This item was submitted to [Loughborough's Research Repository](#) by the author.
Items in Figshare are protected by copyright, with all rights reserved, unless otherwise indicated.

Alcohol usage predicts holistic perception: A novel paradigm to explore addiction

PLEASE CITE THE PUBLISHED VERSION

<https://doi.org/10.1016/j.addbeh.2019.05.024>

PUBLISHER

Elsevier BV

VERSION

AM (Accepted Manuscript)

PUBLISHER STATEMENT

This paper was accepted for publication in the journal Addictive Behaviors and the definitive published version is available at <https://doi.org/10.1016/j.addbeh.2019.05.024>

LICENCE

CC BY-NC-ND 4.0

REPOSITORY RECORD

Burns, Edwin J., and Thom Wilcockson. 2019. "Alcohol Usage Predicts Holistic Perception: A Novel Paradigm to Explore Addiction". figshare. <https://hdl.handle.net/2134/37944>.

Alcohol usage predicts holistic perception: A novel method for exploring addiction

Edwin J. Burns^{a*} & Thomas D. W. Wilcockson^b

^aDepartment of Psychology, University of Richmond, Richmond, USA. eburns@richmond.edu

^bDepartment of Psychology, Loughborough University, Loughborough, UK.
t.wilcockson@lboro.ac.uk

Number of figures and tables: 5

Supplementary materials: See Supplementary Materials

Number of pages (without abstract, title page, figures or references): 24

Abstract Word Count: 201

Word Count (Excluding Title Page, Abstract and References): 3482

EB and TW contributed equally to this work and therefore share first authorship. We declare no competing interests.

*Correspondence:

Dr. Edwin Burns
Department of Psychology
209-B Richmond Hall
University of Richmond
USA 23173
Phone: +1 804 539 8577
Email: eburns@richmond.edu

Abstract

Holistic perception is a special form of automatic and experience dependent processing that prioritises objects of interest through the visual system. We therefore speculated that higher levels of alcohol consumption may be associated with enhanced holistic perception for alcohol cues. In our first experiment, we confirmed this hypothesis by showing that increasing regular alcohol usage was associated with greater holistic perception of alcohol, but not non-alcohol, cues. We replicated this finding in a second experiment, but confirmed drink-specific holistic perception for lager cues was not predicted by experience with that drink, but general alcohol usage. In our final experiment when alcohol images were absent from the task, higher levels of alcohol consumption predicted decreased holistic perception for non-rewarding cues. Alcohol use is therefore linked to inverse alterations in holistic perception for alcohol versus non-alcohol cues, with the latter's effects context dependent. We hypothesise that such inverse relationships may be due to limited cortical resources becoming reutilised for alcohol cues at the expense of other stimuli. Future work will be required to determine holistic perception's role in maintaining addiction, its predictive value in successful abstinence, and its relationship with characteristics of addiction such as cue reactivity, attentional biases and personality traits.

Keywords: Addiction, holistic processing, featural processing, neuronal recycling, substance abuse, inversion effect

1. Introduction

A major question is whether addiction facilitates processing of substances of abuse to the detriment of other items (Robinson & Berridge, 1993). Parallel object recognition work has shown that people with strong interests in certain objects, such as cars or birds, exhibit a special form of processing called holistic perception for such items (Bukach, Phillips, & Gauthier, 2010; Campbell & Tanaka, 2018; Diamond & Carey, 1986; Ross et al., 2018). It is called holistic as it is believed to arise via the brain perceiving the item as a unitary whole, and is thought to be automatic (Richler, Wong, & Gauthier, 2011), based on experience (Bukach, Cottle, Ubiwa, & Miller, 2012; Wong et al., 2011), and prioritises such important stimuli through the human visual system to the detriment of other objects (Langton, Law, Burton, & Schweinberger, 2008). By contrast, featural processing of individual object parts occurs for items that we have little special interest in, with this form of processing piecemeal, and effortful (Carey & Diamond, 1977; Wang, 2018). One way in which holistic perception can be measured is by employing an inversion paradigm (Robbins & McKone, 2007; Yin, 1969). In this type of study, participants recognise items either in an upright or inverted configuration. The difference in performance, measured either through accuracy or response times, is an index of holistic processing (Valentine, 1988). This is because inversion is thought to disrupt experience-based holistic perception, and makes participants rely more heavily upon featural processing (Valentine, 1988).

While the holistic perception literature has never previously overlapped with addiction, it seems intuitive to think that if this form of processing is present in individuals who exhibit intense interests in certain objects (cf. Klinger & Cox, 2004), then it may be similarly apparent for those

who are addicted to rewarding substances¹; i.e., do heavier drinkers employ increased holistic perception for alcohol cues? If they do, then it would suggest that alcohol usage is not impairing visual processing *per se*, but instead making the human visual system become increasingly adept at employing this special form of processing to facilitate the perception of such important objects. Such a finding would be important as based upon prior work holistic perception is largely thought to be processed via the fusiform gyrus (Ross et al., 2018; Ventura et al., 2013). By contrast, attentional biases (Field & Cox, 2008; Townshend & Duka, 2001), in which addiction related cues capture attention to the detriment of other objects, and cue reactivity (Carter & Tiffany, 1999), where viewing addiction-related cues induces cravings, seem linked to subcortical and anterior cortical regions (Goldstein & Volkow, 2011; Kühn & Gallinat, 2011). As it is thought that visual signals may traverse the fusiform gyrus prior to these areas (Pessoa & Adolphs, 2010), and that lesions to the fusiform gyrus are associated with impaired aesthetic appeal, and motivations towards, items processed in an holistic fashion (Iaria, Fox, Waite, Aharon, & Barton, 2008), then treatments targeting this area may be more successful than those focusing on more anterior regions downstream (Amiaz, Levy, Vainiger, Grunhaus, & Zangen, 2009; Li et al., 2013; Shen et al., 2016; Terraneo et al., 2016). First, though, a relationship between holistic perception relationship and rewarding cues needs to be confirmed. We therefore performed three experiments to test this hypothesis.

¹ Please note, we are not claiming that addiction can be reduced to an intense interest for addictive cues, but instead reflect that there seem to be parallels in how individuals with intense interests in objects and those with addictions are driven to pursue their respective items in a way that is distinct from people without such interests (see Klinger & Cox, 2004).

97

98 **2. Experiment 1 Methods**

99 *2.1. Participants*

100 As no related prior work existed to determine an appropriate *a priori* sample size, we
 101 simply attempted to test as many participants as possible subject to time and monetary
 102 constraints. Experiment 1 should therefore be considered to some extent exploratory. Thirty-nine
 103 participants (19 males) took part in this experiment (mean age: 25.92 years, range 18-57 years
 104 old). All participants had normal or corrected-to-normal vision, provided informed consent and
 105 were compensated financially for their time. All studies reported in this paper were approved by
 106 the Lancaster University ethics committee.

107 *2.2. Stimuli and Procedure*

108 Participants reported how many units² of alcoholic beverages they consumed each week
 109 via a questionnaire and also completed the Alcohol Use Disorders Identification Test (AUDIT)
 110 (Saunders, Aasland, Babor, De la Fuente, & Grant, 1993). Stimuli were taken from prior work
 111 examining visual perception in alcohol users (Wilcockson & Pothos, 2015), with examples
 112 presented in Figure 1. The alcohol stimuli depicted a variety of alcoholic drinks that are common
 113 in the UK, where the participants were tested. By contrast, the office-related equipment
 114 comprised images from a common thematic category that participants would all find familiar, but
 115 not rewarding. There were 30 items in each stimulus category.

116 Each trial began with a blank screen for 1000 ms on a monitor. Participants were then
 117 presented with one of the stimulus images in either an upright or inverted configuration for 1000

² One unit of alcohol is half a pint (284ml) of beer, one measure (25ml) of vodka, or half a glass (90ml) of wine.

118 ms. Participants had to categorise each stimulus as either alcohol or office-related, as quickly and
 119 accurately as possible using the appropriate response buttons, thus ending the trial and starting
 120 the next one. If a participant did not respond during this 1000 ms screen, then the trial was
 121 marked as an error. All images were presented in a random order with 240 trials in total, and
 122 equal numbers of upright/inverted. All office stimuli were presented three times whereas the
 123 alcohol items were presented only once. As we employed a very simple 2-alternative forced
 124 choice paradigm, we expected accuracy rates would be close to ceiling. We therefore anticipated
 125 that regular alcohol consumption levels would be more likely to predict the response time, rather

Experiment 1

Experiment 2

Control

Alcoholic

126
 127 **Fig 1** Examples of the control and alcoholic stimuli used in Experiments 1 (top two rows) and 2
 128 (bottom row). All images were presented to participants in either an upright (shown here) or
 129 inverted configuration. While a small proportion of images from Experiment 1 contained faces,

we ensured that there were no such confounds present in Experiment 2 when we aimed to replicate Experiment 1's findings. than the accuracy, inversion effect. To this end, we report the results for the correct response times in the present manuscript, and place our other findings in our supplementary information (see Supplementary Materials).

3. Experiment 1 Results

3.1. Response Times

We predicted that heavy alcohol users might exhibit larger inversion effects than non and light drinkers. To test this, we first used a formula that standardised the inversion effect relative to a participant's own RTs: $[(\text{inverted alcohol stimuli RTs} - \text{upright alcohol stimuli RTs}) / \text{upright alcohol stimuli RTs}]$ (Russell, Duchaine, & Nakayama, 2009). Using this formula, increasingly positive values represent larger inversion effects, whereas negative values reflect superior performance for inverted items. These values were plotted against weekly units of alcohol consumption (Figure 2) and found that the response time inversion effect was significantly correlated with alcohol usage ($r = .35, p = .031, CI = [.03, .66]$): as alcohol usage increases, so too does holistic perception become utilised for alcohol stimuli. The same relationship was, however, not observed between the AUDIT and the response time alcoholic inversion effect ($r = .18, p = .29$). Similarly, the response time inversion effect for the non-alcohol stimuli was not significantly associated with alcohol usage ($r = -.04, p = .8$) or the AUDIT ($r = .11, p = .52$).

A seminal study identified differences between heavy drinkers (i.e., 25 units per week or more) and light drinkers (less than 25 units per week) in how they attended to alcohol stimuli (Townshend & Duka, 2001). We anticipated that our heavier drinkers may therefore have a larger inversion effect than light drinkers. When we split our participants into heavy and light

154

155 **Fig 2** Experiment 1 relationships between the response time (RT) inversion effect and alcohol
 156 consumption. a) The response time inversion effect for the alcohol stimuli plotted against weekly
 157 alcohol consumption (units), b) the relationship between the control stimuli and weekly units.
 158 Only the relationship between the alcohol inversion effect and consumption was significant (top
 159 panel, $n = 39$, $r = .35$, $p = .031$, $CI = [.03, .66]$).

drinkers based upon prior work's guidelines (Townshend & Duka, 2001), we found no significant difference between heavy ($n = XX$, $M = .029$, $CI = .022$) and light ($n = XX$, $M = .001$, $CI = .016$; $t(37)=1.9$, $p = .063$; $d = .77$) users, although this test would have been significant one-tailed based upon our predictions ($p = .032$). There were no differences in the inversion effect for the non-alcohol stimuli (Heavy $M = -.006$, Light $M = -.007$; $t(37)=.1$, $p = .92$, $d = .04$).

4. Experiment 1 Discussion

Using the inversion effect as a measure of holistic perception (Valentine, 1988), increases in alcohol consumption were linked to stronger processing of alcohol cues in a holistic fashion. Moreover, an accuracy-related inversion effect for alcohol-related stimuli was observed at the group level too (Supplementary Materials). The lack of similar effects for the non-rewarding control stimuli shows that holistic perception is present for rewarding items only. In summary, holistic perception is linked to an object's presumed reward salience as indexed by our participants' consumption levels (Robinson & Berridge, 1993).

As our first experiment was to some extent exploratory, we aimed to replicate it with an *a priori* determined sample size. Also, as some of Experiment 1's images included facial information, we wanted to remove any possibility that this was affecting our results (Groefsema, Engels, & Luijten, 2016). Finally, we needed to isolate what was driving the relationship between consumption and holistic perception. In Experiment 1, participants reported their alcohol units with respect to all forms of alcohol, and the alcohol images used were very diverse. We therefore only used lager cues in Experiment 2 and asked our participants to report their general alcohol consumption levels plus their specific lager usage. If lager usage predicts the

lager inversion effect, then it would suggest that drinking experience with a specific drink is essential in engaging holistic perception. By contrast, if general, rather than lager-specific, alcohol consumption were to be correlated with the lager inversion effect, then it would imply that drinking any form of alcohol leads to broad changes in holistic perception for any identifiable alcohol images. Such a result would suggest that experience with specific categories of alcohol is not important for developing holistic processing for such items. Instead, this prioritised form of perception must arguably occur for the general category of alcohol that you find motivationally salient; e.g., the more you drink, the more likely you are to process any alcohol via holistic perception irrespective of specific drink experience.

5. Experiment 2 Methods

5.1. Participants

Sixty-three participants (15 males) took part in this experiment (mean age: 19.86 years, range 18-38 years old). It should be noted that while we aimed for 62 participants, we had an extra subject register for participation before we could close the sign-up system, so tested them anyway. All participants had normal or corrected-to-normal vision, provided consent and were compensated financially for their time or given course credit.

5.2. Stimuli and Procedure

The paradigm was broadly similar to Experiment 1, except that participants also reported their usage of lager in units (which were correlated with alcohol consumption, $r = .51, p < .001$; and the AUDIT, $r = .45, p < .001$). Also, we replaced the alcohol stimuli with two images of

lager (Figure 1) and four control stimuli which were matched roughly for size and colour, but are arguably not considered to have much reward value (chairs, Figure 1).

Each trial began with a 1000 ms fixation cross on a monitor. Participants were then presented with one of the stimulus images in either an upright or inverted configuration until they responded. Participants had to categorise each stimulus as alcohol or chairs as quickly and accurately as possible using the appropriate response buttons. The participant's response would end the trial and start the next one. All images were presented in a random order, with alcohol images presented 14 times in total and the chairs 28 times. Participants had a practice block beforehand to familiarise themselves with the response buttons.

6. Experiment 2 Results

6.1. Response Times

Reassuringly, we replicated our first experiment's findings: our normalised lager response time inversion effect was positively associated with alcohol (Figure 2, $r = .35$, $p = .004$, $CI = [.1, .58]$), but not lager ($r = .07$, $p = .61$), consumption. In contrast to Experiment 1, however, we also found the AUDIT to be significantly correlated with the response time lager inversion effect too (Figure 2, $r = .31$, $p = .015$, $CI = [.03, .52]$). Combining the data from Experiments 1 and 2 further maintained the relationships between alcohol usage and the inversion effect ($r = .35$, $p < .001$, $CI = [.16, .53]$) plus the AUDIT and the inversion effect ($r = .24$, $p = .015$, $CI = [.05, .43]$). This shows that increasing alcohol usage across our two measures is related to higher levels of holistic perception for alcohol images. By contrast, the chair-related inversion effect was not significantly associated with general alcohol usage ($r = .24$, $p = .06$) or the AUDIT ($r = .15$, $p = .24$).

Fig 3. Experiment 2 relationships between the inversion effect and alcohol usage. The top panel illustrates the response time inversion effect for the lager stimuli plotted against weekly alcohol consumption (Units, $n = 63$, $r = .35$, $p = .004$, $CI = [.1, .58]$). The bottom panel shows the relationship between lager stimuli and the Alcohol Use Disorders Identification Test (AUDIT, $n = 63$, $r = .31$, $p = .015$, $CI = [.03, .52]$). Both relationships were still significant when the outlier at the top of each panel was removed (Units, $p = .035$ one-tailed due to our expectations from Experiment 1, $[-.03, .53]$; AUDIT two-tailed, $p = .026$, $CI = [-.01, .58]$).

Surprisingly, lager consumption exhibited a positive association with the chair response time inversion effect ($r = .4, p = .001, CI = [.16, .63]$). However, when we plotted this association it became apparent that the relationship was entirely driven by two outliers that consumed over 50 units of lager a week. Post-hoc removal of these outliers abolished this relationship ($r = 0, p = .98$), plus the non-significant trend that was previously apparent between the chair inversion effect and general alcohol consumption ($r = .09, p = .48$). Future researchers may therefore want to employ similar exclusion criteria *a priori*. By contrast, removing these outliers did not change the significant relationships between the lager inversion effect and our two alcohol usage measures (general consumption, $r = .34, p = .008$; AUDIT, $r = .29, p = .024$). Finally, we found that the heavy drinkers' lager inversion effect (Figure 4, $M = .12, CI = .14$) was significantly larger than the light drinkers ($M = -.02, CI = .03, t(61)=2.96, p = .004, d = .72$). By contrast, there were no differences in the chair inversion effect (Heavy $M = .05$, Light $M = -.008; t(61)=1.53, p = .13, d = .35$), thus replicating Experiment 1.

7. Experiment 2 Discussion

In Experiment 2 we confirmed that holistic perception for lager images was associated with general alcohol consumption and the AUDIT. By contrast, lager usage in itself was not related to the inversion effect for lager images. This suggests that the deployment of holistic perception for alcohol stimuli is not experience-specific to whichever drink we consume, but seems to occur in a more general fashion for stimuli that we can identify as alcohol. However, while we did not find any relationship between alcohol consumption and the control stimuli in Experiments 1 and 2, we were presenting such stimuli more frequently than the alcohol images. The possibility therefore remains that increasing alcohol consumption simply alters holistic

Fig 4 Experiment 2 inversion effects for light (<25 units a week) versus heavy drinkers (≥25 units a week). The heavier drinkers exhibited a significantly larger inversion effect than the light drinkers (LD $n = 51$, HD $n = 12$, $t(61)=2.96$, $p = .004$, $d = .72$). Error bars indicate 95% confidence intervals.

perception for any stimulus that is presented less frequently than the more prevalent control stimulus.

To confirm that this was not the case, we reran Experiment 2 on a new batch of participants, but this time replaced the lager stimuli with yellow lamps. If we were to find the same relationship between lamps and alcohol consumption as we previously identified with alcohol stimuli, then it would suggest alcohol consumption alters holistic perception for all stimuli, not just those that are related to alcohol. By contrast, if we were to find no relationship,

then it would show alcohol consumption leads to alcohol cue specific holistic processing. Finally, we may find that increasing alcohol consumption leads to inversion effects in the opposite direction to those observed for alcohol stimuli; i.e., increasing alcohol consumption may lead to a reduction in inversion effects, whereby the heaviest drinkers find inverted stimuli no more readily identifiable in contrast to upright stimuli. Such a result would be important as it would suggest alcohol consumption likely leads to inverse alterations in holistic perception for motivationally salient (i.e., alcohol), versus non-salient (i.e., lamps), stimuli. This would confirm that reward value does not just impact upon holistic processing for items that are deemed important, but also alters holistic perception in an abnormal fashion for stimulus categories that do not have similar reward values attributed to them.

8. Experiment 3 Methods

Based upon our *a priori* sample size analysis, sixty-two participants (21 males), ranging from 18-59 years old (mean age: 23.55 years) took part in this experiment. The design of the study was identical to Experiment 2 except we replaced the larger images with pictures of lamps.

9. Experiment 3 Results

9.1. Response Times

Surprisingly, our lamp-related response time inversion effect was negatively associated with alcohol consumption (Figure 5, $r = -.27$, $p = .033$, $CI = [-.02, -.52]$); this relationship was therefore in the opposite direction to that found for the alcohol stimuli in Experiments 1 and 2. This suggests that heavier levels of drinking are associated with a disengagement of holistic

286

287 **Fig 5** Relationships between non-rewarding objects' inversion effects and alcohol usage. The
 288 response time inversion effect for the a) lamp and b) chair stimuli plotted against weekly alcohol
 289 consumption (Units). The relationship between units consumed and the lamp ($n = 62$, $r = -.27$, p
 290 $= .033$, $CI = [-.02, -.52]$), but not chair ($n = 62$, $r = -.22$, $p = .083$, $CI = [.03, -.47]$), stimuli was
 291 significant. Although the chairs and lamps analysed together against consumption was significant
 292 ($r = -.25$, $p = .006$, $CI = [-.07, -.42]$).

perception for non-rewarding items. Using a Fisher's r -to- z transform, we confirmed the alcohol correlation coefficients from Experiments 1 ($z = 3.04, p = .002$) and 2 ($z = 3.44, p < .001$) were both significantly different from the lamp correlation in Experiment 3; while we did not control for luminance in the stimuli, these qualitative differences would suggest such low level visual artefacts are not causing these results. There was also a non-significant trend for alcohol consumption to be negatively correlated with the chair inversion effect too ($r = -.22, p = .083, CI = [.03, -.47]$), however, incorporating the inversion effects for the chairs and lamps together produced a significant association with alcohol use ($r = -.25, p = .006, CI = [-.07, -.42]$). In contrast to Experiment 2, however, there were no differences between the heavy and the light drinkers (all $ps > .16$).

10. Discussion

Prior work has suggested that individuals who develop intense interests for certain objects process them via holistic perception (Bukach et al., 2010; Campbell & Tanaka, 2018; Diamond & Carey, 1986; Ross et al., 2018). This paper considered whether this form of processing may also be apparent for substances of abuse. The first two experiments confirmed that alcohol usage, as measured by both consumption levels and the AUDIT, did indeed predict holistic perception for alcohol-related stimuli. Moreover, in the final experiment, it was found that heavier drinking was predictive of reduced holistic perception for non-rewarding items. However, this latter effect was context dependent in that these changes were only apparent when alcohol cues were not in the same environment (i.e., task). In summary, increased alcohol usage leads to an inverse deployment of holistic perception for rewarding alcohol versus non-alcohol cues.

While theories of object perception have no direct predictions for how the fusiform gyrus specialises for addiction-related cues (Bukach, Gauthier, & Tarr, 2006; Kanwisher & Yovel, 2006; Malach, Levy, & Hasson, 2002; Tarr & Gauthier, 2000), we note one in particular that seems to complement our data and prior neuroimaging work in addiction. The neuronal recycling hypothesis posits that the visual cortex, including the fusiform gyrus, is comprised of limited resources that can become specialised for items of important cultural influence (Dehaene, 2005; Dehaene & Cohen, 2007; Dehaene et al., 2010). In this perspective, acquiring new cultural knowledge has a negative impact upon the holistic perception of previously developed objects (Ventura et al., 2013). This hypothesis could be applied to our results here, and more broadly addiction.

For example, increasing reinforcement with a rewarding substance, such as alcohol, would surely mean that visual areas start to become more specialised to process such important items via holistic perception. However, as there are only limited cognitive resources available, holistic perception for non-rewarding stimuli is found to decline in heavier drinkers. These adaptations in the visual cortex startlingly mirror the increased interest for rewarding stimuli in addiction, even to the detriment of family, work and other responsibilities (Robinson & Berridge, 1993). Support for this hypothesis comes from neuroimaging studies that have shown addiction-related cues eliciting enhanced responsiveness throughout the visual regions associated with holistic perception (Adamson & Troiani, 2018; Kilts, Schweitzer, Quinn, & et al., 2001; Park et al., 2007; Wrase et al., 2002; Xiao et al., 2006; Zubieta et al., 2005). Moreover, there are reduced activations in the same areas for other non-addiction-related stimuli (Charlet et al., 2014; Salloum et al., 2007), which suggests that the importance of these latter items declines as

addictive cues take over. Despite this, direct experimental manipulations of holistic perception in addiction combined with neuroimaging techniques will be required.

It is notable that general levels of alcohol consumption, rather than drink specific experience (e.g., lager), are related to holistic perception for alcohol cues, even when those cues are only for a single drink such as lager. While we believe that alcohol consumption levels will not directly predict holistic perception for other reward-related stimuli, the current study is unable to rule this suggestion entirely out. For example, alcohol abuse is related to problematic behaviours for other addictive items (e.g. Benjamin & Wulfert, 2005; Holderness, Brooks-Gunn, & Warren, 1994; Loxton & Dawe, 2001), thereby suggesting that consumption levels of alcohol may to an extent index an underlying susceptibility for reward-related cues. Similarly, certain personality traits common in addiction, such as impulsiveness (Mitchell, Fields, D'Esposito, & Boettiger, 2005) or alexithymia (Thorberg, Young, Sullivan, & Lyvers, 2009), may contribute to these processing effects. Future work will be required to confirm whether or not this is the case.

In addition to engaging holistic perception, heavy usage of abusive substances is associated with attentional biases to such cues (Chanon, Sours, & Boettiger, 2010; Duka & Townshend, 2004; Field & Cox, 2008; Field, Mogg, Zetteler, & Bradley, 2004; Field, Munafò, & Franken, 2009; Lochbuehler, Voogd, Scholte, & Engels, 2011; S. J. Robbins & Ehrman, 2004; Townshend & Duka, 2001; Waters, Marhe, & Franken, 2012; Wilcockson & Pothos, 2015). Other stimuli that are processed holistically also seem to elicit attentional biases (Bindemann, Burton, Hooge, Jenkins, & De Haan, 2005; Langton et al., 2008; Palermo & Rhodes, 2007). It may therefore be tempting to assume that attentional biases and holistic perception are indexing the same cognitive processes, however, holistic perception can still occur to some extent even in

the absence of attention (Boutet, Gentes-Hawn, & Chaudhuri, 2002), suggesting that these processes may be partially distinct. As the present paper is the first to identify holistic perception in addictive cues, there is currently a knowledge gap in how it may be related to attentional biases and cue reactivity. The same knowledge gaps are also present with respect to other forms of rewarding stimuli. Despite this, we anticipate that holistic perception and the neuronal recycling hypothesis will help provide a novel framework within which to explore addiction so that it can be understood in a more nuanced and comprehensive way than was previously possible.

11. References

- Adamson, K., & Troiani, V. (2018). Distinct and overlapping fusiform activation to faces and food. *NeuroImage*, 174, 393-406.
- Amiaz, R., Levy, D., Vainiger, D., Grunhaus, L., & Zangen, A. (2009). Repeated high-frequency transcranial magnetic stimulation over the dorsolateral prefrontal cortex reduces cigarette craving and consumption. *Addiction*, 104(4), 653-660.
- Benjamin, L., & Wulfert, E. (2005). Dispositional correlates of addictive behaviors in college women: Binge eating and heavy drinking. *Eating Behaviors*, 6(3), 197-209.
- Bindemann, M., Burton, A. M., Hooze, I. T., Jenkins, R., & De Haan, E. H. (2005). Faces retain attention. *Psychonomic Bulletin & Review*, 12(6), 1048-1053.
- Boutet, I., Gentes-Hawn, A., & Chaudhuri, A. (2002). The influence of attention on holistic face encoding. *Cognition*, 84(3), 321-341.
- Bukach, C. M., Cottle, J., Ubiwa, J., & Miller, J. (2012). Individuation experience predicts other-race effects in holistic processing for both Caucasian and Black participants. *Cognition*, 123(2), 319-324.
- Bukach, C. M., Gauthier, I., & Tarr, M. J. (2006). Beyond faces and modularity: the power of an expertise framework. *Trends in cognitive sciences*, 10(4), 159-166.
- Bukach, C. M., Phillips, W. S., & Gauthier, I. (2010). Limits of generalization between categories and implications for theories of category specificity. *Attention, Perception, & Psychophysics*, 72(7), 1865-1874.
- Campbell, A., & Tanaka, J. W. (2018). Inversion impairs expert budgerigar identity recognition: a face-like effect for a nonface object of expertise. *Perception*, 47(6), 647-659.
- Carey, S., & Diamond, R. (1977). *From Piecemeal to Configurational Representation of Faces* (Vol. 195).
- Carter, B. L., & Tiffany, S. T. (1999). Meta-analysis of cue-reactivity in addiction research. *Addiction*, 94(3), 327-340.
- Chanon, V. W., Sours, C. R., & Boettiger, C. A. (2010). Attentional bias toward cigarette cues in active smokers. *Psychopharmacology*, 212(3), 309-320.
- Charlet, K., Schlagenhauf, F., Richter, A., Naundorf, K., Dornhof, L., Weinfurter, C. E., . . . Müller, C. A. (2014). Neural activation during processing of aversive faces predicts treatment outcome in alcoholism. *Addiction biology*, 19(3), 439-451.
- Dehaene, S. (2005). Evolution of human cortical circuits for reading and arithmetic: The “neuronal recycling” hypothesis. *From monkey brain to human brain*, ed. S. Dehaene, J.-R. Duhamel, MD Hauser & G. Rizzolatti, 133-157.
- Dehaene, S., & Cohen, L. (2007). Cultural recycling of cortical maps. *Neuron*, 56(2), 384-398.
- Dehaene, S., Pegado, F., Braga, L. W., Ventura, P., Nunes Filho, G., Jobert, A., . . . Cohen, L. (2010). How learning to read changes the cortical networks for vision and language. *science*, 330(6009), 1359-1364.
- Diamond, R., & Carey, S. (1986). Why faces are and are not special: an effect of expertise. *Journal of Experimental Psychology: General*, 115(2), 107.
- Duka, T., & Townshend, J. M. (2004). The priming effect of alcohol pre-load on attentional bias to alcohol-related stimuli. *Psychopharmacology*, 176(3-4), 353-361.

- Field, M., & Cox, W. M. (2008). Attentional bias in addictive behaviors: a review of its development, causes, and consequences. *Drug & Alcohol Dependence*, 97(1), 1-20.
- Field, M., Mogg, K., Zetteler, J., & Bradley, B. P. (2004). Attentional biases for alcohol cues in heavy and light social drinkers: the roles of initial orienting and maintained attention. *Psychopharmacology*, 176(1), 88-93.
- Field, M., Munafò, M. R., & Franken, I. H. (2009). A meta-analytic investigation of the relationship between attentional bias and subjective craving in substance abuse. *Psychological bulletin*, 135(4), 589.
- Goldstein, R. Z., & Volkow, N. D. (2011). Dysfunction of the prefrontal cortex in addiction: neuroimaging findings and clinical implications. *Nat Rev Neurosci*, 12(11), 652-669. doi: 10.1038/nrn3119
- Groefsema, M., Engels, R., & Luijten, M. (2016). The role of social stimuli content in neuroimaging studies investigating alcohol cue-reactivity. *Addictive behaviors*, 58, 123-128.
- Holderness, C. C., Brooks-Gunn, J., & Warren, M. P. (1994). Co-morbidity of eating disorders and substance abuse review of the literature. *International Journal of Eating Disorders*, 16(1), 1-34.
- Iaria, G., Fox, C. J., Waite, C. T., Aharon, I., & Barton, J. J. (2008). The contribution of the fusiform gyrus and superior temporal sulcus in processing facial attractiveness: neuropsychological and neuroimaging evidence. *Neuroscience*, 155(2), 409-422. doi: 10.1016/j.neuroscience.2008.05.046
- Kanwisher, N., & Yovel, G. (2006). The fusiform face area: a cortical region specialized for the perception of faces. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 361(1476), 2109-2128.
- Kilts, C. D., Schweitzer, J. B., Quinn, C. K., & et al. (2001). Neural activity related to drug craving in cocaine addiction. *Archives of General Psychiatry*, 58(4), 334-341. doi: 10.1001/archpsyc.58.4.334
- Klinger, E., & Cox, W. M. (2004). Motivation and the theory of current concerns. *Handbook of motivational counseling: Concepts, approaches, and assessment*, 3-27.
- Kühn, S., & Gallinat, J. (2011). Common biology of craving across legal and illegal drugs—a quantitative meta-analysis of cue-reactivity brain response. *European Journal of Neuroscience*, 33(7), 1318-1326.
- Langton, S. R., Law, A. S., Burton, A. M., & Schweinberger, S. R. (2008). Attention capture by faces. *Cognition*, 107(1), 330-342.
- Li, X., Hartwell, K. J., Owens, M., LeMatty, T., Borckardt, J. J., Hanlon, C. A., . . . George, M. S. (2013). Repetitive transcranial magnetic stimulation of the dorsolateral prefrontal cortex reduces nicotine cue craving. *Biological Psychiatry*, 73(8), 714-720.
- Lochbuehler, K., Voogd, H., Scholte, R. H., & Engels, R. C. (2011). Attentional bias in smokers: exposure to dynamic smoking cues in contemporary movies. *Journal of Psychopharmacology*, 25(4), 514-519.
- Loxton, N. J., & Dawe, S. (2001). Alcohol abuse and dysfunctional eating in adolescent girls: The influence of individual differences in sensitivity to reward and punishment. *International Journal of Eating Disorders*, 29(4), 455-462.

- Malach, R., Levy, I., & Hasson, U. (2002). The topography of high-order human object areas. *Trends in cognitive sciences*, 6(4), 176-184.
- Mitchell, J. M., Fields, H. L., D'Esposito, M., & Boettiger, C. A. (2005). Impulsive responding in alcoholics. *Alcoholism: Clinical and Experimental Research*, 29(12), 2158-2169.
- Palermo, R., & Rhodes, G. (2007). Are you always on my mind? A review of how face perception and attention interact. *Neuropsychologia*, 45(1), 75-92.
- Park, M.-S., Sohn, J.-H., Suk, J.-A., Kim, S.-H., Sohn, S., & Sparacio, R. (2007). Brain substrates of craving to alcohol cues in subjects with alcohol use disorder. *Alcohol and Alcoholism*, 42(5), 417-422. doi: 10.1093/alcalc/agl117
- Pessoa, L., & Adolphs, R. (2010). Emotion processing and the amygdala: from a 'low road' to 'many roads' of evaluating biological significance. *Nature Reviews Neuroscience*, 11(11), 773-783.
- Richler, J. J., Wong, Y. K., & Gauthier, I. (2011). Perceptual expertise as a shift from strategic interference to automatic holistic processing. *Current Directions in Psychological Science*, 20(2), 129-134.
- Robbins, R., & McKone, E. (2007). No face-like processing for objects-of-expertise in three behavioural tasks. *Cognition*, 103(1), 34-79.
- Robbins, S. J., & Ehrman, R. N. (2004). The role of attentional bias in substance abuse. *Behavioral and Cognitive Neuroscience Reviews*, 3(4), 243-260.
- Robinson, T. E., & Berridge, K. C. (1993). The neural basis of drug craving: an incentive-sensitization theory of addiction. *Brain research reviews*, 18(3), 247-291.
- Ross, D. A., Tamber-Rosenau, B. J., Palmeri, T. J., Zhang, J., Xu, Y., & Gauthier, I. (2018). High-resolution Functional Magnetic Resonance Imaging Reveals Configural Processing of Cars in Right Anterior Fusiform Face Area of Car Experts. *Journal of cognitive neuroscience*(Early Access), 1-12.
- Russell, R., Duchaine, B., & Nakayama, K. (2009). Super-recognizers: people with extraordinary face recognition ability. *Psychon Bull Rev*, 16(2), 252-257. doi: 10.3758/PBR.16.2.252
- Salloum, J. B., Ramchandani, V. A., Bodurka, J., Rawlings, R., Momenan, R., George, D., & Hommer, D. W. (2007). Blunted rostral anterior cingulate response during a simplified decoding task of negative emotional facial expressions in alcoholic patients. *Alcoholism: Clinical and Experimental Research*, 31(9), 1490-1504.
- Saunders, J. B., Aasland, O. G., Babor, T. F., De la Fuente, J. R., & 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.
- Shen, Y., Cao, X., Tan, T., Shan, C., Wang, Y., Pan, J., . . . Yuan, T.-F. (2016). 10-Hz repetitive transcranial magnetic stimulation of the left dorsolateral prefrontal cortex reduces heroin cue craving in long-term addicts. *Biological Psychiatry*, 80(3), e13-e14.
- Tarr, M. J., & Gauthier, I. (2000). FFA: a flexible fusiform area for subordinate-level visual processing automatized by expertise. *Nature neuroscience*, 3(8), 764.
- Terraneo, A., Leggio, L., Saladini, M., Ermani, M., Bonci, A., & Gallimberti, L. (2016). Transcranial magnetic stimulation of dorsolateral prefrontal cortex reduces cocaine use: a pilot study. *European Neuropsychopharmacology*, 26(1), 37-44.
- Thorberg, F. A., Young, R. M., Sullivan, K. A., & Lyvers, M. (2009). Alexithymia and alcohol use disorders: A critical review. *Addictive behaviors*, 34(3), 237-245.

- 506 Townshend, J., & Duka, T. (2001). Attentional bias associated with alcohol cues: differences
507 between heavy and occasional social drinkers. *Psychopharmacology*, 157(1), 67-74.
- 508 Valentine, T. (1988). Upside-down faces: A review of the effect of inversion upon face
509 recognition. *British Journal of Psychology*, 79(4), 471-491.
- 510 Ventura, P., Fernandes, T., Cohen, L., Morais, J., Kolinsky, R., & Dehaene, S. (2013). Literacy
511 acquisition reduces the influence of automatic holistic processing of faces and houses.
512 *Neuroscience letters*, 554, 105-109.
- 513 Wang, C.-C. (2018). Investigating the Time Course of Part-Based and Holistic Processing in Face
514 Perception. *Frontiers in psychology*, 9.
- 515 Waters, A. J., Marhe, R., & Franken, I. H. (2012). Attentional bias to drug cues is elevated before
516 and during temptations to use heroin and cocaine. *Psychopharmacology*, 219(3), 909-921.
- 517 Wilcockson, T., & Pothos, E. (2015). Measuring inhibitory processes for alcohol-related
518 attentional biases: introducing a novel attentional bias measure. *Addictive behaviors*, 44,
519 88-93.
- 520 Wong, A. C.-N., Bukach, C. M., Yuen, C., Yang, L., Leung, S., & Greenspon, E. (2011). Holistic
521 processing of words modulated by reading experience. *PLoS One*, 6(6), e20753.
- 522 Wrase, J., Grüsser, S. M., Klein, S., Diener, C., Hermann, D., Flor, H., . . . Heinz, A. (2002).
523 Development of alcohol-associated cues and cue-induced brain activation in alcoholics.
524 *European Psychiatry*, 17(5), 287-291. doi: [https://doi.org/10.1016/S0924-9338\(02\)00676-](https://doi.org/10.1016/S0924-9338(02)00676-4)
525 4
- 526 Xiao, Z., Lee, T., Zhang, J. X., Wu, Q., Wu, R., Weng, X., & Hu, X. (2006). Thirsty heroin addicts
527 show different fMRI activations when exposed to water-related and drug-related cues.
528 *Drug & Alcohol Dependence*, 83(2), 157-162.
- 529 Yin, R. K. (1969). Looking at upside-down faces. *Journal of experimental psychology*, 81(1), 141.
- 530 Zubietta, J.-K., Heitzeg, M. M., Xu, Y., Koeppe, R. A., Ni, L., Guthrie, S., & Domino, E. F. (2005).
531 Regional cerebral blood flow responses to smoking in tobacco smokers after overnight
532 abstinence. *American Journal of Psychiatry*, 162(3), 567-577.

533