Smells like inhibition: The effects of olfactory and visual alcohol cues on inhibitory control

R. L. Monk\(^1\) \cdot J. Sunley\(^1\) \cdot A. W. Qureshi\(^1\) \cdot D. Heim\(^1\)

Abstract

**Rationale** How the smell of alcohol impacts alcohol-related thoughts and behaviours is unclear, though it is well-documented that alcohol-related stimuli and environments may trigger these.

**Objectives** The current study, therefore, aimed to investigate the priming effects of both visual and olfactory alcohol cues on inhibitory control.

**Method** Forty individuals (M age = 23.65, SD = 6.52) completed a go/no-go association task (GNAT) which measured reaction times, response accuracy and false alarm rates whilst being exposed to alcohol-related (or neutral) olfactory and visual cues.

**Results** Alcohol-related visual cues elicited lower false alarm rates, slower reaction times and higher accuracy rates relative to neutral pictorial cues. False alarm rates were significantly higher for those exposed to alcohol as opposed to neutral olfactory and visual cues.

**Conclusions** By highlighting that exposure to alcohol-related olfactory cues may impede response inhibition, the results indicate that exposure to such stimuli may contribute to the activation of cognitive responses which may drive consumption.
whilst heavy drinkers are actively engaged with the alcohol-related cues in their environment (when drinking). As such, light drinkers display higher levels of attentional bias towards alcohol-related words (passive cues) in comparison to heavy drinkers. Specifically, in contrast to light drinkers, heavy drinkers are actively involved in alcohol consumption, meaning they display high levels of alcohol-related attentional interference, regardless of how much time they spend in alcohol-related contexts. Further attentional interference in response to passive cue exposure is thus not evident (Albery et al. 2015). It is therefore apparent that alcohol-related attentional biases fluctuate and are shaped by exposure to the contextual cues that individuals encounter in everyday life. Context can therefore influence the degree of attentional bias individuals have towards alcohol.

Inhibition controls the strength of alcohol-related attentional biases (Field and Cox 2008) and is one of the processes believed to underlie the aetiology of addictive behaviours (Wiers et al. 2002). Inhibitory control relies on a limited resource (Inzlicht and Berkman 2015; Muraven and Baumeister 2000) which may be overwhelmed in the presence of motivational alcohol cues (although see Monti and Rohsenow 1999 for cue exposure therapy). Indeed, it has been suggested that higher levels of impulsiveness and lower inhibitory control are associated with stronger cue-elicited cravings for alcohol in clinical samples (Park et al. 2013). Changes in inhibitory control responses during exposure to alcohol-related pictorial cues have also been observed. Specifically, in a go/no-go task, participants appear to make more commission errors (false alarm rate; FAR) when no-go stimuli are super-imposed on alcohol-related images (Petit et al. 2012). Further, participants seem to respond faster when alcohol stimuli are ‘go’ stimuli (Kreusch et al. 2013).

However, whilst research has focused on the way in which alcohol-related visual, auditory and tactile cues shape alcohol-related thoughts and behaviours (Stein et al. 2000), there has been a distinct lack of exploration into possible effects of olfactory stimuli. Early research indicates that the smell of alcohol leads to an increase in self-reported desire to drink (Laberg 1990), whilst smelling an alcoholic drink appears to increase reported craving (Litt and Cooney 1999). Whilst a review by Schacht and colleagues (2013) notes the use of olfactory cues in studies of alcohol-related cue reactivity, the impact of olfaction on inhibitory processes remains unexplored. The current research therefore aims to examine this suggestion by introducing olfactory cues during the administration of the go/no-go task (GN; Nosek and Banaji 2001).

It was predicted that alcohol-related (as opposed to neutral) olfactory cues would make alcohol-related stimuli more salient, leading to difficulties in inhibiting responses and resulting in higher FARs for these no-go alcohol-related stimuli.

### Method

#### Participants

Forty participants (21 females, aged 19–48 years, M = 22.76, SD = 5.97, 19 males, aged 19–52 years, M = 24.63, SD = 7.11) were recruited via opportunity sampling and were randomly allocated to either alcohol (n = 20) or neutral olfactory cue conditions. Preliminary analyses suggested that there were no significant differences in the age (t (38) = .49, p = .63), gender (χ² (1, N = 40) = 0.09, p = .77) or AUDIT scores (t (38) = −0.33, p = .75) of those randomly allocated to the alcohol or control olfactory conditions. Demographics for the groups are shown in Table 1, as well as mean AUDIT scores. The latter are slightly above the cut-off for clinical assessment (scores of 8 or above being deemed to indicate hazardous or harmful alcohol use; Babor et al. 2001; Saunders et al. 1993). Participants are hence comparable with recent research using UK student samples (Clarke et al. 2015; Moss et al. 2015).

#### Design

A 2 (visual stimuli: alcohol and neutral) × 2 (olfactory cues: alcohol or neutral) mixed-groups design was used to examine the effect of olfactory and visual cues on FARs, reaction time on go trials (ms), and accuracy on the GNAT. All participants were exposed to both alcohol and neutral visual stimuli and random allocation was used to allocate participants to the olfactory cueing or control conditions.

#### Stimuli and materials

The Alcohol Use Disorder Identification Test (AUDIT—Saunders et al. 1993) is a 10-item questionnaire which explores the domains of alcohol consumption, drinking behaviour and alcohol-related problems. Responses to each question are scored from 0 to 4, with a maximum possible score of 40. AUDIT provides a simple method of early detection of hazardous and harmful alcohol use in primary health care settings and is derived from a cross-national study. Good internal consistency on this measure was demonstrated in the current sample (Cronbach’s α = 0.72).

| Table 1 | Mean and standard deviations for age and AUDIT values, N for gender, for olfactory cue conditions |
|---------|------------------------------------------|
| Alcohol smell | Neutral smell |
| Age | 24.56 (7.88) | 23.21 (6.99) |
| AUDIT* | 9.75 (7.40) | 10.50 (7.05) |
| Gender (N) | 9 M, 11 F | 10 M, 10 F |

*Alcohol cue group range 0–28, and neutral cue range 1–29. Boxplots reveal no outliers.
The go/no-go association task (GNAT) used in this research utilised two picture sets for the visual cues: one set contained neutral pictures (the letter K vs. the other 25 letters) and the other set with bar-related pictures (a beer bottle vs. 25 water bottle pictures). Pictures of the letter K and beer were the target stimuli (14% were no-go—36 no-go, 224 go stimuli used). All pictures were graphically equivalent in terms of colours, contrasts, objects shown and viewing angles. Branding was removed as appropriate and all pictures were presented on a white background using E-Prime 2.0 software.

A pre-treated olfactory mask was worn by all participants. This design was preferred to more traditional olfactory research designs in which participants inhale from a beaker, as it has been suggested that this earlier design may produce demand characteristics in responses (Litt and Cooney 1999). Participants in the current study were informed that external light, sound and smell have been previously demonstrated to adversely impact performance in the GNAT. The task instructions then went on to explain that it was for this reason that the current study had taken steps to control these factors, by using a mask, controlled lighting and sound-cancelling headphones which respondents were also required to wear. This was done with the intention of making the olfactory cues less overt so as to prevent demand characteristics. Post-test assessments suggested that although participants had noticed a slight smell from the mask, they had not inferred the true aim of the research nor interpreted smell as a variable of interest in the research. During debriefing, participants were also asked not to share the aims of the research with other potential study candidates.

Research indicates that an odour that is not from the same semantic category as alcohol, but is equally liked or disliked, will ensure a priming effect (Smeets and Dijksterhuis 2014). Furthermore, olfactory intensity has been shown to impact odour perception, specifically at higher concentrations (Smeets and Dijksterhuis 2014). It was therefore necessary to ensure that the filters inside the masks worn by participants contained subtle yet comparable scents. Pilot testing was, therefore, carried out using a number of varying alcohol-related and neutral smells (at varying doses) in order to uncover two scents (one from each category) which were equally liked and rated as having an equivalent intensity. A pipette was utilised in order pre-treat the masks with small amounts of vodka (5 ml of diluted Glenn’s vodka, 1:5 dilution, administered as the alcohol-related olfactory cue) or citrus oil (5 ml of diluted oil, 1:10 dilution, as the control condition).

**Procedure**

This research was approved by the appropriate ethics committee and the research was therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. All persons gave their informed consent prior to their inclusion in the study. This research introduced olfactory cues into the paradigm of Kreusch et al. (2013), who inserted alcohol-related visual into the GNAT. Following ethical approval, participants were recruited, briefed and seated in front of a computer. They were then asked to fit the inhalation mask.

Response inhibition towards alcohol cues was assessed by a GNAT programmed with E-Prime 2.0. In the GNAT, each trial began with a white fixation cross on a black background for 500 ms. Immediately, after the onset of the fixation cross, a stimulus was presented in the centre against the black screen for 500 ms Fig. 1.

Participants were required to inhibit their response to target stimuli (see materials; alcohol condition = bottle of beer; neutral condition = letter K), but to respond to all other stimuli. If participants responded incorrectly (i.e. they pressed the space bar when a target stimuli was presented in no-go trials), a feedback tone (250 ms) was presented. The experiment was organised into 16 blocks, eight with alcohol visual stimuli and eight with neutral (letter) stimuli. The order of blocks was randomised and trial order was pseudo-randomised (with no more than three of any given trial being permitted in a row and no blocks starting with a no-go trial). The distribution of the blocks and trials was also checked post hoc in order to ensure distribution equivalency between olfactory and neutral cue conditions. The study lasted approximately 30 min and included breaks between blocks to mitigate fatigue. The mask was removed at the end of testing. Following the GNAT task, participants were asked to provide basic demographic information and to complete the AUDIT, prior to receiving a full debrief. This was the final component of testing in order to limit the signal strength of the study (c.f. Davies and Best 1996).
Results

Missing trial data accounted for only 4% (1371/31201). A low pass filter (200 ms) was used, as stimuli were presented for 500 ms, with the experiment moving onto the next trial at that point. Following screening for normality, a 2 (visual stimuli: alcohol and neutral) × 2 (olfactory cues: alcohol or non-alcohol) mixed Factorial ANOVA was used to examine the effect of olfactory and visual stimuli on a go/no-go task. Three analyses were conducted: one with FAR as the dependent variable, one with reaction times on go trials (ms), and one with response accuracy on Go trials.1 Means and standard deviations of participants’ FAR, accuracy and reaction times across olfactory and visual cueing conditions are reported in Table 2. A main effect of olfactory cue was found \((F(1, 38)=5.42, p=0.03, \eta_p^2=0.13)\) such that the FAR was higher for those receiving the alcohol olfactory cue (M = 0.56, SD = 0.04) than for the control olfactory cue (M = 0.42, SD = 0.04). Furthermore, there was a main effect of pictorial target \((F(1, 38)=15.65, p \leq 0.01, \eta_p^2=0.29)\), such that the FAR was higher for the neutral (letters) pictorial targets in comparison with the alcohol pictorial targets. There was no significant interaction between olfactory cue and pictorial target \((F(1, 38)=0.29, p=0.60, \eta_p^2=0.01)\).

Reaction time on go trials

Whilst there was no main effect of olfactory cue on reaction time \((F(1, 38)=0.16, p>0.69, \eta_p^2=0.00)\), a significant main effect of pictorial target on reaction time was found \((F(1, 38)=4.77, p=0.04, \eta_p^2=0.11)\) such that reaction time was slower for the neutral pictorial target than for the alcohol pictorial target. There was no significant interaction between olfactory cue and the pictorial target \((F(1, 38)=0.93, p=0.34, \eta_p^2=0.02)\).

Accuracy on go trials

There was no main effect of olfactory cue on go accuracy rates \((F(1, 38)=0.76, p=0.39, \eta_p^2=0.02)\) with the accuracy slightly higher for the control olfactory cue than the alcohol olfactory cue. Yet there was a main effect of pictorial target on accuracy \((F(1, 38)=4.26, p=0.05, \eta_p^2=0.01)\), such that accuracy was significantly higher for the alcohol pictorial target than the neutral pictorial target. There was no significant interaction between olfactory cue and pictorial target \((F(1, 38)=0.71, p=0.41, \eta_p^2=0.02)\).

Discussion

The aim of the present research was to examine the extent to which olfactory cues impact response inhibition in a population of social-drinkers using GNAT. As hypothesised, FARs were significantly higher among respondents receiving the alcohol olfactory cue than those in the control condition. Nonetheless, that this effect was generalised across both alcohol and non-alcohol-related visual cues was not predicted. Early research indicates that the smell of alcohol leads to increases in self-reported desire to drink (Labe
ger1990) and craving (Litt and Cooney 1999). The current research contributes to this body of knowledge by suggesting that inhibitory control may also be affected by the smell of alcohol in a similar fashion. It may be hypothesised that this operates via the triggering of associated physiological and cognitive processes, in-line with theories of cue reactivity. These findings are also apparently in-line with the assertion that (non-olfactory) cues elicit a psychomotor-activating response (c.f. Wiers et al. 2002). This may lead to difficulties in inhibiting a dominant response (also see Roberts et al. 2014), thus leading to more errors than in those not exposed to such cues. In this way, the current findings support the findings of previous research that exposure to alcohol-related stimuli results in reduced accuracy in tasks requiring inhibitory control (Petit et al. 2012).

Separate analyses for alcohol and neutral visual stimuli were also run (Appendix 1). The pattern shown was the same as for combined analyses. D′ scores were also calculated2 (as per Macmillan and Creelman 1991). Combined analyses showed the same pattern of results as for FAR, as did separate analyses (Appendix 1). The separate analyses were conducted due to the different processes involved in letter recognition and selection of pictures (Carr et al. 1982).

Footnotes

1 FAR to no-go stimuli are commission errors to K or alcohol images—when participants are not meant to respond but do. The ‘hit rate’ to Go trials is equivalent to omission errors (proportion of stimuli responded to correctly).

2 Combined analyses: There was a main effect of olfactory cue \((F(1, 38)=4.66, p=0.04, \eta_p^2=0.11)\), insomuch that D′ for those receiving the alcohol cue was lower (M = 1.66, SD = 0.61) than those receiving the neutral cue (M = 2.00, SD = 0.62), indicating performance was significantly affected by the alcohol olfactory cue. There was also a main effect of pictorial target \((F(1, 38)=3.07, p=0.00, \eta_p^2=0.05)\), with D′ for alcohol stimuli higher (M = 2.06, SD = 0.67) than for neutral stimuli (M = 1.60, SD = 0.51), indicating performance on the neutral stimuli was significantly worse than for alcohol stimuli. There was no interaction between olfactory cue and pictorial target \((F(1, 38)=0.17, p=0.68, \eta_p^2=0.00)\).

Separate analyses: For the alcohol stimuli, there was a marginal main effect of olfactory cue \((F(1, 38)=3.48, p=0.07, \eta_p^2=0.08)\), insomuch that D′ for those receiving the alcohol cue was lower (M = 1.87, SD = 0.66) than those receiving the neutral cue (M = 2.25, SD = 0.63). For the neutral stimuli, there was also a marginal main effect of olfactory cue \((F(1, 38)=4.10, p=0.05, \eta_p^2=0.10)\), with D′ for those receiving the alcohol cue lower (M = 1.44, SD = 0.48) than those receiving the neutral cue (M = 1.75, SD = 0.50). Overall, this suggests that performance for both types of stimuli was affected by the alcohol olfactory cue.
However, it was not expected that alcohol-related olfactory cues would affect inhibition (manifest in increased FARs), irrespective of the type of visual cue. These findings may therefore demonstrate a pattern of generalised response impairment (i.e. inhibition impairment regardless of visual stimuli). This effect is in keeping with the wider literature that suggests that responses to unique stimuli (e.g. Baldi et al. 2004; Mühlberger et al. 2014) including olfactory cues (e.g. Daly et al. 2001), can become generalised to wider contexts and stimuli. In other words, there may be a carryover effect from responding to specific cues, meaning that responses translate to wider stimuli. Whilst not hitherto examined in this field, such findings may therefore suggest that alcohol-related olfactory cues may reduce inhibition to both alcohol-related and non-alcohol-related cues. The real-world drivers of processes such as attentional bias and inhibitory control require further examination. Even so, the current research contributes to the growing body of research that proffers the role of a myriad of complex contextual cues.

Nonetheless, it should be noted that there were no observed effects of olfactory cue on response time or accuracy on go trials. In the GNAT, response selection occurs in conjunction with response inhibition, as respondents must select whether to execute an appropriate response or to inhibit an inappropriate response (Suskaier et al. 2008). If one considers that response selection is needed to process which responses to make, then response inhibition is needed to withhold the response for ‘no-go’ target (see below for further discussion). If the olfactory cue impacted selection (rather than or more than response inhibition) then it would be expected that performance on the task using letters would be impaired over and above performance on the alcohol-related pictorial stimuli, as the former arguably places a greater demand on response selection. The current findings may therefore indicate that olfactory cues may have very specific effects on response inhibition (rather than selection). Such assertions are, nonetheless, speculative at this stage and further research is recommended to test this hypothesis.

Hypotheses regarding the effect of visual alcohol-related cues were not supported. Here, FAR and accuracy was higher, and reaction times slower, for the neutral stimuli in comparison with responses to alcohol-related pictures. Such findings do not align with previous indications of heightened response times and cue reactivity towards alcohol stimuli (Kreusch et al. 2013; Petit et al. 2012). Petit et al. (2012) also showed that participants found it harder to inhibit responses to alcohol-related stimuli, leading to reduced accuracy. These divergent results may be explained by a number of differences between the stimuli used in the current study compared to others. First, Kreusch et al. (2013) used pictures of neutral objects (e.g. a stapler) as the non-target stimuli, whereas the current study used letters, which are of a different semantic category and thus may evoke different responses and or processes in responding. Second, there were more non-target stimuli in the current study when compared to previous research. This may require a greater degree of response selection from participants, in addition to the response inhibition necessitated by this task. As response selection involves the selection of either the appropriate response or the choice to inhibit an inappropriate response (Simmonds et al. 2008), tasks requiring response selection as well as response inhibition may result in slower responses and greater chances of errors due to additional processing. Furthermore, as noted by Kreusch and colleagues (2013), the provision of alcohol-related questions prior to testing may have primed participants, whilst in this study this was avoided. Further research is required to test such assertions.

It should be noted that, in the current research, there was no inclusion of a non-odour condition. That the citrus scent could have had an independent effect over the alcohol olfactory cue can thus not be excluded (Smeets and Dijksterhuis 2014). Further research in this regard may therefore be recommended. It is also suggested that other scents should be tested in the future, in order to assess which types of alcohol elicit the greatest response (c.f. Schneider et al. 2001 on beer). The expansion of this research beyond a purely student-based sample is also recommended, given that University students are immersed in a social, pub-based drinking culture (Borsari and Carey 2001; Karam et al. 2007; Strauss and Bacon 1953). Context-related cueing may therefore be particularly likely (c.f. Rumelhart and Todd 1993). It is also advisable that future research test trait levels of impulsivity during testing, as baseline variability in impulsiveness between the alcohol and neutral olfactory conditions cannot presently be ruled out. Whilst the random allocation of participants to olfactory condition reduces this possibility, such potential does require acknowledgment.

Finally, it is recommended that further research is required before firmer claims can be made as the effect of alcohol-
related visual cues on inhibition. This is recommended in light of two potential limitations of the current research. First, reverse instruction blocks were not inserted into the current GNAT paradigm (i.e. where identical stimuli are assigned as both go targets or no-go distracters in randomly administered trials). Whilst recent research has shown little variation in results when reversed conditions are included within an alcohol-related GNAT (c.f. Pennington et al. in press), the exploration of reversed conditions response patterns would add further weight to the current findings. Specifically, a recent review has suggested that the valence of stimuli can affect the selection of appropriate or inappropriate actions, with possible implications for impulsivity and addiction (Guitart-Masip et al. 2014). Including a reversed condition, where responses are only made to target stimuli (alcohol-related or letter K) may therefore have allowed for deductions regarding whether the effects were primarily due to generalised response invigoration or inhibitory deficits. Second, there were inherent variations in task difficulty within the current tasks: In the first task, the participants must select an alcohol no-go target among non-alcohol visual distracters. In the second task, they must select a K-letter no-go target among other letter visual distracters (a potentially more difficult task). This means that further research is necessary in order to disentangle the effects of task difficult and stimuli type on response times, accuracy and reaction time. Nevertheless, the main finding, that olfactory cues affected such measures, irrespective of visual cues, is a novel and important research finding worthy of further consideration.

Overall, this research offers an original insight into the importance of acknowledging olfactory alcohol cues in developing a comprehensive understanding of alcohol-related behaviour. Context-related reductions in inhibitory control may lead to increases in consumption, or to relapse in abstinence users.

Compliance with ethical standards

Conflict of interest  The authors declare that they have no competing interests.

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