). Expectancy ratings and emotional ratings also provided a measure of predictive and emotional salience respectively.

Attentional biases for stimuli with negative or positive valence are shown to be affected by the arousal state that these stimuli induce [3,20,35]. To evaluate the impact of the conditioned stimuli on emotional arousal skin conductance responses to the stimuli at the end of conditioning were taken.

The choice of the two levels of outcome in the money and noise condition was based on the data from a pilot study (Austin and Duka, unpublished), in which it was established that the two levels were equivalent in motivational value across conditions. Participants were asked to respond by pressing the space bar in a variable interval (VI) schedule to obtain a money reward (5p, 10 p or 50p) or to avoid an aversive noise (92 dB, 97 dB, 102 dB) in a within subjects, randomised sequence, block design. The rate of responses in the variable interval was the measurement of the motivational value. A main effect of level only ($F(2, 22) = 7.10$, $p < 0.05$) was found indicating that motivation was higher for the two higher intensity outcomes, regardless of valence. Number of responses made (mean (SD) were comparable for the 102 dB and 50p [26.21(10.90) and 24.83 (7.09) respectively] and for the 97 dB and 10p condition [22.73 (5.91) and 24.65 (5.53) respectively]. In the current study a VI schedule of reinforcement was also employed to examine how motivation to respond to avoid the noise or obtain the money would relate to conditioned measures.

To evaluate individual differences among participants in reward and aversive motivation [4], subjective ratings from the Behavioural Inhibition Scale (BIS) and Behavioural Activation Scale (BAS) were taken. BIS and BAS measures one category for behavioural inhibition, and three subsets of behavioural activation: reward responsiveness, reward drive, and fun-seeking. As there was no particular prediction regarding which subset of the reward scale would be most relevant to the current investigation, reward subsets were combined to create a summed value [24].

Anxiety and depression have also been shown to influence attention [22,31], so these were also measured prior to the conditioning procedure to ensure there were no differences between groups in this regard.

Thus, the present study set out to compare attention to conditioned stimuli with different probabilities for a positive outcome with those for a negative outcome. Our hypotheses were that attention to threatening stimuli, would be guided by the emotional response and would be in the order of magnitude A > B > C where A is the full predictor of the aversive event, while in the money condition attention would be guided by the requirement of learning and would be greater for the partial predictor in the order of magnitude B > A = C; the pattern of learning should not differ between these two groups.

2. Materials and methods

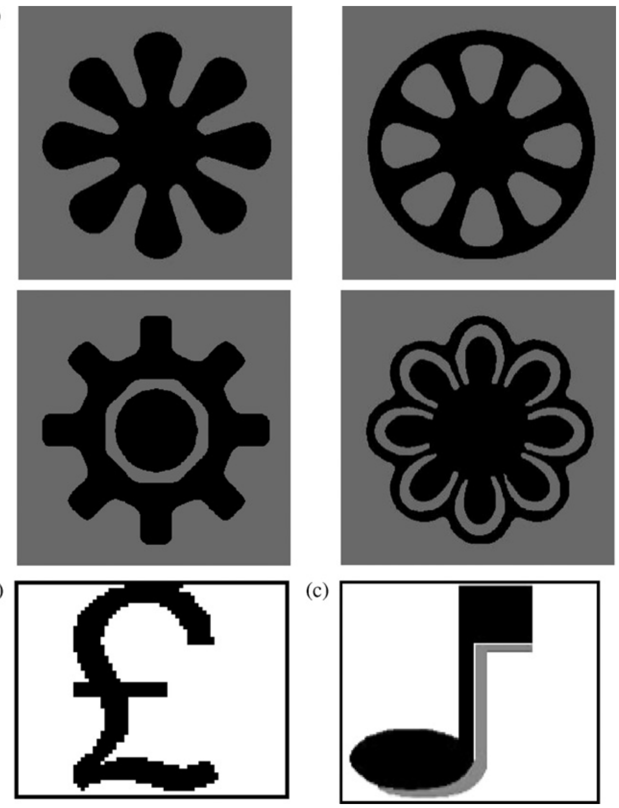
2.1. Participants and exclusion criteria

Sixty-four healthy participants (32 males and 32 females) were recruited from the student population at the University of Sussex. All Participants had 20:20 or 20:30 vision and gave informed written consent. None of them had hearing difficulties, or were currently taking anti-depressant or anxiolytic medication. Participants were randomly assigned to 1 of 4 conditions: high money, low money, high noise, or low noise. The University of Sussex ethics committee approved the study. Participants were paid for their participation in the study.

2.2. Apparatus

The four stimuli shown in Fig. 1a were displayed on a 17-in. Viglen Trinitron colour monitor at a size of 10.2 cm squared (the palette index was 92 for the grey and zero for the black in Paint Shop Pro version 4.12 shareware). Stimulus presentations and response collection was controlled by a Pentium PC running E-prime software. All other screen stimuli were black on a grey background (selected from the colour options in E-prime software from Psychology Software Tools Inc., http://pstnet.com). An Eyelink II eye tracker was used to measure visual attention (SR Research Ltd. 5516 Main St., Osgoode, Ontario, Canada K0A 2W0. <http://www.eyelinkinfo.com>).

(a)



(b) (c)

Fig. 1. Stimuli used (not to scale). The four stimuli used in discriminative training were counterbalanced between participants in the role of A, B, C, and X (a). Stimuli developed from clipart images used as the instrumental cue in the VI schedule in the money (b) and noise (c) conditions.

Participants were seated at a table 100 cm away from a desktop computer screen to create 5° of visual angle between the centre of the screen and the centre of either stimulus. Also on the table was a keyboard which participants used to answer questions about the stimuli. In the noise conditions the outcome was either a 97 dB (low aversive condition) or 102 dB (high aversive condition) white noise lasting 40 ms presented binaurally through headphones (Sennheiser, PX200). In the money conditions there were two tins on either side of the keyboard – the one on the right contained either eighty-six 10p coins (low appetitive condition) or eighty-six 50p coins (high appetitive condition). During the trials if participants were informed they had received money they would take the money out of the box on the right and move it into the box on the left.

Galvanic skin response was measured using Skin Conductivity Measurement software version 1.0 for Windows 98 (written by Peter Reed, School of Biological Sciences, University of Sussex). Skin prep fluid (TD-260) and electrode paste (TD-246) were employed (http://med-associates.com/index.htm).

2.3. Questionnaires

A medical history questionnaire ensured that participants were in general good health and adhered to the exclusion criteria. The POMS [25] was used to measure participants' current anxiety, depression and arousal level, and a BIS and BAS questionnaire [4] assessed the strength of participants' level of activation of systems regarding reward and punishment.

2.4. Procedure

The study lasted approximately one hour for each participant. After the participants filled in the questionnaires described in the materials section, and gave their written informed consent they were given the Snellen 3-m visual acuity test. All participants were then seated at the table described in the apparatus section and the eye tracker device and headphones were attached to their head. Eye movement was then calibrated by the experimenter using the Eyelink II program. Participants underwent 144 trials of discriminative training for the different stimulus contingencies. After this set of trials, electrodes were attached to the index and ring finger and two more of each of the three trial types (AX, BX, CX) from the discriminative training were presented in random order (on one BX trial they received the outcome, on the other they did not). The electrodes were removed and participants completed 10 trials of a variable interval (VI) schedule of instrumental response to either obtain the reward in the money conditions or to cancel the aversive outcome in the noise conditions. Participants were then debriefed as to the purpose of the experiment and received appropriate monetary payment. The experimenter was present for all stages of the procedure.

2.4.1. Discrimination training

Pairs of visual stimuli were presented on the screen. The four visual stimuli shown in Fig. 1a predicted differing probabilities of the outcome occurring and were counterbalanced in the roles of A, B, C, and X. When stimulus A was on the screen it predicted that the outcome would occur 100% of the time, when stimulus B was on the screen it predicted that the outcome would occur 50% of the time, and when the C stimulus appeared on the screen it predicted that the outcome would occur 0% of the time. X stimulus was a control stimulus and appeared as part of a stimulus pair in conjunction with A, B, or C. Order of presentation on which side of the screen the stimulus appeared in the pair was also counterbalanced giving a total of 6 stimulus pairs. These six pairs were presented six times per block giving a total of 36 trials per block. There were four blocks of training in total. Order of presentation in each block was randomised within a block of 12 that was repeated three times in order to minimise the number of consecutive presentations of the same stimulus pairs.

The following instructions were given for the money conditions: "On the following trials you will be presented with picture pairs that will sometimes be followed by you receiving 10p (OR 50p). After the picture pairs appear you will be asked to rate how likely it is you will receive 10p (OR 50p) on a scale of 1 to 9. 1 = not at all likely, 9 = very likely. You can use any of the keys 1 to 9 to answer. After you have made your rating you will sometimes receive 10p (OR 50p). When this happens put 10p (OR 50p) into your box. At the end of the experiment you get to keep the money you have in your box. Press the spacebar when you are ready to begin." For the noise conditions the instructions were the same except that the 10p/50p text was replaced with the words "a noise", and no reference was made to transferring money.

Each trial then proceeded in the following way: a fixation cross appeared in the centre of the screen and once the pupil was fixated on the centre of the cross the experimenter pressed the space bar on a separate computer and the cross disappeared to be replaced by a stimulus pair. This pair remained on the screen for 3 s then disappeared. Participants were then asked to rate how likely they thought the outcome would occur using a 9-point Likert scale. Once they had responded there was a blank screen for 1.5 s, followed by the appropriate outcome for that trial. For the noise conditions there was either a 40 ms noise or 40 ms silence. For the money conditions this was either presentation of the words "You have received 10p (OR 50p)" on the screen for 2 s or no text for 2 s. For the noise condition the outcome was followed by 3.6 s of blank screen, while for the money conditions there was 2 s of blank screen.

After every 36 trials each individual stimulus was presented in the centre of the screen with a question asking either how anxious or how pleasant they found the stimulus. Responses were made using a 9-point Likert scale. The order of presentation of these questions with each stimulus was randomized.

2.4.2. Galvanic skin response (GSR)

At the end of discrimination training GSR measurements were introduced in a series of six trials. GSR baseline readings were taken while participants watched a blank screen for 2 min. The trials then proceeded as in the discriminative training sessions but there was an additional minute of blank screen in-between trials. The only differences during the trials in this part of the procedure were that when making a response during the expectancy question there was a fixed 5 s in which to respond, and the fixation cross that appeared was up for a fixed 2-s period. There were two presentations of each trial type; one with the predictive stimulus on the left, the other with it presented on the right. For the B trial type, one presentation was followed by the outcome while the other was not. The side of the screen the B was on when it was followed by the outcome was counterbalanced between participants within each condition. Order of presentation of these trials was also randomized.

2.4.3. Variable-interval schedule

At the end of the conditioning a variable interval (VI) schedule of response was introduced to measure participants' motivation to obtain the positive or to avoid the negative outcome depending on which condition participants were allocated to. Participants were presented with a new stimulus that predicted the outcome (see Fig. 1b and c). There was one presentation trial where the new stimulus was paired with the outcome. They were then instructed that when the picture subsequently appeared on the screen they would have to press the spacebar many times in order to avoid/receive the outcome. For each VI trial the stimulus appeared for a total of 5 s. There was a 1 s time window, which could occur at any time point within the 5 s period, and at least one spacebar press had to fall within this time window in order to receive the reward or avoid the noise. At the end of the 5 s stimulus presentation, if they pressed during the time window they received the money or received written feedback that they had avoided the noise. Failure to press the spacebar during the time window resulted in written feedback that they had not received the money, or a blast of noise. There were 10 trials in total. The instrumental response measurement was added at the end to demonstrate that there was a higher motivation to obtain the 50p than the 10p outcome, and a higher motivation to cancel the 102 dB than the 97 dB noise.

2.5. Measurement and analysis

To make sure that the groups were balanced in terms of age, BIS, BAS, anxiety and depression a one-way ANOVA was performed on all of these variables.

The total looking time (dwell time) for each stimulus on every trial was recorded and log transformed. Dwell time bias was calculated by subtracting the dwell time for the context stimulus X from the dwell time for the predictive stimulus (A, B, or C).

Expectancy ratings and dwell time bias were analysed using a mixed ANOVA with level of reward/punishment (high vs. low) and valence (appetitive vs. aversive) as the between subjects factors and stimulus (A vs. B vs. C) as the within subject factor.

Anxiety and pleasantness ratings were analysed separately for noise and money conditions such that there were two mixed ANOVAs with level (high vs. low) as the between-subjects factor, and stimulus (A vs. B vs. C) as the within-subjects factor. Anxiety was the dependent variable in the noise conditions, while pleasantness was the dependent variable in the money conditions.

In addition, learning and dwell time, as well as anxiety and pleasantness discrimination scores were calculated by subtracting the response for C from the response for A. These scores were used in subsequent correlations in the money and noise conditions. Pleasantness scores were used in the money conditions, and anxiety scores were used for the noise conditions.

For the GSR measurements, baseline amplitude (measured in the 1 s period before the trial began) was subtracted from the highest amplitude of the response from stimulus onset for that trial. Measurements were given in μsiemens. GSR measurements were analysed using a level (high vs. low) × valence (appetitive vs. aversive) × stimulus (A vs. B vs. C) mixed ANOVA. Motivation (number of spacebar presses) was analysed using a 2-way ANOVA with level (high vs. low) × valence (appetitive vs. aversive) as factors.

Assumptions of all statistical procedures applied were checked. In the case of violation of the assumption of homogeneity of variances, the Greenhouse–Geisser adjustment was applied and adjusted degrees of freedom are reported. All results were significant at $p < 0.05$ unless otherwise stated. All analyses were performed using the Statistical Package of Social Sciences (SPSS 11.5).

3. Results

3.1. Participant characteristics

There were no differences between groups in terms of BIS and BAS, anxiety, depression, or age (see Table 1).

3.2. Expectancy ratings

There was a main effect of stimulus ($F(1, 78) = 150.60$, $p < 0.05$) in the expected direction of A > B > C.

Importantly there was also a stimulus × valence interaction ($F(1, 78) = 5.12$, $p < 0.05$) due to a better discrimination in the noise condition compared to the money condition; post-hoc independent *t*-tests showed that expectancy ratings were higher for stimulus A ($t(56) = 2.25$, $p < 0.05$)) and lower for stimulus C ($t(49) = 2.04$, $p < 0.05$)) in the noise compared to the money condition (Fig. 2a). No difference was found in the expectancy ratings for B stimulus between noise and money ($t(62) = 0.63$, $p = 0.53$)). There was also a

Table 1
Mean (SEM) age as well as BIS and BAS, anxiety and depression ratings of participants in each condition.

Conditions	Age	BIS	BAS	Anxiety	Depression
Noise low (97 dB)	20.38 (0.78)	3.05 (0.13)	2.95 (0.10)	0.51 (0.23)	0.47 (0.17)
Noise high (102 dB)	22.94 (1.66)	2.94 (0.09)	2.93 (0.11)	0.38 (0.17)	0.42 (0.11)
Money low (10p)	23.13 (2.40)	3.22 (0.12)	3.04 (0.10)	0.65 (0.26)	0.64 (0.17)
Money high (50p)	22.37 (0.97)	2.90 (0.14)	3.03 (0.08)	0.18 (0.11)	0.36 (0.11)

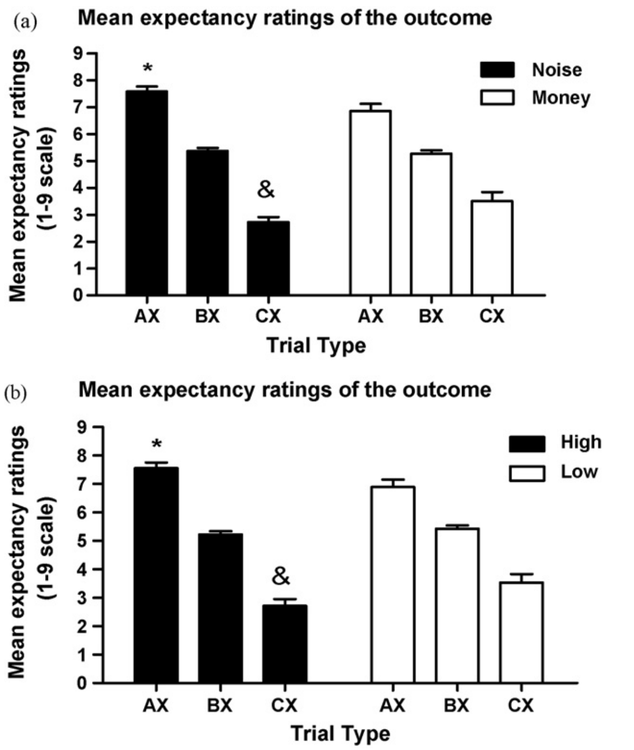


Fig. 2. Expectancy ratings (mean + SEM), of the outcome at trials AX, BX and CX for the money and noise conditions irrespective of level (a) and for the high and low level condition irrespective of valence (b). $^{*}p < 0.05$ compared to trials AX and $^{\&}p < 0.05$ compared to trials CX, in money condition (a) and in low condition (b), respectively.

Table 2
Mean (SEM) outcome expectancy ratings for trials AX, BX and CX in each condition.

Condition	AX	BX	CX
Noise low (97 dB)	7.13 (0.31)	5.48 (0.15)	3.06 (0.30)
Noise high (102 dB)	8.03 (0.14)	5.25 (0.19)	2.39 (0.20)
Money low (10p)	6.65 (0.41)	5.35 (0.15)	3.99 (0.49)
Money high (50p)	7.06 (0.34)	5.18 (0.15)	3.02 (0.43)

stimulus × level interaction ($F(1, 78) = 4.95$, $p < 0.05$) due to a better overall discrimination with higher ratings for A ($t(58) = 2.02$, $p < 0.05$)) and lower ratings for C ($t(62) = 2.15$, $p < 0.05$)) in the high reinforcer compared to the low reinforcer groups (Fig. 2b). Outcome expectancy ratings during AX, BX and CX trials for each condition separately are given in Table 2.

3.3. Attentional measures

There was a main effect of stimulus ($F(2, 120) = 13.37$, $p < 0.001$) with attentional bias being greater for stimulus A and B compared to stimulus C. There was a main effect of valence ($F(1, 60) = 5.87$, $p < 0.05$) where the mean dwell time bias was greater in the noise conditions than in the money conditions.

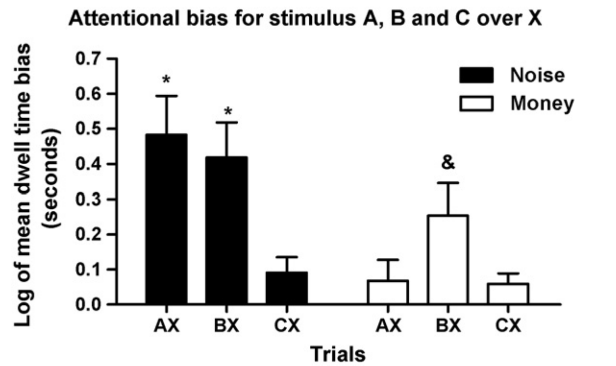


Fig. 3. Dwell time bias (mean log + SEM) for stimulus A, B and C over X in the money and noise conditions irrespective of level. $^{*}p < 0.05$ compared to trials CX; $^{\&}p < 0.05$ compared to trials AX and CX.

Table 3
Mean (SEM) dwell time bias (log seconds) for the predictive stimuli A, B, and C over the concurrent contextual stimulus X in each condition.

Condition	A-X	B-X	C-X
Noise low (97 dB)	0.27 (0.11)	0.36 (0.08)	0.06 (0.08)
Noise high (102 dB)	0.67 (0.21)	0.47 (0.14)	0.21 (0.08)
Money low (10p)	0.18 (0.06)	0.32 (0.10)	0.14 (0.04)
Money high (50p)	−0.05 (0.03)	−0.02 (0.05)	−0.07 (0.05)

There was a stimulus × valence interaction ($F(2, 120) = 3.73$, $p < 0.05$) due to a linear stimulus effect ($F(1, 30) = 11.88$, $p < 0.05$) in the noise conditions and a quadratic stimulus effect ($F(1, 30) = 6.87$, $p < 0.05$) in the money condition (Fig. 3). Planned within subjects contrasts in the noise condition showed that attentional bias to A and B were greater than to stimulus C ($Fs(1, 30) > 11.51$, $p < 0.05$). In the money condition this was true for stimulus B (B > C; $F(1, 30) = 5.27$, $p < 0.05$) but not for stimulus A (A = C; $F(1, 30) = 0.10$, $p = 0.76$)); in addition, bias for stimulus B was greater than for stimulus A in the money condition ($F(1, 30) = 6.85$, $p < 0.05$). Attentional bias for stimulus A, B and C for each condition separately are given in Table 3. Data on mean dwell time for each stimulus (before log linear transformation and before bias were calculated) are given in Table 4.

3.4. Anxiety (noise conditions only)

There was a main effect of stimulus ($F(2, 60) = 16.33$, $p < 0.05$) showing that anxiety was highest for A and B over C (Fig. 4). Planned within subjects contrasts showed a significant difference between B and C ($F(1, 30) = 21.87$, $p < 0.05$) and A and C ($F(1, 30) = 25.63$, $p < 0.05$), but not A and B ($F(1, 30) = 0.75$, $p = 0.40$).

3.5. Pleasantness ratings (money only)

There was a main effect of stimulus ($F(2, 48) = 19.96$, $p < 0.05$) where repeated contrasts showed significant differences between A and B ($F(1, 30) = 29.61$, $p < 0.05$) and between B and C ($F(1, 30) = 4.20$, $p < 0.05$; Fig. 5). A stimulus × level interaction ($F(2, 48) = 3.39$, $p < 0.05$) indicated a greater pleasantness discrimination

Table 4
Mean (SEM) dwell time values prior to log linear transformation for the predictive stimuli A, B, and C compared to the dwell time value of the concurrent contextual stimulus X with A (X(A)) with B (X(B)) and with C (X(C)) in each condition.

Condition	A	X(A)	B	X(B)	C	X(C)
Noise low (97 dB)	1033.77 (73.00)	844.69 (50.22)	1115.49 (78.18)	791.70 (40.12)	963.74 (55.10)	922.89 (42.82)
Noise high (102 dB)	953.59 (66.87)	701.62 (69.58)	1039.58 (73.27)	812.55 (66.42)	994.05 (81.05)	808.35 (68.18)
Money low (10p)	1067.87 (67.35	873.41 (53.44)	1090.59 (75.01)	815.71 (58.79)	1043.44 (60.47)	863.31 (42.34)
Money high (50p)	1004.08 (51.55)	1058.68 (50.96)	992.87 (50.91)	1007.908 (51.29)	994.11 (58.72)	1024.66 (54.94)

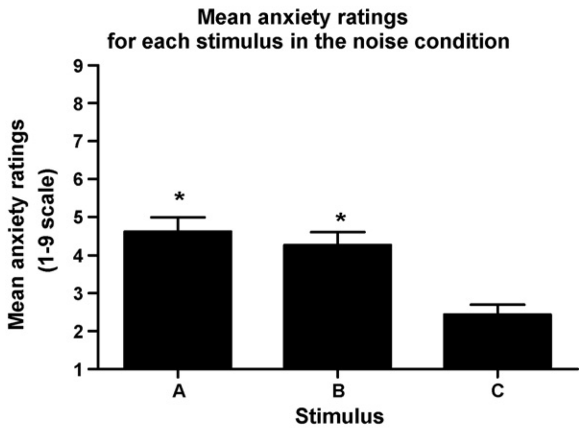


Fig. 4. Anxiety ratings (mean + SEM) for each stimulus in the noise condition irrespective of level. *$p < 0.05$ compared to stimulus C.

between A and B in the 50p condition ($F(1, 30) = 5.39$, $p < 0.05$; data not shown). Post-hoc t-tests confirmed that the larger discrimination in the 50p condition was due to a greater pleasantness rating for A ($t(30) = 2.15$, $p < 0.05$), while pleasantness for B did not differ between groups ($t(30) = 1.24$, $p = 0.23$).

3.6. Correlations

3.6.1. Noise conditions

There was no significant correlation between expectancy discrimination and dwell time discrimination ($r = 0.29$, $p = 0.12$) or between anxiety and dwell time discrimination ($r = -0.04$, $p = 0.82$).

3.6.2. Money conditions

There was no significant correlation between expectancy and dwell time discrimination ($r = 0.28$, $p = 0.13$) pleasantness and dwell time discrimination ($r = 0.24$, $p = 0.18$).

3.7. Measurement of arousal and motivation

For GSR there was a main effect of stimulus ($F(2, 114) = 7.87$, $p < 0.05$) where GSR for A stimulus was greater compared to C ($F(1, 57) = 13.4$, $p < 0.05$) but also compared to B ($F(1, 57) = 5.14$, $p < 0.05$) irrespective of valence or level (see Fig. 6).

For the number of presses during the VI schedule there was a main effect of level ($F(1, 60) = 6.70$, $p < 0.05$) indicating that groups receiving the higher outcome responded with higher motivation compared to groups with the lower outcomes irrespective of valence (Fig. 7).

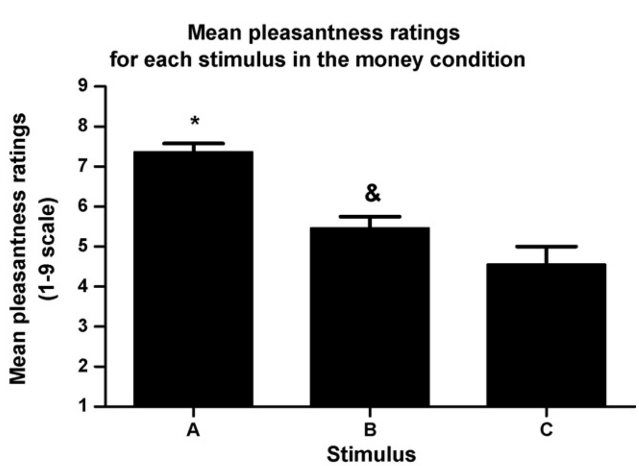


Fig. 5. Pleasantness ratings (mean + SEM) for each stimulus in the money condition irrespective of level. *$p < 0.05$ compared to stimulus B and C. [&]$p < 0.05$ compared to stimulus C.

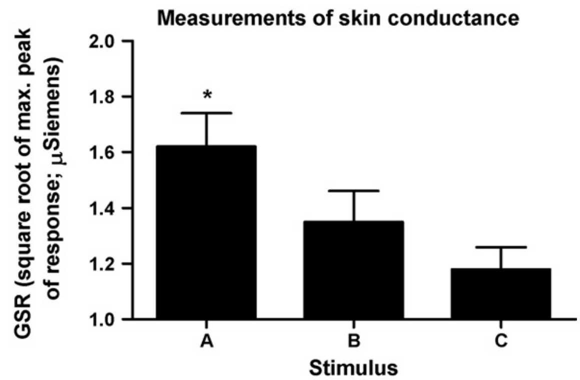


Fig. 6. Skin conductance measurements (mean + SEM) in the presence of stimulus A, B and C irrespective of valence or level of the outcome. *$p < 0.05$ compared to stimulus B and C.

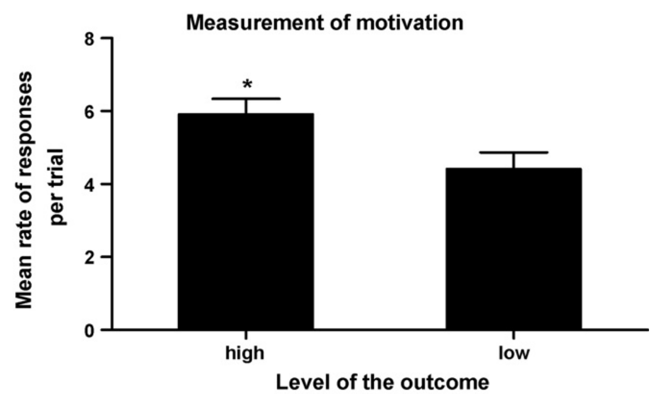


Fig. 7. Measurement of response rates (mean + SEM) in a VI schedule to receive the outcome in the case of money or to avoid the outcome in the case of noise for the high and low level of outcome irrespective of valence. *$p < 0.05$ compared to low level.

4. Discussion

The present report has demonstrated differential attentional mechanisms and discrimination learning in aversive and appetitive conditioning. Factors that could have affected attention and discrimination learning such as arousal and motivational salience were not different between the conditions of appetitive and aversive outcome. The level of the outcome increased discrimination learning and affected motivation regardless of valence (appetitive or aversive), however, it did not affect attention to individual stimuli or discrimination learning with regard to valence. Thus, it is likely that the differences in appetitive and aversive conditioning are related to the valence of the stimuli. Comparisons between the groups also showed that there were no differences with regard to BIS and BAS, anxiety or depression, as such traits may contribute to conditioned responses.

An overall attentional bias for the full predictor (A) and the partial predictor (B) of the outcome over the full predictor (C) of no outcome was found in the noise condition. This finding supports the stimulus salience theory that the most salient stimuli capture attention [23]. While it is difficult to separate the effects of predictive salience from emotional salience, additional findings in the present study provide evidence that the emotional saliency drove attention in the case of aversive conditioning. Mean anxiety ratings followed the pattern of dwell time biases indicating that attention to stimulus B, as with stimulus A, was mediated by the emotional rather than the predictive salience. No attentional bias for the full predictor of no outcome (and low anxiety ratings) further supports this assumption. However, there are still some issues with this proposal. There was no correlation between anxiety and dwell time, which poses a problem for the proposal that attention is mediated by the emotional properties of the stimuli. Lack of a linear relationship between anxiety ratings and attention could be due to individual differences in anxiety states among participants that could have affected attentional bias. For instance some studies have found that subjects who have high fear for certain unconditioned stimuli such as spiders [32] or blood injury [27] exhibit attentional avoidance for such stimuli.

Another point of concern is that if attention had been mediated by emotion, one would expect that increasing the affective value of the unconditioned stimulus would likewise increase attention to the conditioned stimulus. However, there were no differences in dwell time for the stimulus A between the two levels of noise. It is possible that the 102 dB noise was not sufficiently different from the 97 dB noise to produce an increase in emotional reactivity. Indeed, anxiety ratings for the A stimulus associated with the 102 dB noise were no different to the anxiety ratings for the A stimulus associated with the 97 dB noise, indicating that emotional reactivity was equal across the two noise conditions. However, the anxiety measure may not have been sensitive enough to reflect the differences in affective value between the two conditions. Indeed, there was a trend for dwell time biases to be greater for the A stimulus in the 102 dB condition compared to the 97 dB condition (post-hoc, independent t-test: $p = 0.110$; see Table 3), implying that there may have been differences in affective value that the anxiety ratings failed to detect (post-hoc independent t-tests for anxiety ratings between the high and low noise condition did not reveal any trend). Differences in the motivational value of the outcomes may also not have been present in the current study (in contrast to the pilot study) as they were taken at the end of conditioning when habituation or sensitization effects may have masked differences between high and low reinforcers.

In the money conditions the dwell time bias for the uncertain predictor (B) was greater than dwell time for the two certain predictors (A and C) supporting Pearce and Hall's theory (1980) that attention is error-driven. Both emotional and predictive salience had little effect on attention. Pleasantness ratings indicated that the affective value of stimulus A, which predicted the reward, was greater than both the partial predictor (B) and the predictor of no reward (C). Expectancy ratings reflecting learning were also in the direction A > B > C, yet dwell time biases did not match this pattern.

Although the evidence is consistent with different processes driving attention in aversive and appetitive learning, there are elements that still need to be resolved in order to determine how robust these findings are. In aversive learning, attention as driven by prediction error cannot entirely be disproved as mean expectancy ratings for stimulus A were not at the maximum level of expectancy. Thus, learning had not yet reached asymptote and therefore it is possible that attention was directed to stimulus A to support learning. An additional block of trials would be required to see if, after learning has reached asymptote, attention to stimulus A would decrease while attention for the uncertain predictor B would continue to remain high. Also a previous study on aversive conditioning using a similar procedure has shown in contrast to the present study that the attentional bias is greater for a partial predictor over a full predictor [12]. In this study, the length of time that the stimulus could be viewed for was controlled by the participants. It has been shown previously that attention diminishes over time for a full predictor when the length of its presentation is controlled by the participants [13]. In addition, the study that found an attentional bias for the partial predictor [12] used a low level 97 dB blast of noise, which might not have been emotionally as aversive as 102 dB used in the present study. Although the level of the aversive outcome in the present study did not significantly affect the attentional bias, post-hoc inspection of the mean values of bias for stimulus A, B and C showed that the linear relationship A > B > C was more pronounced in the high level blast of noise (102 dB; see Table 3).

Concerning the money condition, lower attentional bias for the full predictor of reward (stimulus A) compared to the uncertain predictor (stimulus B) might also have been due to the monetary rewards having low emotional significance for the participants. Previous studies have found that attention increased to a conditioned stimulus associated with primary rewards that were motivationally salient to the individual [8,28]. A future study could adapt the current paradigm using a primary reward in order to see to what extent the prediction error effect applies to all rewards.

The level of the outcome affected the motivational response (higher rate of responses were found for the high versus the low level of money and noise) but did not influence the attentional bias. Valence on the other hand was important for attentional bias but did not affect the motivational response (no differences were found for the motivational measurements with regard to valence). Thus, it seems that increased value of the outcome whilst associated with increased motivational significance is not important for attention. On the basis of these findings it is reasonable to suggest that there might be differential brain mechanisms underlying attention to significant emotional stimuli of aversive or appetitive origin, whereas a common brain mechanism might underlie the response output to approach or avoid the outcome predicted by the stimuli. In parallel with this proposal, increasing reward expectation increased excitability in the motor cortex in the presence of reward stimuli, while a manipulation to enhance attention for reward stimuli did not increase excitability in this region [17]. In addition, separate regions in the posterior parietal cortex were found to be related to attention and intention. Activity was altered in one region according to whether stimuli were targets or distracters, while another region was correlated with the variability in response time for these same stimuli [16]. This fine tuning of approach or avoid response may therefore be more susceptible to damage in the progression of pathological learning leading to clinical conditions such as anxiety or drug addiction.

Measurements of arousal showed differential GSR responses to the stimuli in accordance with their predictive value for the outcome (A > B > C) and irrespective of valence. There was also no effect of level for the arousal measure, suggesting that the two levels of outcome were not sufficiently different from each other to induce differences in arousal. Thus, the effects of valence on attentional bias and the effects of valence and level of the outcome on learning were not confounded by differences in arousal. This is in accordance with previous studies, which also found that attentional bias to negative information take place in the absence of differences in arousal [3].

In summary, the study found greater attentional bias for a partial predictor over a full predictor of reward and non-reward only in appetitive conditioning, supporting the prediction error hypothesis that attention is controlled by uncertainty [29]. In aversive conditioning attentional bias was higher for both the full and the partial predictor of the aversive outcome over the predictor of no outcome. Emotional conditioning supported a relationship in the pattern of the stimulus-evoked emotionality and the attentional bias to that stimulus in the aversive, but not in the appetitive conditioning, supporting the stimulus salience model that salience of a predictive stimulus controls attention [23]. Furthermore, the present study has shown that arousal, which was evoked by the stimuli irrespective of valence, and motivational significance, which was related to the level of the outcome but not to valence, were not associated with the differential attentional bias for the stimuli in the aversive and appetitive conditioning. Future studies should identify the brain mechanisms underlying the emotional reactivity and prediction error responses by using aversive and appetitive conditioning. Further investigations are also required to see how these effects on attention lead to a differential effect on behaviour as this could have implications in the treatment of anxiety disorders and drug addictions. If it is proven that attentional biases control avoidance behaviours (anxiety) or drug-seeking responses in different ways then interventions specific to anxiety and drug addictions may develop to disrupt such biases and help in breaking the cycle of maladaptive responses.

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