Addictive Behaviors 154 (2024) 108010

Contents lists available at ScienceDirect

Addictive Behaviors

journal homepage: www.elsevier.com/locate/addictbeh

Sign-tracking to non-drug reward is related to severity of alcohol-use problems in a sample of individuals seeking treatment

Poppy Watson [a,b,*], Katrina Prior [c], Nicole Ridley [d], Lauren Monds [e], Victoria Manning [f,g], Reinout W. Wiers [h], Mike E. Le Pelley [b]

[a] University of Technology Sydney, Australia
[b] UNSW Sydney, Australia
[c] The Matilda Centre for Research in Mental Health and Substance Use, The University of Sydney, Australia
[d] South Eastern Sydney Local Health District Drug and Alcohol Services, Sydney, Australia
[e] Specialty of Addiction Medicine, Faculty of Medicine and Health, University of Sydney, Australia
[f] Monash Addiction Research Centre, Eastern Health Clinical School, Monash University, Melbourne, Australia
[g] Turning Point, Eastern Health, Melbourne, Australia
[h] Developmental Psychology, University of Amsterdam, Netherlands

ARTICLE INFO

Keywords:
Sign-tracking
Incentive sensitization
Alcohol use
AUDIT
Reward seeking
Attentional bias

ABSTRACT

Background: A prominent neuroscientific theory of drug addiction is the incentive sensitization model. Individual differences in the tendency to ascribe motivational salience to cues that predict reward, and involuntary "sign-tracking" (orientation towards) such cues have been identified as potentially important in understanding vulnerability to addiction and relapse. However, to date this behaviour has not been assessed in a treatment-seeking clinical population, who typically represent those most susceptible to alcohol-related harms and episodes of relapse. This highlights a significant gap in the literature pertaining to incentive sensitization and drug dependence.

Methods: Individuals accessing inpatient drug and alcohol services with alcohol as primary drug of concern were recruited to participate in a Cognitive Bias Modification (CBM) intervention. At the baseline assessment, participants completed various self-report measures (including the Alcohol Use Disorders Identification Test; AUDIT) in addition to a visual search task measuring sign-tracking to cues signalling monetary reward. At 3-month follow up, abstinence from alcohol was the primary outcome measure. All analyses and hypotheses were pre-registered.

Results: At baseline (57 participants), AUDIT scores correlated with sign-tracking to signals of monetary reward. In a subsequent regression analysis sign-tracking, gender and self-reported alcohol craving predicted abstinence at 3-month follow up (41 participants).

Conclusions: Our work demonstrates that involuntary sign-tracking to cues signalling non-drug reward is associated with problematic alcohol use and return to use at 3-month follow up, in a treatment-seeking sample. Whether this automatic prioritisation of cues signalling reward is a consequence or vulnerability for problematic alcohol use remains to be investigated.

1. Introduction

Alcohol use disorders are highly prevalent affecting more than 5 % of the global population in 2016 (Rehm & Shield, 2019). The majority (50–80 %) of patients return to use within 1 year of treatment (Charney et al., 2010; Manning et al., 2022). Arguably the most prominent theory of drug addiction is the incentive sensitization model (Robinson & Berridge, 1993, 2000, 2001). Repeated drug use leads to hypersensitivity to the rewarding effects of the drug and to stimuli that are predictive of the drug. Cues that signal potential drug outcomes are imbued with excessive 'incentive salience', becoming motivational magnets that are difficult to ignore, and that bias attention and ultimately behaviour towards obtaining the drug.

Individual differences in the tendency to ascribe incentive salience to

* Corresponding author at: School of Psychology, Graduate School of Health, University Technology Sydney, 100 Broadway, Ultimo, NSW 2007, Australia.
E-mail address: poppy.watson@uts.edu.au (P. Watson).

https://doi.org/10.1016/j.addbeh.2024.108010
Received 28 November 2023; Received in revised form 28 February 2024; Accepted 8 March 2024
Available online 9 March 2024

cues that predict reward, and their ability to promote reward-seeking behaviour, are potentially important in understanding vulnerability to addiction and relapse (Colaizzi et al., 2020; Flagel et al., 2009). In non-human animals, these individual differences have been identified during Pavlovian conditioning protocols as 'sign-tracking' and 'goal-tracking' profiles. When learning about the predictive relationship between Pavlovian cues (e.g., lights) and outcomes (e.g., food pellets), goal-tracking animals use the cue as a signal to orient to the location where the food is going to be delivered. Sign-trackers however, approach and engage with the Pavlovian cue (e.g., the light) rather than the food location (Hearst & Jenkins, 1974; Killeen, 2003). In line with the incentive sensitization model, sign-tracking towards signals of food reward in animals is related to increased vulnerability for the development of addiction-like behaviours (B. T. Saunders & Robinson, 2010, 2011; Tomie et al., 2008). For example, rats showing increased sign-tracking to cues that signalled food rewards were later more likely to self-administer cocaine in the presence of cues signalling cocaine availability, despite concurrent foot shocks (B. T. Saunders et al., 2013).

Arguably the best analogue for sign-tracking behaviour in humans is value-modulated attentional capture (VMAC). The VMAC paradigm is a computerized visual search task in which participants must search the display for a unique diamond shape (the target) among a set of circles. On each trial one of the circles (the distractor) is rendered in colour, with the colour signalling whether a high or a low monetary reward is available for successfully locating the target. Numerous eye-tracking studies have shown that participants look more often at a distractor signalling high vs. low reward, even if they are aware that looking at the distractor will result in the loss of the signalled reward on that trial (Le Pelley et al., 2015; Pearson et al., 2015; Albertella et al., 2017; reviews: Watson et al., 2019a; Colaizzi et al., 2020). Similarly, using a response time (RT) version of the task, where faster reaction times earn more money (particularly on high reward trials), participants respond to the target more slowly when a high-reward distractor is present in the display, despite this being counterproductive to the goal of earning money (Albertella et al., 2019, 2021). This pattern of attentional orienting to the signal of reward is interpreted as involuntary Pavlovian sign tracking (Albertella et al., 2021; Colaizzi et al., 2020; Watson et al., 2019b).

Using this task, increased sign-tracking to cues that predict monetary reward has been related to illicit drug use in students (Albertella et al., 2017), increased self-reported addictive compulsions in a community sample (Albertella et al., 2019) and increased likelihood of failing a one-month alcohol abstinence challenge in individuals wishing to reduce their alcohol consumption (Albertella et al., 2021). However, to date sign-tracking behaviour has not been assessed in a treatment-seeking clinical population, highlighting a significant gap pertaining to incentive sensitisation and alcohol dependence (Cofresi et al., 2019; Colaizzi et al., 2020). Understanding the role of this behaviour in problematic and compulsive alcohol use may offer future directions for the development of treatments that target incentive salience processes in alcohol dependence.

All study hypotheses and analyses were pre-registered at https://osf.io/z5d6k. Firstly, in a baseline assessment we aimed to assess whether sign-tracking to cues signalling monetary reward was correlated to problematic alcohol use in this treatment-seeking population. Secondly, we aimed to determine the effectiveness of an adapted cognitive bias modification protocol (designed to reduce attentional orienting and increase behavioural inhibition towards images of alcohol) for enhancing treatment efficacy in alcohol dependence. Due to COVID lockdowns, recruitment was severely affected, and it was not feasible to recruit 40 participants in each intervention group (as originally pre-registered). As such, pre-registered aims 1 and 2 which focus on investigating the between-group effectiveness of the intervention were unable to be examined. It was possible, however, to assess the factors predicting return to alcohol use at 3-month follow up (after controlling for intervention group assignment).

2. Method

2.1. Participants

Participants, abstinent from drugs and alcohol, were recruited from two residential drug and alcohol treatment facilities in Sydney. Both facilities offered 12-week inpatient programmes focusing on psycho-education and holistic care. Inclusion criteria were alcohol as primary drug of disorder and referral from clinicians/caseworkers. Poly-drug use was not an exclusion criterion. Exclusion criteria were non-native speakers of English, diagnosis of alcohol-induced amnestic confabulatory neurocognitive disorder, serious neurological problems including repeated seizures, a history of schizophrenia, current strong withdrawal symptoms, learning disorders (specifically reading/writing) and visual or motor disabilities that would impact their ability to engage in the procedure.

In total 59 participants (see Table 1 and Supplemental materials) were enrolled in the study and completed the baseline assessment earning $20, plus a performance-contingent bonus of between $5-$8 in the sign-tracking (VMAC) task. Most participants reported at least five years of alcohol dependence and had attempted multiple times to cease alcohol use (Figure S1). Fifty-four participants successfully completed the 2-week intervention earning $10 for each of six 15-minute sessions in addition to a performance-contingent bonus totalling $30-$50 across the intervention sessions. Three months after the end of the intervention, 50 participants (84.75 %) completed the online follow-up Qualtrics survey and received the bonus payment they had earned during the intervention (four participants lost to follow up).

2.2. Materials

2.2.1. Baseline measurements

VMAC task. To measure sign-tracking to signals of monetary reward, participants completed the RT version of the VMAC task (Fig. 1). On each trial, participants saw six shapes appear – five circles and one diamond (the target). Participants were asked to make a forced choice response to the orientation of the line within the diamond (horizontal or vertical) as quickly as possible to earn points (later translated into a monetary bonus). On most trials, one circle (the distractor) was rendered in either blue or orange and all other shapes were grey. Participants were instructed that the coloured circle indicated whether it was a'10 x bonus' trial (high reward) or a 'standard' trial (low reward), with the assignment of colour to reward counterbalanced across participants. Feedback on each trial (1500 ms) either indicated that participants had made an error, responded too slowly (RT > 1300 ms) or, after correct responses, the number of points that had been won. For correct responses on low-reward trials participants earned 0.1 points for every ms that their response time was below 1300 ms (e.g., RT of 700 ms = 60 points). On high-reward trials the points were multiplied by 10 (e.g., RT of 700 ms = 600 points) and the feedback screen also displayed the text "10 x BONUS TRIAL!". Each block contained 24 randomised trials, consisting of 10 trials with the high-reward distractor, 10 trials with the low-reward distractor, and four distractor-absent trials in

Table 1
Demographic and clinical profile of participants.

N = 59	Mean (SEM)
Age (years)	40.7 (1.3)
Gender (male/ female) ratio	49/10
Years of education	13.0 (0.5)
Baseline AUDIT	31.8 (0.9)
Baseline OCDS	24.9 (0.9)
Baseline BDI	12.9 (1.2)

Table notes: AUDIT = Alcohol Use Disorders Identification Test, OCDS = Obsessive Compulsive Drinking Scale, BDI = Beck Depression Inventory.

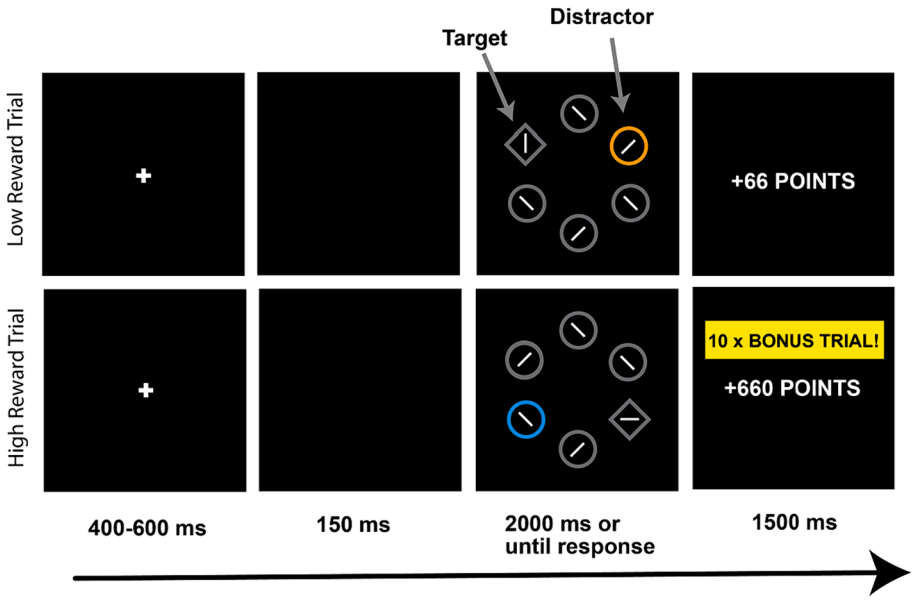

Fig. 1. Trial structure of the VMAC task used to measure sign-tracking to signals of monetary reward. Participants were asked to respond to the orientation of the line in the diamond target, with faster (correct) responses earning more points. Whether the current trial was a 'standard' (low-reward) trial or a '10 x BONUS' (high-reward) trial was signalled by a colour-singleton distractor circle in the search display: in this example, an orange distractor signals low reward and a blue distractor signals high reward (in the experiment, the relationship between colour and reward was counterbalanced across participants). Images not to scale.

which all shapes were grey). Participants completed 12 blocks (288 trials total) with a break after every two blocks. Counterproductive slowing of RT on high-reward relative to low-reward trials is indicative of sign-tracking behaviour.

AUDIT. During the baseline assessment participants completed the 10-item Alcohol Use Disorders Identification Test (AUDIT; J. B. Saunders et al., 1993), a screening tool to assess hazardous and risky alcohol use behaviour, with good test–retest reliability and internal validity (Reinert & Allen, 2002).

OCDS. During the baseline assessment and again at 3-month follow up participants completed the 14-item Obsessive Compulsive Drinking Scale (OCDS; Anton et al., 1996). This scale measures obsessive thoughts about alcohol use and compulsive behaviours toward drinking with good internal consistency (Roberts et al., 1999).

Beck Depression Inventory. During the baseline assessment participants completed the 21-item Beck Depression Inventory (BDI-II) measuring symptoms associated with depression (Beck, Steer, & Brown, 1996). The BDI has high internal consistency (Beck, Steer, Ball, et al., 1996).

2.2.2. Intervention

Participants were randomly assigned to one of the three intervention groups. Across two weeks participants completed six computer-based sessions of either alcohol attentional bias retraining (modified dot-probe task: Rinck et al., 2018), alcohol response inhibition retraining (modified Go/No-Go task: Houben et al., 2011) or were assigned to an active control group who saw the same images as the other two groups within the context of a working memory task (N-back task: Jaeggi et al., 2010). Participants in all groups saw the same images of alcoholic and non-alcoholic beverages, sourced from the 'Australian Beverage Picture Set' (Onie et al., 2020; Watson & Onie, 2023). For full details of the intervention tasks see Supplemental Information.

2.2.3. Post intervention questionnaire

After completing the final session of the intervention (session six) participants were asked to indicate the degree to which the images of alcohol made them crave alcohol during the sessions (VAS anchored with 0 "I never craved", 50 "moderate" and 100 "very intense"). Participants were asked to indicate whether they planned to remain abstinent from alcohol (yes/no/unsure).

2.2.4. 3-month follow up questionnaire

Three-months after the final intervention session participants were asked to complete a follow-up questionnaire. The primary dependent variable was the yes/no response to the question *"In the last three months, have you been continuously abstinent (no use of any alcohol or drugs)? 'Drugs' does not include nicotine but does include prescription drugs (obtained off prescription) and/or illegal drugs."* The full questionnaire and all data can be found at https://osf.io/4afme.

2.3. Procedure

Individuals who met inclusion criteria for the study were informed of the study within the first three-six weeks of intake by a psychologist/case manager (independent of their clinical care). Participants could then make an appointment with the researcher who obtained informed consent. The baseline assessment and intervention sessions were conducted individually, onsite, on a laptop. During the 1 hr baseline assessment participants first completed the sign-tracking (VMAC) task before completing the baseline demographic/clinical questionnaires. The first of the six intervention sessions occurred within the subsequent 2–3 days. Over the course of 14 days, participants performed the same intervention task across six sessions (with no more than one session per day). At the end of the sixth intervention session participants were asked to complete the Post Intervention Questionnaire. Three months after the final intervention session participants were contacted and asked to fill in the 3-month follow up questionnaire and then received their bonus payment.

2.4. Data Processing

Processing of behavioural data in the VMAC task followed our standard procedures (Le Pelley et al., 2022; Watson et al., 2019a). We discarded trials with anticipatory (<150 ms) or too slow (>1300 ms) responses. Analysis of RTs used correct responses only. Sign-tracking behaviour was indexed by slowing of RT on trials with a high-reward distractor relative to trials with a low-reward distractor (VMAC scores).

3. Results

3.1. Reliability of baseline measures

Cronbach's alpha was calculated for the questionnaire measures. All scales showed good reliability in the current sample with AUDIT α = 0.83, OCDS α = 0.91 and BDI α = 0.91. Split-half reliability of the sign-tracking measure (VMAC scores: RT on high-reward minus low-reward trials) was r_{full} = 0.68 (Spearman-Brown prophecy formula adjusted), which closely approached the standard acceptable value of 0.7.

3.2. Baseline Assessment: Sign-tracking

Fifty-seven participants completed the VMAC task at baseline. This sample size gives power of 0.96 to detect a VMAC effect of size dz = 0.50, as observed in previous research with this task (Watson et al., 2019b). Consistent with this previous research, we observed that participants were indeed significantly slower in the presence of distractors signalling high reward relative to low reward, $t(56) = 3.49$, $p < .001$, $d_z = 0.463$. As pre-registered, simple correlational analyses were used to investigate the relationship between VMAC scores (index of sign tracking towards non-drug reward), AUDIT and OCDS. AUDIT and VMAC score were non-normally distributed (Shapiro–Wilk $p < .05$), so non-parametric Spearman's rank correlations were used. As expected, VMAC scores at baseline correlated significantly with both AUDIT scores, $r_s(55) = 0.321$, $p = .015$ (see Fig. 2), and OCDS scores $r_s(55) = 0.320$, $p = .015$. Control analyses confirmed that AUDIT was uniquely related to sign-tracking behaviour and not to overall RT or perceptual effects (see Supplemental Materials).

Exploratory regression analysis was used to examine whether baseline AUDIT predicted variance in baseline sign-tracking behaviour after controlling for demographic factors. Demographic data was missing for one participant who was excluded from the model. The model at Step 1 including age, years of education and gender was not significant, $F(3,52) = 2.454$, $p = .074$. After entry of the AUDIT and BDI scores at Step 2, the model was significant, $F(5, 50) = 2.624$, $p = .035$, explaining 21 % of the variance in the baseline VMAC score. In the final model, only age (B = -0.326, $p = .018$) and AUDIT score (B = 0.289, $p = .027$) were statistically significant predictors of sign-tracking.

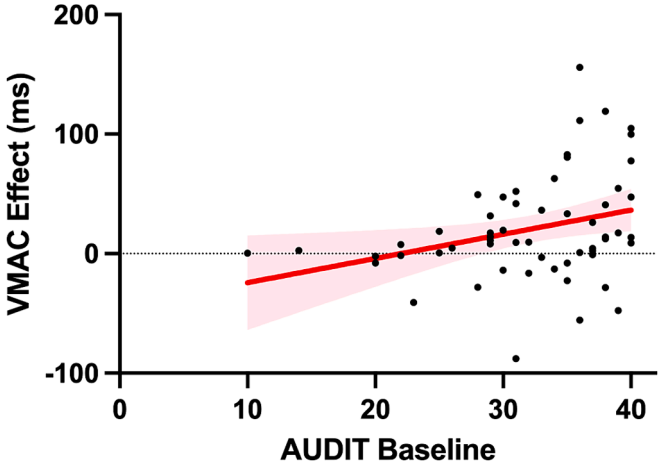

Fig. 2. Correlation between sign-tracking to monetary reward and problematic alcohol use. Larger VMAC scores at baseline (indicative of increased sign-tracking towards cues signalling high reward relative to low reward) were associated with increased AUDIT scores. Shaded area indicates 95% confidence interval.

3.3. Factors that predicted abstinence at 3-month follow up

Of the 50 participants who completed the 3-month follow-up survey, 41 (82 %) indicated an intention to remain abstinent from alcohol in the Post Intervention Questionnaire, five (10 %) were unsure, and four (8 %) did not record a response. As pre-registered, only those who indicated that they intended to remain abstinent were included in the analyses of data from the 3-month follow-up, and demographic and clinical information for these participants is shown in Supplemental Information. There were no significant differences in the demographic or clinical profiles of the sample included in the baseline compared to those who remained in the 3-month follow-up analysis. Specifically these groups did not differ on baseline AUDIT, $t(57) = 0.65$, $p = .517$; OCDS, $t(57) = 0.77$, $p = .443$; BDI, $t(56) = 1.39$, $p = .17$; age, $t(56) = 1.64$, $p = .106$; years of education, $t(56) = 0.93$, $p = .356$; VMAC score, $t(55) = 0.85$, $p = .40$ or gender distribution, $X^2 = 0.96$, $p = .615$.

Fifteen participants (37 %) reported return to alcohol use at 3-month follow up. As pre-registered, a multilevel binary logistic regression model was used with abstinence (1) versus return to use (0) as dependent variable. First level regressors included AUDIT score, sign-tracking (VMAC) at baseline, age, gender, years of education, intervention group and reported craving during the retraining sessions (as measured at the end of session 6). Participants were nested within treatment facility at the second level. As shown in Table 2, the strongest predictors of abstinence were being male ($p = .040$), having a smaller VMAC score (i.e., displaying less sign-tracking) at baseline ($p = .056$; marginally significant), and reporting lower craving in the post intervention questionnaire ($p = .033$), with the latter having an odds ratio of 0.95.

Given the observed correlation between VMAC and AUDIT scores (see section 3.2), we ran follow-up (non-preregistered) regressions removing each one of these two regressors from the model in turn. When VMAC scores were removed from the model, AUDIT scores remained non-predictive of the likelihood of abstinence ($p = .467$), similarly when AUDIT scores were removed the predictive value of the VMAC score was reduced ($p = .067$).

4. Discussion

In this pre-registered study, we used the value-modulated attentional capture (VMAC) task to assess whether sign-tracking behaviour towards non-drug reward would be related to severity of alcohol use disorder symptoms at baseline in an abstinent, treatment-seeking group of individuals. Results indicated that during the baseline assessment AUDIT and OCDS scores (both indexing severity of alcohol use problems) were correlated positively with sign-tracking behaviour towards monetary reward. Furthermore, reduced sign-tracking at baseline predicted abstinence at 3-month follow-up (albeit marginally significant, $p = .056$), along with being male and reporting in the post-intervention questionnaire that the alcohol images used during the intervention sessions evoked less craving.

Sign-tracking describes the tendency to approach and engage with cues that have acquired motivational salience by virtue of their association with rewarding outcomes. The fact that involuntary sign-tracking behaviour is observed across species (Colaizzi et al., 2020; Hearst & Jenkins, 1974; Pace et al., 1980) suggests that automatic orienting to signals of reward is (in general) an adaptive trait. Nonetheless it has been suggested that the tendency to ascribe incentive salience to cues that predict reward may become pathological and thus potentially important in understanding vulnerability to addiction (Colaizzi et al., 2020; Flagel et al., 2009). This study is the first to experimentally demonstrate the hypothesized relationship between sign-tracking towards non-drug reward and problematic alcohol use in a sample of individuals seeking treatment for alcohol and drug use. The results are in line with previous demonstrations in non-human animals and subclinical populations that sign-tracking for non-drug reward (e.g., towards cues signalling food or monetary outcomes) is related to

Table 2
Multilevel binary logistic regression predicting likelihood of abstinence at 3-month follow up.

	B	*SEM*	Wald	*df*	*p*	Odds ratio	95 % CI Lower	95 % CI Upper
Years of education	0.13	0.17	0.61	1	0.436	1.14	0.82	1.60
Baseline AUDIT	0.04	0.06	0.43	1	0.510	1.04	0.92	1.17
Baseline Age	−0.10	0.046	3.00	1	0.083	0.90	0.82	1.01
Gender (Male = 0)	−2.7	1.219	4.22	1	0.040	0.06	<0.01	0.88
Baseline VMAC effect RT	−0.03	0.01	3.66	1	0.056	0.98	0.94	1.00
Intervention group			0.47	2	0.791			
Group AB vs. control	0.77	0.99		1	0.518	1.89	0.27	13.08
Group RI vs. control)	0.55	1.17		1	0.638	1.73	0.18	17.15
Craving reported final Session	−0.05	0.03	4.53	1	0.033	0.95	0.90	0.10
Intercept	−0.11	0.54			0.823	0.88	0.31	2.53

Notes: AUDIT = Alcohol use disorders identification test, VMAC = Value -modulated attentional capture, AB = attentional bias, RI = response inhibition

compulsive drug and alcohol use (Albertella et al., 2017, 2019, 2021; Flagel et al., 2009).

Following the baseline assessment participants were assigned to receive a cognitive bias modification intervention, alongside treatment as usual. Unfortunately, due to COVID-19 lockdowns and restrictions, the study was not appropriately powered to compare the relative efficacy of the different interventions, relative to the active control. Nonetheless, we were able to carry out pre-registered regression analyses examining the unique factors that predicted abstinence vs. return to drug and/or alcohol use at 3-month follow up. Self-reported craving in response to alcohol images at the final intervention session was the strongest predictor of return to use. Craving has been previously identified as a reliable predictor of drug and alcohol relapse (Sliedrecht et al., 2019; Stohs et al., 2019). In the current study gender was also an important factor with males more likely to maintain abstinence at 3-month follow up. However, the relatively small number of females in the analysis (seven, 17 % of the sample) means that this effect should be interpreted with caution. Finally, sign-tracking at baseline had some predictive value with an increased tendency to be distracted by the cue signalling high versus low monetary reward increasing the likelihood of return to use at 3-month follow up. Although this effect was only marginally significant, this hypothesis was pre-registered and was not an exploratory finding. This effect warrants replication, but it clearly aligns with the predictions of the incentive sensitization model of addiction (Cofresi et al., 2019; Colaizzi et al., 2020; Robinson & Berridge, 1993, 2001).

Using other types of behavioural paradigms, Pavlovian stimuli that signal non-drug reward have been shown to have powerful effects on ongoing instrumental behaviour, exaggerated in treatment-seeking populations (Garbusow et al., 2016; Sommer et al., 2017, 2020). However, it is not clear from that literature (or the current study) whether increased sensitivity to Pavlovian reward cues precedes drug and alcohol use, or is a consequence of drug and alcohol use (or both). Carefully controlled animal studies have reported that sign-tracking towards cues signalling food, assessed before exposure to drugs of abuse, is linked to increased vulnerability for the later development of addiction-like behaviours (Flagel et al., 2009; B. T. Saunders & Robinson, 2010; Tomie et al., 2008). On the other hand, neuroadaptations in the brain following repeated drugs and alcohol use are well documented across species(Cofresi et al., 2019; Lüscher & Malenka, 2011; Self, 2004; Ungless et al., 2001) and increased sensitivity to Pavlovian cues signalling reward could be a consequence of these changes. Longitudinal studies across childhood and early adulthood are required to understand whether exaggerated sign-tracking behaviour, and sensitivity to Pavlovian cues more broadly, emerge in humans before exposure to drugs and alcohol.

Finally, this study had some limitations. Sign-tracking was operationalised as the VMAC score (RT difference on high-reward minus low-reward trials) but the adjusted split-half reliability of 0.68 was slightly below the value of 0.7 typically taken to be the acceptable threshold for research into individual differences (see also: Garre-Frutos et al., 2024). This is an issue common to many experimental paradigms and the resulting scores may best reveal characteristics of groups (e.g., abstainers vs. non-abstainers, as here) rather than more fine-grained individual differences (MacLeod et al., 2019). To assist with recruitment and increase ecological validity (Díaz-Batanero et al., 2018; Verdejo-García & Pérez-García, 2007) poly-drug use was not considered an exclusion criterion. Participants were referred for participation by clinicians in cases where alcohol was considered the primary drug of dependence. It is clear however that some participants did not consider themselves dependent on alcohol, and two participants had AUDIT scores at baseline that were below the cut-off of 15 sometimes cited as likely clinical dependence (Rubinsky et al., 2010). Note that the AUDIT score focuses primarily on alcohol harms in the last year, so it is possible to be concerned about the potential of relapse and seeking treatment for ongoing alcohol dependence, even if AUDIT scores are not particularly high. To reduce the burden of participation and ensure that the baseline assessment could be carried out during a one-hour timeslot, we collected only limited demographic and clinical information from participants (as pre-registered). The lack of information about (for example) the socio-economic status of participants, their religious and cultural identities and prior history of treatment seeking may therefore limit the generalisability of the study findings to other treatment settings.

To reduce likelihood of drop out, all follow-up data was self-reported via an online questionnaire. Although self-report measures are potentially vulnerable to false report, concordance between self-reported drug use and more objective biochemical measures is generally high in treatment-seeking populations (Clark et al., 2016). Finally, there was not sufficient power to be able to assess the impact of the different intervention groups on rates of abstinence vs. return to use. We refer interested readers to larger randomized controlled trials of cognitive bias modification that highlight the potential usefulness of this intervention when administered alongside treatment as usual (Manning et al., 2016, 2019, 2021; Rinck et al., 2018; Wiers et al., 2023). We also note that all data from the current study is freely available for future research purposes https://osf.io/4afme/.

In conclusion, this study demonstrates that involuntary sign-tracking to cues signalling non-drug reward is associated with problematic alcohol use and (potentially) return to use at 3-month follow up, in a treatment-seeking sample. Whether this automatic prioritisation of cues signalling reward is a consequence or vulnerability for problematic drug use is yet to be established.

Funding

This research was funded by National Drug and Alcohol Research Centre Grant awarded to PW (PS56909). PW is also supported by an Australian Research Council Discovery Early Career Researcher Award (DE200100591).

CRediT authorship contribution statement

Poppy Watson: Writing – original draft, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Katrina Prior:** Writing – review & editing, Funding acquisition, Conceptualization. **Nicole Ridley:** Writing – review & editing, Funding acquisition, Conceptualization. **Lauren Monds:** Writing – review & editing, Funding acquisition, Conceptualization. **Victoria Manning:** Writing – review & editing, Funding acquisition, Conceptualization. **Reinout W. Wiers:** Writing – review & editing, Funding acquisition. **Mike E. Le Pelley:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data and code is available at https://osf.io/4afme. The study was preregistered at https://osf.io/z5d6k.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.addbeh.2024.108010.

References

Albertella, L., Copeland, J., Pearson, D., Watson, P., Wiers, R. W., & Le Pelley, M. E. (2017). Selective attention moderates the relationship between attentional capture by signals of nondrug reward and illicit drug use. *Drug and Alcohol Dependence, 175*, 99–105. https://doi.org/10.1016/j.drugalcdep.2017.01.041

Albertella, L., Le Pelley, M. E., Chamberlain, S. R., Westbrook, F., Fontenelle, L. F., Segrave, R., Lee, R., Pearson, D., & Yücel, M. (2019). Reward-related attentional capture is associated with severity of addictive and obsessive–compulsive behaviors. *Psychology of Addictive Behaviors, 33*(5), 495–502. https://doi.org/10.1037/adb0000484

Albertella, L., Vd Hooven, J., Bovens, R., & Wiers, R. W. (2021). Reward-related attentional capture predicts non-abstinence during a one-month abstinence challenge. *Addictive Behaviors, 114*, Article 106745. https://doi.org/10.1016/j.addbeh.2020.106745

Anton, R. F., Moak, D. H., & Latham, P. K. (1996). The obsessive compulsive drinking scale: A new method of assessing outcome in alcoholism treatment studies. *Archives of General Psychiatry, 53*(3), 225–231. https://doi.org/10.1001/archpsyc.1996.01830030047008

Beck, A. T., Steer, R. A., Ball, R., & Ranieri, W. (1996). Comparison of Beck depression inventories -IA and -II in psychiatric outpatients. *Journal of Personality Assessment, 67*(3), 588–597. https://doi.org/10.1207/s15327752jpa6703_13

Beck, A. T., Steer, R. A., & Brown, G. K. (1996). *BDI-II: Beck depression inventory : Manual.* Psychological Corp: Harcourt Brace.

Charney, D. A., Zikos, E., & Gill, K. J. (2010). Early recovery from alcohol dependence: Factors that promote or impede abstinence. *Journal of Substance Abuse Treatment, 38*(1), 42–50. https://doi.org/10.1016/j.jsat.2009.06.002

Clark, C. B., Zyambo, C. M., Li, Y., & Cropsey, K. L. (2016). The impact of non-concordant self-report of substance use in clinical trials research. *Addictive Behaviors, 58*, 74–79. https://doi.org/10.1016/j.addbeh.2016.02.023

Cofresi, R. U., Bartholow, B. D., & Piasecki, T. M. (2019). Evidence for incentive salience sensitization as a pathway to alcohol use disorder. [review]. *Neuroscience & Biobehavioral Reviews, 107*, 897–926. https://doi.org/10.1016/j.neubiorev.2019.10.009

Colaizzi, J. M., Flagel, S. B., Joyner, M. A., Gearhardt, A. N., Stewart, J. L., & Paulus, M. P. (2020). Mapping sign-tracking and goal-tracking onto human behaviors. *Neuroscience & Biobehavioral Reviews, 111*, 84–94. https://doi.org/10.1016/j.neubiorev.2020.01.018

Díaz-Batanero, C., Domínguez-Salas, S., Moraleda, E., Fernández-Calderón, F., & Lozano, O. M. (2018). Attentional bias toward alcohol stimuli as a predictor of treatment retention in cocaine dependence and alcohol user patients. *Drug and Alcohol Dependence, 182*, 40–47. https://doi.org/10.1016/j.drugalcdep.2017.10.005

Flagel, S. B., Akil, H., & Robinson, T. E. (2009). Individual differences in the attribution of incentive salience to reward-related cues: Implications for addiction. *Neuropharmacology, 56*(Supplement 1), 139–148. https://doi.org/10.1016/j.neuropharm.2008.06.027

Garbusow, M., Schad, D. J., Sebold, M., Friedel, E., Bernhardt, N., Koch, S. P., Steinacher, B., Kathmann, N., Geurts, D. E. M., Sommer, C., Müller, D. K., Nebe, S., Paul, S., Wittchen, H.-U., Zimmermann, U. S., Walter, H., Smolka, M. N., Sterzer, P., Rapp, M. A., & Heinz, A. (2016). Pavlovian-to-instrumental transfer effects in the nucleus accumbens relate to relapse in alcohol dependence. *Addiction Biology, 21*(3), 719–731. https://doi.org/10.1111/adb.12243

Garre-Frutos, F., Vadillo, M. A., González, F., & Lupiáñez, J. (2024). On the reliability of value-modulated attentional capture: An online replication and multiverse analysis. *Behavior Research Methods*. https://doi.org/10.3758/s13428-023-02329-5

Hearst, E., & Jenkins, H. M. (1974). *Sign-tracking: The stimulus-reinforcer relation and directed action*. Psychonomic Society.

Houben, K., Nederkoorn, C., Wiers, R. W., & Jansen, A. (2011). Resisting temptation: Decreasing alcohol-related affect and drinking behavior by training response inhibition. *Drug and Alcohol Dependence, 116*(1–3), 132–136. https://doi.org/10.1016/j.drugalcdep.2010.12.011

Jaeggi, S. M., Buschkuehl, M., Perrig, W. J., & Meier, B. (2010). The concurrent validity of the N-back task as a working memory measure. *Memory (Hove, England), 18*(4), 394–412. https://doi.org/10.1080/09658211003702171

Killeen, P. R. (2003). Complex dynamic processes in sign tracking with an omission contingency (negative automaintenance). *Journal of Experimental Psychology: Animal Behavior Processes, 29*(1), 49–61. https://doi.org/10.1037/0097-7403.29.1.49

Le Pelley, M. E., Pearson, D., Griffiths, O., & Beesley, T. (2015). When goals conflict with values: Counterproductive attentional and oculomotor capture by reward-related stimuli. *Journal of Experimental Psychology. General, 144*(1), 158–171. https://doi.org/10.1037/xge0000037

Le Pelley, M. E., Ung, R., Mine, C., Most, S. B., Watson, P., Pearson, D., & Theeuwes, J. (2022). Reward learning and statistical learning independently influence attentional priority of salient distractors in visual search. *Attention, Perception & Psychophysics.*. https://doi.org/10.3758/s13414-021-02426-7

Lüscher, C., & Malenka, R. C. (2011). Drug-evoked synaptic plasticity in addiction: From Molecular changes to circuit remodeling. *Neuron, 69*(4), 650–663. https://doi.org/10.1016/j.neuron.2011.01.017

MacLeod, C., Grafton, B., & Notebaert, L. (2019). Anxiety-linked attentional bias: Is it reliable? *Annual Review of Clinical Psychology, 15*(1), 529–554. https://doi.org/10.1146/annurev-clinpsy-050718-095505

Manning, V., Garfield, J. B. B., Mroz, K., Campbell, S. C., Piercy, H., Staiger, P. K., Lum, J. A. G., Lubman, D. I., & Verdejo-Garcia, A. (2019). Feasibility and acceptability of approach bias modification during methamphetamine withdrawal and related methamphetamine use outcomes. *Journal of Substance Abuse Treatment, 106*, 12–18. https://doi.org/10.1016/j.jsat.2019.07.008

Manning, V., Garfield, J. B. B., Reynolds, J., Staiger, P. K., Piercy, H., Bonomo, Y., Lloyd-Jones, M., Jacka, D., Wiers, R. W., Verdejo-Garcia, A., & Lubman, D. I. (2022). Alcohol use in the year following approach bias modification during inpatient withdrawal: Secondary outcomes from a double-blind, multi-site randomized controlled trial. *Addiction, 117*(11), 2837–2846. https://doi.org/10.1111/add.15989

Manning, V., Garfield, J. B. B., Staiger, P. K., Lubman, D. I., Lum, J. A. G., Reynolds, J., … Verdejo-Garcia, A. (2021). Effect of cognitive bias modification on Early relapse among adults undergoing inpatient alcohol withdrawal treatment: A randomized clinical trial. *JAMA Psychiatry, 78*(2), 133–140. https://doi.org/10.1001/jamapsychiatry.2020.3446

Manning, V., Staiger, P. K., Hall, K., Garfield, J. B. B., Flaks, G., Leung, D., … Verdejo-Garcia, A. (2016). Cognitive bias modification training during inpatient alcohol detoxification reduces Early relapse: A randomized controlled trial. *Alcoholism: Clinical and Experimental Research, 40*(9), 2011–2019. https://doi.org/10.1111/acer.13163

Onie, S., Gong, S., Manwaring, E., Grageda, D., Webb, K., Yuen, W. S., & Most, S. B. (2020). Validation of the australian beverage picture set: A controlled picture set for cognitive bias measurement and modification paradigms. *Australian Journal of Psychology, 72*(2), 223–232. https://doi.org/10.1111/ajpy.12272

Pace, G. M., McCoy, D. F., & Nallan, G. B. (1980). Feature-positive and feature-negative Learning in the rhesus monkey and pigeon. *The American Journal of Psychology, 93*(3), 409–427. https://doi.org/10.2307/1422721

Pearson, D., Donkin, C., Tran, S. C., Most, S. B., & Le Pelley, M. E. (2015). Cognitive control and counterproductive oculomotor capture by reward-related stimuli. *Visual Cognition, 23*(1–2), 41–66. https://doi.org/10.1080/13506285.2014.994252

Rehm, J., & Shield, K. D. (2019). Global burden of disease and the impact of mental and addictive Disorders. *Current Psychiatry Reports, 21*(2), 1–7. https://doi.org/10.1007/s11920-019-0997-0

Reinert, D. F., & Allen, J. P. (2002). The alcohol use Disorders identification test (AUDIT): A review of recent research. *Alcoholism, Clinical and Experimental Research, 26*(2), 272–279.

Rinck, M., Wiers, R. W., Becker, E. S., & Lindenmeyer, J. (2018). Relapse prevention in abstinent alcoholics by cognitive bias modification: Clinical effects of combining approach bias modification and attention bias modification. *Journal of Consulting and Clinical Psychology, 86*(12), 1005–1016. https://doi.org/10.1037/ccp0000321

Roberts, J. S., Anton, R. F., Latham, P. K., & Moak, D. H. (1999). Factor structure and predictive validity of the obsessive compulsive drinking scale. *Alcoholism, Clinical and Experimental Research, 23*(9), 1484–1491.

Robinson, T. E., & Berridge, K. C. (1993). The neural basis of drug craving: An incentive-sensitization theory of addiction. *Brain Research. Brain Research Reviews, 18*(3), 247–291.

Robinson, T. E., & Berridge, K. C. (2000). The psychology and neurobiology of addiction: An incentive-sensitization view. *Addiction, 95*(Suppl 2), S91–S.

Robinson, T. E., & Berridge, K. C. (2001). Incentive-sensitization and addiction. *Addiction, 96*(1), 103–114. https://doi.org/10.1080/09652140020016996

Rubinsky, A. D., Kivlahan, D. R., Volk, R. J., Maynard, C., & Bradley, K. A. (2010). Estimating risk of alcohol dependence using alcohol screening scores. *Drug and Alcohol Dependence, 108*(1), 29–36. https://doi.org/10.1016/j.drugalcdep.2009.11.009

Saunders, B. T., & Robinson, T. E. (2010). A cocaine Cue acts as an incentive stimulus in some but not others: Implications for addiction. *Biological Psychiatry, 67*(8), 730–736. https://doi.org/10.1016/j.biopsych.2009.11.015

Saunders, B. T., & Robinson, T. E. (2011). Individual Variation in the motivational properties of cocaine. *Neuropsychopharmacology, 36*(8). https://doi.org/10.1038/npp.2011.48. Article 8.

Saunders, B. T., Yager, L. M., & Robinson, T. E. (2013). Cue-evoked cocaine "craving": Role of dopamine in the accumbens Core. *Journal of Neuroscience, 33*(35), 13989–14000. https://doi.org/10.1523/JNEUROSCI.0450-13.2013

Saunders, J. B., Aasland, O. G., Babor, T. F., Fuente, J. R. D. L., & Grant, M. (1993). Development of the alcohol use Disorders identification test (AUDIT): WHO collaborative project on Early detection of persons with Harmful alcohol consumption-II. *Addiction, 88*(6), 791–804. https://doi.org/10.1111/j.1360-0443.1993.tb02093.x

Self, D. W. (2004). Regulation of drug-taking and -seeking behaviors by neuroadaptations in the mesolimbic dopamine system. *Neuropharmacology, 47*, 242–255. https://doi.org/10.1016/j.neuropharm.2004.07.005

Sliedrecht, W., de Waart, R., Witkiewitz, K., & Roozen, H. G. (2019). Alcohol use disorder relapse factors: A systematic review. *Psychiatry Research, 278*, 97–115. https://doi.org/10.1016/j.psychres.2019.05.038

Sommer, C., Birkenstock, J., Garbusow, M., Obst, E., Schad, D. J., Bernhardt, N., … Zimmermann, U. S. (2020). Dysfunctional approach behavior triggered by alcohol-unrelated pavlovian cues predicts long-term relapse in alcohol dependence. *Addiction Biology, 25*(1), e12703.

Sommer, C., Garbusow, M., Jünger, E., Pooseh, S., Bernhardt, N., Birkenstock, J., … Zimmermann, U. S. (2017). Strong seduction: Impulsivity and the impact of contextual cues on instrumental behavior in alcohol dependence. *translational. Psychiatry, 7*(8), Article 8. https://doi.org/10.1038/tp.2017.158

Stohs, M. E., Schneekloth, T. D., Geske, J. R., Biernacka, J. M., & Karpyak, V. M. (2019). Alcohol craving predicts relapse after residential addiction treatment. *Alcohol and Alcoholism, 54*(2), 167–172. https://doi.org/10.1093/alcalc/agy093

Tomie, A., Grimes, K. L., & Pohorecky, L. A. (2008). Behavioral characteristics and neurobiological substrates shared by pavlovian sign-tracking and drug abuse. *Brain Research Reviews, 58*(1), 121–135. https://doi.org/10.1016/j.brainresrev.2007.12.003

Ungless, M. A., Whistler, J. L., Malenka, R. C., & Bonci, A. (2001). Single cocaine exposure in vivo induces long-term potentiation in dopamine neurons. *Nature, 411*(6837). https://doi.org/10.1038/35079077. Article 6837.

Verdejo-García, A., & Pérez-García, M. (2007). Ecological assessment of executive functions in substance dependent individuals. *Drug and Alcohol Dependence, 90*(1), 48–55. https://doi.org/10.1016/j.drugalcdep.2007.02.010

Watson, P., & Onie, S. (2023). Images of australian alcoholic and non-alcoholic beverages: A validation dataset. *Data in Brief, 47*, Article 108914. https://doi.org/10.1016/j.dib.2023.108914

Watson, P., Pearson, D., Most, S. B., Theeuwes, J., Wiers, R. W., & le Pelley, M. E. (2019). Attentional capture by pavlovian reward-signalling distractors in visual search persists when rewards are removed. *PLOS ONE, 14*(12), e0226284.

Watson, P., Pearson, D., Wiers, R. W., & Le Pelley, M. E. (2019). Prioritizing pleasure and pain: Attentional capture by reward-related and punishment-related stimuli. *Current Opinion in Behavioral Sciences, 26*, 107–113. https://doi.org/10.1016/j.cobeha.2018.12.002

Wiers, R. W., Pan, T., van Dessel, P., Rinck, M., & Lindenmeyer, J. (2023). Approach-bias retraining and other training interventions as add-on in the treatment of AUD patients. *Current Topics in Behavioral Neurosciences*. https://doi.org/10.1007/7854_2023_421