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Slow associative learning in alcohol dependence and the alcohol cue exposure treatment paradox

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ABSTRACT

Aims To examine two explanations for the observation that cue–exposure treatment has not been clearly effective in the treatment of alcohol dependence: do alcohol-dependent individuals have either (1) slower extinction and/or (2) greater contextual specificity of extinction than non-dependent individuals? **Design** In two exploratory laboratory experiments we used mixed factorial designs with two-group between-subjects factors and within-subjects factors corresponding to performance in different parts of a computer-based learning task. **Setting** University of Southampton psychology research laboratories and two addiction treatment services in the city of Southampton, UK. **Participants** Experiment 1: 74 (54 female) undergraduates from the University of Southampton (age mean = 20.4 years). Experiment 2: 102 (40 female) participants from the University of Southampton, the local community, and from two Southampton alcohol treatment services (age mean = 41.3 years). **Measurements** The Alcohol Use Disorders Identification Test, a 1-week time-line follow-back alcohol consumption questionnaire, the Barratt Impulsiveness Scale (11th edn), and a computerized learning task. Experiment 2 additionally used the 44-item Big Five Inventory, a drug use history checklist, and the Hospital Anxiety and Depression Scale. **Findings** Experiment 1: light and heavy drinkers did not differ significantly in extinction [extinction block × drinking status interaction, $P = 0.761$, $\eta_p^2 = 0.005$, 95% confidence interval (CI) = (0,0.028)] or on contextual control of extinction [recovery block × drinking status interaction, $P = 0.514$, $\eta_p^2 = 0.009$, 95% CI =(0, 0.084)]. Experiment 2: slower extinction in abstinent alcohol-dependent participants compared with light drinkers [extinction block × drinking status interaction, $P = 0.023$, $\eta_p^2 = 0.031$, 95% CI = 0, 0.069)] but no significant difference on contextual control of extinction [recovery block × drinking status interaction, $P = 0.069$, $\eta_p^2 = 0.033$, 95% CI = (0, 0.125)]. **Conclusion** Abstinent alcohol-dependent people may have slower extinction learning for alcohol-related cues than non-dependent light drinkers.

Keywords ABC recovery, alcohol dependence, associative learning, cue exposure, extinction, predictive learning.

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INTRODUCTION

Pavlovian and instrumental learning play a critical role in alcohol dependence (AD) [1]. Through Pavlovian conditioning, discrete environmental stimuli and contexts (e.g. sight and smell of alcohol or a bar-room setting) become conditioned stimuli (CSs) by their association with the effects of alcohol, an unconditioned stimulus (US). The consequence is that exposure to alcohol CSs can produce conditioned responses (CRs) and craving, increasing the probability of drinking [2–4]. Thus, alcohol-related cues can be crucial antecedents to relapse and a threat to abstinence.

Extinction of Pavlovian conditioning occurs when CSs are repeatedly presented without the US. CRs weaken and may ultimately disappear. Extinguished alcohol cues produce weaker craving than they did pre-extinction in social [5], heavy [6] and dependent drinkers [7, 8]. Therefore, an extinction-based treatment is a theoretically grounded potential intervention for treating alcohol dependence (AD). However, despite strong theoretical support and support from some clinical trials [9, 10] meta-analyses

demonstrate that cue–exposure treatment (CET) has not proved an effective treatment for AD [11–13]. This is a surprising contrast to the efficacy of CET for other disorders, such as phobia and obsessive–compulsive disorder (OCD), where learning plays a role parallel to that in AD. One explanation for this contrast is that USs are appetitive in the case of addiction and aversive in the case of anxiety disorders. It is not possible to rule this out on the basis of the existing literature, but it is not a clear-cut explanation because there is some evidence that cue–exposure can reduce over-eating and binge-eating where there is an appetitive US [14–16].

The term 'alcohol cue exposure treatment paradox' (ACETP) is used to define this surprising contrast, and we explore two potential explanations for it. First, we examined whether or not there were any differences between light, heavy and dependent drinkers on extinction of CRs. Slower extinction of CRs could potentially explain the ACETP, as CET may not fully extinguish CRs by the end of treatment. Conditioned inhibition has been implicated in extinction of CRs [17, 18] and it is established that response inhibition is weaker in AD [19]. However, although there is little evidence linking conditioned inhibition with response inhibition [20], both are fundamentally about the capacity to inhibit a response to a cue, so we also asked whether or not there were any differences between light, heavy and dependent drinkers on conditioned inhibition.

The second candidate explanation for the ACETP was based on poor generalization of extinction across contexts —recovery of CRs after extinction is frequently observed if there is a contextual change [21, 22]. Although response–recovery after exinction has been put forward as a possible explanation for poor CET outcomes in AD [5, 11] response–recovery cannot alone explain why CET works for some disorders and not for others. Therefore, we looked for evidence of differences between light, heavy and dependent drinkers that might support the hypothesis that greater response–recovery after extinction could be a contributing factor in the ACETP.

The aim of this study was to test two candidate hypotheses for the relatively poor CET outcomes for AD: (1) slower extinction and/or (2) greater response–recovery in dependent drinkers. As extinction and response–recovery may be mediated by the extinction context becoming inhibitory [17, 18] we also explored a secondary hypothesis (3) of group differences on the development of inhibitory control by the extinction context. We examined these hypotheses using the performance of light, heavy and dependent drinkers in a computer-based associative learning task.

METHODS

In two experiments we compared the performance of two groups of participants in a computer task designed to study Pavlovian learning. The experiments were not preregistered, so the results which follow should be considered exploratory. In a we compared light with heavy drinkers and in Experiment 2 we compared light with abstinent dependent drinkers. The computer task used has well-established methods and is typical of tasks used in the study of human Pavlovian learning [17, 23–25]. The task consists of a series of trials in which distinctive onscreen cues (CSs) and outcomes (USs) are presented. Participants learn to predict the US on each trial on the basis of the CS for that trial. Predictions are made by pressing keys on the computer keyboard. CSs appear at the start of each trial as three-dimensional (3D) objects (e.g. a yellow cube) which 'fall' from the top to the bottom of the screen passing a 'sensor' at the bottom of the screen. Experimental instructions explain that the sensor may be triggered to flash red or green by some objects, and that the task is to learn how the sensor responds to the different objects. The screen background is rendered in different 3D environments to manipulate context. For additional details see Table 1, Fig. 1 and Supporting information, which includes a video of the task.

Design

The learning task used in both experiments had similar mixed designs—a single between-subjects independent variable with two levels, drinking status and a within-subjects independent variable trial, corresponding to different points in the learning task. The number of levels varied for trial in different parts of the task, details below. In Experiment 1 the two levels of drinking status were light and heavy, with drinkers categorized based on a median split on weekly UK units of alcohol consumption (1 unit = 8 g ethanol). Light drinkers consumed fewer than 10.95 units per week. In Experiment 2 the two levels of drinking status were light and dependent. Light drinkers scored ≤ 5 on the Alcohol Use Disorder Identification Test (AUDIT-C) and dependent drinkers had a diagnosis of AD, but were currently abstinent.

Participants

An a priori estimate of sample size required for detecting main effects of group in the analysis of variance (ANOVA) of the extinction was obtained using G*Power [26]. A medium effect size was assumed (Cohen's $f = 0.25$ [27]) and α and β were set to 0.05 and 0.8, respectively. G*Power indicated that a sample size of was 78 required, given the default correlation of 0.5 between the repeated measurements, holding all parameters constant that gave $\beta > 0.99$ for detection of main effects of block and for the block × group interaction.

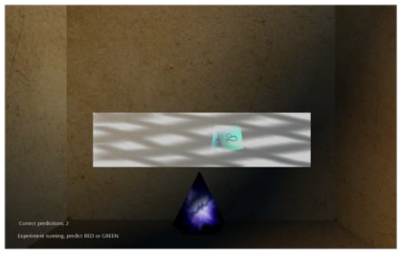
Table 1 Summary of learning task; see Methods and Supporting information for additional details. Each trial started with a cue (A, B, C or G) appearing on screen and ended with an outcome (X, Y or Z). The cues were visually distinct three-dimensional objects (e.g. yellow cube), the X and Y outcomes were red or green flashes, while Z was 'no outcome'. Participants pressed key-R or key-G to register predictions for red or green flashes or did nothing if they expected no outcome. Trials were arranged in randomized order within stages, in the numbers indicated, and took place in one of three distinctive visual contexts (A, B or C). For example, A, A → X (×10) indicates that cue A was presented in context A, with outcome X presented for 10 trials during the acquisition phase. The physical identity of the stimuli serving the different cue and context roles was randomly determined for each participant by selecting from a range of possibilities. Similarly, the identity of the outcomes was determined at random for each participant, e.g. for some participants X was red and Y was green and vice versa for the remainder; see also Fig. 1.

Stage 1: acquisition	*Stage 2: extinction*	*Stage 2a: summation test*	*Stage 3: recovery test*
A: A → X (×10)	B: A → Z (×8)		C: A → Z (×2)
A: B → Y (×20)	B: B → Y (×8)		
A: C → Z (×20)	B: C → Z (×8)		
A: G → X (×10)		B: G → Z (×2)	

Participants were recruited via electronic and poster advertisements and by word of mouth. For Experiment 1, 74 participants (age M = 20.4 years) were recruited from the University of Southampton. Course credit or entry into a prize draw for a £50 Amazon voucher was given upon completion. For Experiment 2, 102 participants (age M = 41.3 years) took part. Fifty-one outpatient participants currently in treatment, having abstained for at least 15 days, were recruited from two Southampton treatment services for the AD group. Fifty-one participants in the light drinking group were recruited from the University of Southampton and the general public of Southampton. We did not expect age (within the range of our sample) or gender to influence computer task performance, but to avoid a confound we ensured that the groups were balanced for age and gender by testing AD participants first and then recruiting light drinkers until gender balance within 5-year age bands was achieved. Demographic characteristics of all participants are summarized in Table 2 and full inclusion criteria are given in the Supporting information.

Materials and apparatus

Three personal computers (PCs) and a laptop were used for the learning task. All participants completed the Barratt Impulsiveness Scale (BIS-11) [29]. Non-dependent participants completed the AUDIT-C [30] based on the previous 6 months and a 1-week time-line follow-back questionnaire (TLFB) [31] to establish weekly UK units of alcohol consumption, whereas AD participants completed the full AUDIT in relation to the 6 months prior to the participants' abstinence. In addition, participants in Experiment 2 completed the Hospital Anxiety and Depression Scale (HADS) [32] and the 44-item Big Five Inventory (44-BFI) [33]



On each trial of the learning task participants viewed an object fall from the top to the bottom of the computer screen. Whilst the object was behind the translucent 'prediction window' participants could press a key to indicate whether they expected a red or a green flash when the object passed the pyramid shaped sensor. On the left an object is shown passing the prediction window. Below an object has trigged a red flash from the sensor.

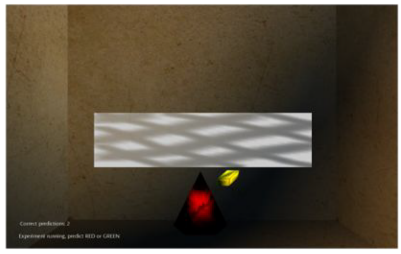


Figure 1 Illustration of computer-based predictive learning task; see also Table 1 [Colour figure can be viewed at wileyonlinelibrary.com]

Table 2 Participant characteristics for experiments 1 and 2, *n*s and means (SD).

	Experiment 1		*Experiment 2*	
	Light drinkers	*Heavy drinkers*	*Light drinkers*	*Dependent drinkers*
N	37	37	51	51
Gender *n*s (♀, ♂)	24, 13	30, 7	20, 31	20, 31
Age	20.7 (3.8)	19.9 (1.7)	41.1 (12.4)	41.5 (11.6)
AUDIT-C	5.2 (2.4)	7.9 (2)**	2.3 (1.7)	10.8 (1.6)**
Impulsivity	64.6 (10)	65.8 (8.3)	56.6 (7.5)	74.7 (15.8)**
Weekly units	4.74 (3.79)	31.2 (27.8)**	4.5 (6.1)	0[b]
Depression	NA	NA	2.7 (2.6)	5.7 (4.0)**
Anxiety	NA	NA	5.4 (3.1)	10.4 (5.0)**
Extraversion	NA	NA	25.8 (6)	27.9 (7.2)
Neuroticism	NA	NA	19.8 (5.4)	27.6 (6.4)**
Agreeableness	NA	NA	36.6 (4.4)	34.1 (6.4)*
Conscientiousness	NA	NA	35.9 (5.1)	30.6 (8.6)**
Openness	NA	NA	36.9 (5.4)	36.6 (6.6)
Drug-taking	NA	NA	7	46[a]
Drug-taking exc. Tobacco	NA	NA	5	30[a]

AUDIT-C = alcohol use disorders identification test; Barratt Impulsiveness Scale 11 (BIS11) = total score impulsivity; Hospital Anxiety and Depression Scale (HADS) = subscales depression and anxiety; 44-item Big Five Inventory (44BFI) = subscales extroversion, neuroticism, agreeableness, conscientiousness and openness; [a]drug-taking obtained from author-made checklist covering tobacco, cannabis, stimulant, opiate, hallucinogen, benzodiazepine and ketamine, number of participants reporting use in last 6 months, significant difference $\chi^2_{(1\ d.f.)}$, $P < 0.001$; [b]dependent drinkers in experiment 2 were abstaining at the time of test and had an average of 78.4 abstinent days [standard deviation (SD) = 69.5]. For the alcohol-dependent (AD) group the full AUDIT score mean was 30.7 (SD = 5.6), typical cut-off indicating dependence AUDIT ≥ 20;[28] NA = not available. Asterisks indicate between-group differences using *t*-tests [72 and 100 degrees of freedom (d.f.) for experiments 1 and 2, respectively] *$P < 0.05$; **$P < 0.001$.

questionnaires and a checklist for reporting prescribed and non-prescribed drug use.

Procedure

Testing for non-dependent participants was carried out in the department of psychology at Southampton University. Participants were tested individually using personal computers (PCs) in experimental cubicles after reading an information sheet and signing a consent form. They then completed their questionnaires followed by the computer task. AD participants were tested individually using a laptop in a quiet private room within their treatment facility and, for the questionnaires, the experimenter read the questions out loud and recorded responses. The experiments took approximately 30–45 minutes, after which participants were thanked and debriefed.

Analyses

Participant responses involving critical cues A and G were coded 1 if outcome X was predicted and 0 otherwise, and averaged into two trial blocks to give the proportion of X-outcome predictions [P (xrsp)] in each block for the analyses presented below. The SPSS ANOVA procedure was used and, in cases of sphericity violation, based on Mauchley's test, Greenhouse–Geisser adjusted degrees of freedom (d.f.) were applied [34, 35]. Significant results are reported below with $\alpha = 0.05$. For each experiment a series of mixed ANOVAs were conducted. Each had a two-level between-subjects factor of drinking status (light versus heavy or light versus dependent). For cue A, acquisition and extinction ANOVAs had a five-level repeated-measures factor for block (blocks 1–5 for the acquisition analysis and blocks 5–9 for the extinction analysis) and the recovery test had a two-level repeated-measures factor for block (blocks 9 and 11). For cue G acquisition and summation, ANOVAs had a five or two-level repeated-measures factor for block (blocks 1–5 for the acquisition analysis and blocks 5 and 10 for the summation analysis). The extinction and recovery ANOVAs were used to test hypotheses (1) and (2) and the summation ANOVA tested hypothesis (3). The acquisition ANOVAs were used for a simple validity check—a successful acquisition phase is a pre-requisite for the hypothesis tests. In Experiment 2, regression and mediation analyses were used in exploratory analyses to examine whether or not group differences in acquisition and extinction could be explained in terms of differences observed on personality traits or drug-taking rather than differences in AD *per se*. An SPSS macro 'PROCESS' [36] was used to run the mediation analysis. PROCESS uses regression to estimate mediation models in which direct effects of variable X on variable Y are separated from indirect effects of X on Y mediated by mediator variables M -- i.e. X is modelled to affect M and M is modelled to affect Y.

Ethics

For Experiment 1, approval was obtained from the University of Southampton ethics committee (ERGO ID 18770). For Experiment 2, approval was obtained from the University of Southampton ethics committee (ERGO ID 21201.A2) and National Health Service (NHS) ethics committees (16/SW/0343 17/EM/0111 East Midlands–Nottingham1).

RESULTS

Experiment 1

Hypotheses (1) extinction and (2) recovery

Figure 2 displays the mean proportion of X responses to cue A across acquisition, extinction and recovery phases. Responding increased during acquisition and decreased in extinction, with most extinction complete in the first two blocks. Responding increased again during recovery. Figure 2 suggests no clear difference between the two drinking groups at any stage of the task. Although the extinction data showed numerically less extinction and more response–recovery in heavy compared to light drinkers, these differences were not significant. Table 3 presents the ANOVAs which show the main effects of block during acquisition, extinction and recovery, indicating that the experimental procedure was working as intended by reproducing standard effects, and confirming the visual inspection of Fig. 2, that there were no group effects or interactions.

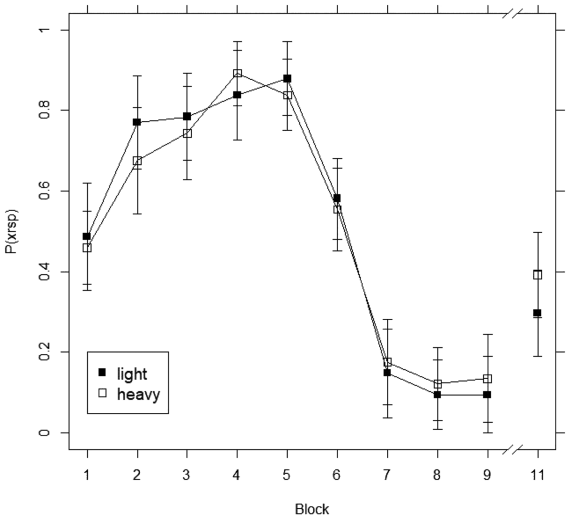


Figure 2 Probability of an X-outcome prediction in response to cue A during Experiment 1. Acquisition (blocks 1–5), extinction (blocks 6–9) and recovery test (block 11) for light and heavy drinkers; means with 95% confidence intervals

Hypothesis (3) inhibition

Figure 3 displays the mean proportion of X responses to cue G across acquisition and summation test phases. Responding increased during acquisition and decreased in the summation test. Again, there was no clear indication of group differences. The ANOVAs in Table 3 show the expected main effects of block, but no evidence of group effects or interactions.

Experiment 2

Hypotheses (1) extinction and (2) recovery

Figure 4 displays the mean proportion of X responses to cue A across the acquisition, extinction and recovery phases. The overall pattern for the light drinkers closely resembled that seen in Experiment 1, but the AD group was slower to learn the CS–US pairing than the light drinkers, although they were comparable by block 5. The AD participants were also slower to extinguish, showed less extinction overall, and showed less response–recovery than the light drinkers. The ANOVAs in Table 3 again confirm the standard effects of acquisition, extinction and recovery via effects of block; however, there was also a significant block × group interaction for extinction and a main effect of group in recovery. Following-up the interaction, independent *t*-tests for the effect of group at each block during extinction showed a group difference in block 9 ($t_{(100)} = 2.74$, $P < 0.01$).

Hypothesis (3) inhibition

Figure 5 displays the mean proportion of X responses to cue G across acquisition and summation test phases. As observed for cue A, light drinkers in Experiment 2 behaved comparably with the light drinkers from Experiment 1. However, the AD group was slower to acquire the CS–US pairing than the light drinkers, but learned to a comparable level by block 5. The ANOVAs in Table 3 show the expected main effects of block and a main effect of group for cue G during acquisition, but block × drinking interactions were not significant.

Exploratory analyses

Two dependent measures were used alongside two analyses. The first dependent measure, EA, summarized performance during extinction for cue A and was obtained as the linear regression coefficient for the regression of P (xrsp) for cue A on block for each participant. The second dependent measure, AG, summarized performance during acquisition for cue G and was obtained by averaging P (xrsp) for cue G across blocks for each participant.

The first analysis assessed whether or not differences in drug use between light and dependent drinkers (cf. Table 2)

Table 3 Analysis of variance results for experiments 1 and 2; 95% confidence intervals given for η_p^2. The analysis column identifies the purpose of each ANOVA—either to test a hypothesis or for a procedural validity check.

Analysis		*Experiment 1*			*Experiment 2*		
(hypothesis)	*Effect*	$F_{(d.f.)}$	*P*	$\eta_p^2(l, u)$	$F_{(d.f)}$	*P*	η_p^2 *(l, u)*
Cue A	Block	26.5 (3.13, 225.6)	< 0.001	0.269 (0.169, 0.350)	16.7 (3.47, 347.0)	< 0.001	0.143 (0.076, 0.205)
Acquisition	Block × drinking	0.75 (3.13, 225.6)	0.531	0.010 (0, 0.037)	1.86 (3.47, 347.0)	0.126	0.018 (0, 0.046)
(validity)	Drinking	0.34 (1, 72)	0.561	0.005 (0, 0.080)	3.23 (1, 100)	0.075	0.031 (0, 0.122)
Cue A	Block	120.8 (2.65, 190.7)	< 0.001	0.627 (0.542, 0.684)	80.57 (3.09, 309.1)	< 0.001	0.446 (0.364, 0.509)
Extinction	Block × drinking	0.35 (2.65, 190.7)	0.761	0.005 (0, 0.028)	3.17 (3.09, 309.1)	0.023	0.031 (0, 0.069)
(1)	Drinking	0.02 (1, 72)	0.896	< 0.001 (0, 0.010)	1.03 (1, 100)	0.312	0.010 (0, 0.080)
Cue A	Block	31.3 (1, 72)	< 0.001	0.302 (0.135, 0.446)	4.49 (1, 100)	0.037	0.043 (0, 0.141)
Recovery	Block × drinking	0.43 (1, 72)	0.514	0.009 (0, 0.084)	3.37 (1, 100)	0.069	0.033 (0, 0.125)
(2)	Drinking	1.28 (1, 72)	0.514	0.017 (0, 0.115)	4.68 (1, 100)	0.033	0.045 (0, 0.144)
Cue G	Block	21.7 (3.26, 234.5)	< 0.001	0.232 (0.136, 0.311)	26.9 (3.55, 355.2)	< 0.001	0.212 (0.136, 0.277)
Acquisition	Block × drinking	1.67 (3.26, 234.5)	0.171	0.023 (0, 0.061)	2.46 (3.55, 355.2)	0.052	0.024 (0, 0.055)
(validity)	Drinking	0.167 (1, 72)	0.684	0.002 (0, 0.068)	7.44 (1, 100)	0.008	0.069 (0.005, 0.179)
Cue G	Block	78.2 (1, 72)	< 0.001	0.520 (0.355, 0.631)	106.2 (1, 100)	< 0.001	0.515 (0.377, 0.613)
Summation	Block × drinking	0.14 (1, 72)	0.710	0.002 (0, 0.065)	3.02 (1, 100)	0.086	0.029 (0, 0.119)
(3)	Drinking	1.89 (1, 72)	0.173	0.026 (0, 0.131)	0.089 (1, 100)	0.766	0.001 (0, 0.036)

ANOVA = analysis of variance; d.f. = degrees of freedom.

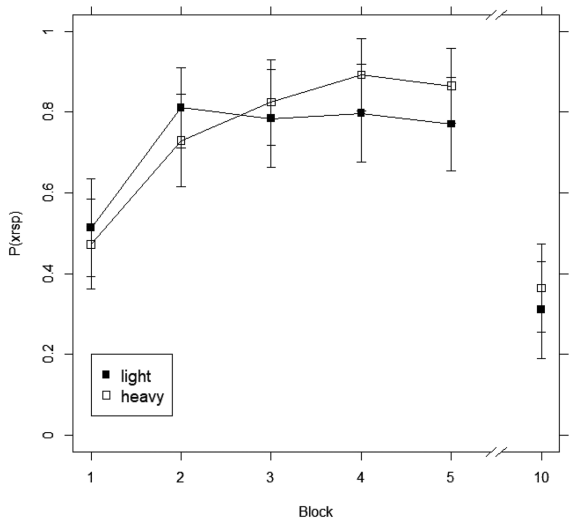


Figure 3 Probability of an X-outcome prediction in response to cue G during Experiment 1. Acquisition (blocks 1–5) and summation test (block 10) for light and heavy drinkers; means with 95% confidence intervals

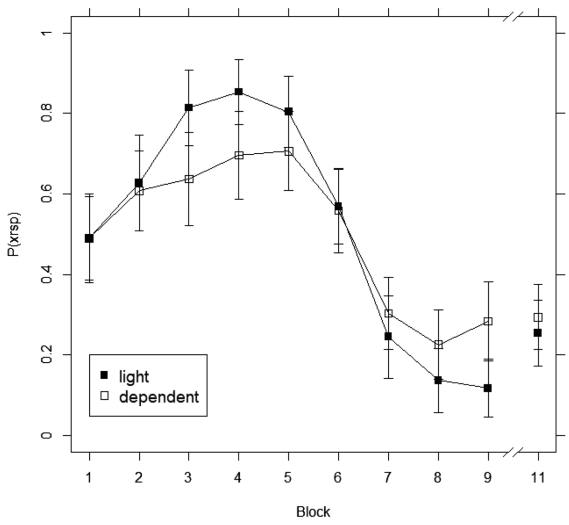


Figure 4 Probability of an X-outcome prediction in response to cue A during Experiment 2. Acquisition (blocks 1–5), extinction (blocks 6–9) and recovery test (block 11) for light and dependent drinkers; means with 95% confidence intervals

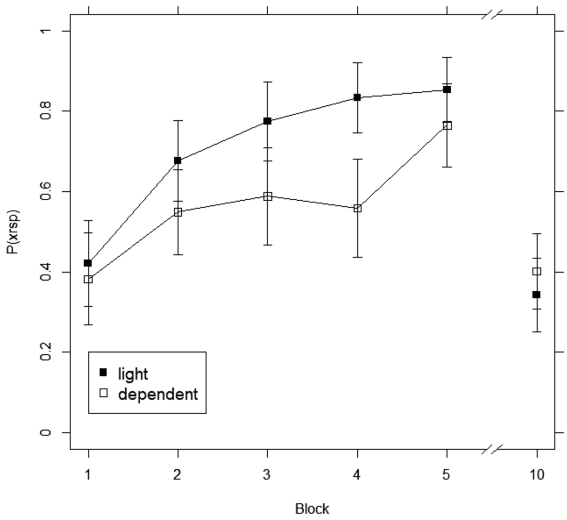


Figure 5 Probability of an X-outcome prediction in response to cue G during experiment 2. Acquisition (blocks 1–5) and summation test (block 10) for light and dependent drinkers; means with 95% confidence intervals

could account for the observed group differences on extinction and acquisition. Results of regressions of EA and AG on group and drug-taking (no or some drug-taking in last 6 months) are shown in Table 4. The overall regression effect and the effect of group, controlling for drug use, was significant in all cases except on EA, when tobacco use was taken into account. In no case was the effect of drug-taking significant.

The second analysis assessed whether or not the differences on personality variables between light and dependent drinkers (cf. Table 2) could account for the observed group differences on extinction and acquisition. The SPSS macro PROCESS was used to perform a mediation analysis to assess direct and indirect effects of personality variables and group on EA and AG. Personality variables with a significant difference between light and dependent drinkers (BIS11, HADS-D, HADS-A, 44BFI-N, 44BFI-A and 44BFI-C) were used as parallel mediators (model 4 PROCESS version 3.1), with group as a direct effect variable.

The results of this analysis indicated a direct effect of group on EA (effect = 0.08, $t_{(94\ \text{d.f.})} = 2.67$, $P = 0.009$), but no indirect effects of group on EA mediated via personality. There was also a direct effect of group on AG (effect = 0.146, $t_{(94\ \text{d.f.})} = 2.29$, $P = 0.024$) and direct effects of 44BFI-A and 44BFI-C on AG (effect = −0.065, $t_{(94\ \text{d.f.})} = 2.25$, $P = 0.027$, effect = −0.078, $t_{(94\ \text{d.f.})} = 2.19$, $P = 0.031$, respectively), but no indirect effect of group on AG mediated by personality.

GENERAL DISCUSSION

In two experiments, participants learned appropriate responses to cues in one context and showed extinction of responding in another context. They also showed suppression of responding to an excitatory cue in the extinction context (suggestive of context inhibition) and then showed recovery of responding in a third context (ABC recovery). In Experiment 1, as light and heavy drinkers did not differ, there was no support for the hypothesis that the ACETP could be due to differences on extinction (hypothesis 1) or on response–recovery (hypothesis 2) between the participants with AD and other groups, where CET has been used with success. However, these conclusions were not definitive because, assuming continuity between light drinking and dependent drinking [37], differences between light and heavy drinkers may have been too small to easily detect. Even though our heavier drinkers were consuming more than twice the median weekly consumption of 13 UK units [38] and their mean AUDIT-C score of 7.9 indicated that many were drinking at an increased risk level [28], it remains plausible that differences between light and dependent drinkers should be greater than differences between light and heavy drinkers.

In Experiment 2, we found that light drinkers and AD participants differed on extinction (confirming hypothesis 1) and on acquisition. Specifically, (1) extinction proceeded more slowly in AD participants than in light drinkers and (2) there was lower responding during acquisition in AD participants than in light drinkers. The groups in this experiment were balanced on age and gender, but differed on a number of personality traits and on other drug use. However, regression and mediation analyses showed that the effect of AD on learning remained after drug use was included in the regression models and that the effects of AD of learning was not mediated by personality variables.

Table 4 Experiment 2 exploratory regressions of cue A extinction (EA) and cue G acquisition (AG) performance as a function of drinking status group and self-reported drug use.

			Standardized coefficient β, $t_{(99\ \text{d.f.})}$, P	
Drug use	*Dependent variable*	*Overall regression $F_{(2,99)}$, P*	*Group*	*Drug use*
Includes tobacco	EA	3.92, 0.023	0.263, 1.75, 0.083	0.010, 0.07, 0.947
	AG	4.10, 0.019	0.365, 2.43, 0.017	0.132, 0.88, 0.379
Excludes tobacco	EA	3.92, 0.023	0.273, 2.42, 0.017	0.005, 0.04, 0.968
	AG	5.32, 0.006	0.364, 3.26, 0.002	0.195, 1.75, 0.084

To date, cue–exposure treatment for AD has not produced consistent positive results despite a clear theoretical base, and evidence for the effectiveness of cue–exposure treatment in other disorders where the underlying theoretical reasoning is directly analogous. A priori, we speculated that slow Pavlovian extinction and/or greater response–recovery after extinction and context change may differentiate the AD and general population, and in Experiment 2 we found group differences on extinction leading to the conclusion that slower associative learning in AD could indeed provide an explanation for the ACETP. We conclude with some discussion of limitations and implications of these results for our understanding of the ACETP and suggestions for follow-up work.

First, we test whether our comparison of AD and normal controls could provide an explanation for the ACETP, as this question is perhaps best answered by a direct comparison of extinction in, e.g. specific phobia and AD patients. There are some examples of general learning deficits which may differentiate participants with anxiety disorders from normal controls [39, 40] and an enormous literature on learning in anxiety disorders which has clearly established slower extinction of conditioned responding based on aversive USs in anxiety disorders compared to normal controls [41, 42]. However, we are not aware of any work which has shown slower extinction in other forms of associative learning (e.g. with appetitive USs or in predictive or causal learning preparations) in anxiety disorders compared to normal controls. We therefore speculate that normal and anxiety disordered controls would be interchangeable for comparison with AD participants using the current, or similar, tasks. Of course, the comments above are subject to limitations on the extent to which we can generalize learning in a computer-based task such as ours to the clinical situation, but the purpose of these studies is to provide a guide for future clinical work; for example, as suggested below, for further studies of cue–exposure.

Secondly, we note that, as far as we are aware, this is the first study to report differences between AD participants and controls on a predictive associative learning task. These results are preliminary, but of interest because of treatment implications. However, assuming that impaired extinction learning in AD is confirmed, crucial questions would still remain concerning the causal role of alcohol exposure. For example, alcohol is linked to reduced inhibition [43, 44] so we might expect that alcohol could cause impaired extinction. Alternatively, impaired inhibition and extinction learning could pre-date alcohol exposure and have a causal role in AD, but these two causal scenarios are not mutually exclusive [19]. Furthermore, if alcohol has a causal role in impaired learning, perhaps abstinence would reverse the effect? As the duration of abstinence in our dependent drinkers was too short (mean = 78 days) to suggest that the observed deficits were permanent [45] we are unable to answer this question. Nevertheless, even short-term deficits could be relevant to recovery and treatment. Finally, alcohol may acutely impact learning, and although our participants reported abstinence and they were subject to breathalyser checks in their treatment facilities we cannot be absolutely sure of complete abstinence at the time of testing. However, the learning status of dependent drinkers at the time they undergo cue exposure is critical (e.g. during attempted abstinence and when in contact with a treatment agency), so our observations are still relevant to CET whether or not self-reported alcohol consumption is fully accurate.

In conclusion, these results have implications for alcohol CET. Our results suggest that AD patients undergoing CET would fail to comprehensively extinguish CRs to alcohol-related cues and therefore would remain prone to relapse. A straightforward follow-up study would involve comparing standard and extended CET; but how much cue exposure might be needed? To address this question we reviewed 12 alcohol CET studies (see Supporting information) and found cue exposure times between 30 and 90 minutes [46, 47] so perhaps a reasonable way to determine whether extended cue–exposure would lead to improved outcomes would be to compare a 'standard' treatment, including 60 minutes of exposure with extended treatment involving 180 or 240 minutes of cue–exposure.

Declaration of interests

None.

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Author Contributions

Carl Buckfield: Conceptualization; investigation; methodology; project administration. **Julia Sinclair:** Conceptualization; funding acquisition; methodology; supervision. **Steven Glautier:** Conceptualization; funding acquisition; methodology; supervision.

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Data S1. Supplementary information, including data and SPSS code, is available at https://osf.io/r273p/.

