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Facets of impulsivity and alcohol use: What role do emotions play?

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Highlights:

- Increased temporal and motor impulsivity seem to predispose to alcohol use.
- Heightened motor impulsivity is also an effect of alcohol use.
- Brain regions of impulsive behaviours and emotional experiences overlap
- Highly impulsive individuals use alcohol to deal with negative emotional states.
- Poor interoceptive abilities may further encourage drinking as a coping mechanism.

Keywords:

Binge drinking, alcoholism, alexithymia, interoception, mindfulness, arousal, insula

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Abstract

Alcohol misuse is a major public concern. Impulsivity has been recognised as a significant risk factor predisposing for the initiation of alcohol use, continuation and excessive alcohol use. Evidence suggests that impulsivity is also a result of both acute alcohol intoxication and long-term alcohol abuse. The multifaceted character of impulsivity and the various ways of assessing it in humans and animal models, hampers the full understanding of how impulsivity relates to alcohol use and misuse. Therefore, in this review we evaluate recent developments in the field, trying to disentangle the contribution of different impulsivity subtypes as causes and effects of alcohol use. Moreover, we review a growing body of evidence, including brain imaging, suggesting the importance of emotional states in engaging in alcohol consumption, particularly in highly impulsive individuals. We also present recent insights into how emotional processing is manifested in alcoholism and binge drinking and suggest novel approaches to treatment and prevention opportunities which target emotional-regulation as well as emotional perception and insight.

1. Impulsivity, emotions and alcohol drinking

Alcohol dependency is a chronic relapsing disorder characterised by compulsive drinking, which denotes harmful use of alcohol despite its negative consequences. Recently published statistics on alcohol use in the United Kingdom (National Statistics, 2017) states that 57% of those aged 16 or above drink alcohol; 15% of responders report heavy drinking (i.e. consumption of over eight units of alcohol for men and over six units for women at one occasion) in the previous week. Adolescents are also using alcohol – 38% of those aged 11-15 had already drunk alcohol. Moreover, 4% of adolescents report regular drinking (at least once a week). Alarmingly, nearly half (49%) of pupils who had drunk alcohol in the last month had been drunk; 63% of whom did it deliberately. Shockingly, there has been a 10% increase in alcohol-related deaths in the UK between 2005 and 2015. In the United States, alcohol is the third leading preventable cause of death, after tobacco and poor diet and physical activity (Mokdad et al., 2004). Alcohol use, therefore, is a major public concern. The importance of impulsivity in development of alcohol use, continuation and escalation of drinking leading to alcohol dependency has long been recognized. The difficulties in defining impulsivity in its multifaceted character and the various ways of assessing it in humans and animals, as well as problems with distinguishing between cause and effect have hampered the understanding of the true role that impulsivity plays in alcohol abuse (Dick et al., 2010; Lejuez et al., 2010; Potenza and de Wit, 2010). In the current review, we explore the role of distinct impulsivity subtypes in their contribution to alcohol drinking, referring to the research which tries to disentangle the impulsivity as a risk factor for alcohol use and impulsivity as a consequence of alcohol consumption. Finally, research on the role of emotional states as driving force for alcohol drinking is presented, and the role of impulsivity in the relationship between emotional states and alcohol drinking is evaluated, providing evidence for overlapping brain circuits underlying these processes. In addition, recent insights related to emotional processing in heavy social drinkers as well as in alcohol-dependent individuals is presented suggesting novel treatment and prevention opportunities.

1.1. What is 'impulsivity'?

Impulsivity can be defined as a predisposition for rapid, unplanned actions, without considering potential negative consequences of these actions (Moeller et al., 2001). Increasingly, it becomes recognised that 'impulsivity' is a heterogeneous concept which encompasses a variety of behaviours (Caswell et al., 2015a; Congdon and Canli, 2008; Evenden, 1999a; Moeller et al., 2001). Research describes impulsivity as a stable personality trait, or as a behavioural marker of actions and decision making. The Barratt Impulsiveness Scale (BIS; Patton et al., 1995) and UPPS-P Impulsive Behaviour Scale (Urgency, Premeditation, Perseverance, Sensation Seeking, Positive Urgency; Cyders and Smith, 2007; Whiteside and Lynam, 2001) are self-report questionnaires, which measure impulsivity as a personality trait and distinguish different subtypes of impulsive trait via subscales. Behavioural approaches, which view impulsivity as actions and decisions, allow also measurements of different subtypes of impulsivity via behavioural paradigms, but in addition are susceptible to manipulations, e.g. pharmacological influences, which allows researchers to identify modulators of impulsivity.

There is a large body of research showing a positive association between trait impulsivity and alcohol consumption, including social drinking (Adams et al., 2013; Bø et al., 2016; Caswell et al., 2015b; Cyders et al., 2014; Johnson et al., 2013; Karyadi and King, 2011; King et al., 2011; Kiselica and Borders, 2013; Lannoy et al., 2017; Sanchez-Roige et al., 2014a) as well as harmful and problematic drinking (e.g. Adams et al., 2012; Coskunpinar et al., 2013; Fox et al., 2010; Stautz and Cooper, 2013). In this review we aim to focus on the role of different behavioural impulsivity dimensions in alcohol use and abuse within the context of emotional dysregulation.

Several different types of behavioural impulsivity might be distinguished, but a detailed discussion of distinct subtypes is beyond the scope of this review. For this, we refer the reader to recent publications which deal with the topic in greater detail (e.g. Dalley and Robbins, 2017; Herman et al., 2018). Below, we briefly describe a division into three dimensions depending on the stage at which behavioural output is affected by impulsivity, namely: reflection impulsivity (impulsive action preparation), motor impulsivity (impulsive action execution), and temporal impulsivity (impulsivity at the action outcome stage) (Caswell et al., 2015a; Evenden, 1999a). Figure 1 summarises different subtypes of 'impulsivity' construct together with some commonly used measures.

Reflection impulsivity refers to a tendency to make fast decisions without an adequate accumulation and evaluation of information (Kagan, 1965; Kagan et al., 1964). In humans, it can be assessed with tasks which measure the amount of information gathering before reaching a decision, such as the Information Sampling Task (IST; Clark et al., 2006) or Matching Familiar Figures Test (MFFT; Cairns and Cammock, 1978). Both tasks assume that quick choices lead to more errors and suboptimal decisions. Homologous procedures have been employed in animal research (Evenden, 1999b).

Motor impulsivity refers to an inappropriate execution of motor actions. Motor impulsivity can be further divided into two subtypes. "Stopping impulsivity" refers to an inability to stop a pre-potent motor response which is no longer adequate. It can be assessed with the Stop

Signal Task (SST; Logan, 1994) or Go/No-Go task (GNG; Hogg et al., 1975). The performance on the SST is thought to reflect action cancellation, that is inhibition of the already initiated motor response, while the GNG task reflects action selection and restraint: Participants need to choose a response (either to go or to stop) and override the urge to respond to the infrequently occurring stop stimuli (Dalley et al., 2011; Eagle et al., 2008; Robinson et al., 2009; Winstanley, 2011). Animal versions of both tasks have been developed.

The second subtype of motor impulsivity reflects an inability to wait for an appropriate signal to act (“waiting impulsivity”; Dalley et al., 2011; Robinson et al., 2009). It can be assessed with the Immediate and Delayed Memory Task (IMT, DMT; Dougherty et al., 2002), used to assess attention, memory and impulsivity. The 5-Choice Serial Reaction Time Task (5-CSRTT; Carli et al., 1983; Sanchez-Roige et al., 2014; Voon et al., 2014), is recently used to assess waiting impulsivity and attention both in humans and rodents. In this task, subjects have to wait and respond to a signal in order to obtain a reward. Premature responses indicate “waiting impulsivity”.

Temporal impulsivity reflects the difficulty in awaiting gratification. Impulsive individuals discount delayed rewards more steeply (Ainslie, 1975; Kirby et al., 1999). Temporal impulsivity in humans can be assessed with hypothetical choice procedures in which participants are asked to choose between a smaller amount of money available immediately, or a larger amount available after a specified delay period (e.g. Kirby et al., 1999). Alternatively, tasks such as Two Choice Impulsivity Paradigm (TCIP; Dougherty et al., 2005) can be used to assess real decisions during which participants experience a delay between their choice and reward delivery. In animal versions of the tasks, an animal chooses between different food rewards, delivered immediately or after a delay (Thiebot et al., 1985).

Differences at the behavioural level of those distinct subtypes of impulsivity are also reflected in separate neural substrates underlying each of them (Figure 2).

Although little is known about neural correlates of *reflection impulsivity*, some volumetric studies indicate that greater reflection impulsivity, as indexed by lower information sampling in the IST, is associated with larger volumes of the left dorsal cingulate cortex and right precuneus (Banca et al., 2016). Lesion studies, on the other hand, indicate prefrontal, particularly orbitofrontal cortex (OFC), involvement in the MFFT performance: Patients suffering from the OFC lesions are more impulsive on the task, showing faster response times and producing more errors, than healthy controls and those with prefrontal lesions outside of the OFC (Berlin et al., 2005, 2004).

On the contrary, the brain correlates of *motor impulsivity* are well-defined. Neuroimaging studies indicate a common neural circuit underlying “stopping impulsivity”, which include right inferior and middle frontal gyri, anterior cingulate, pre-supplementary motor area, right inferior parietal lobe, and left middle temporal cortex (Rubia et al., 2001). However, the GNG task was associated primarily with left-hemisphere activation, while SST with the right-hemisphere (D’Alberto et al., 2017; Rubia et al., 2001). Circuitry underlying “waiting impulsivity” has been well studied in animals is shown to be different from “stopping impulsivity”. It is thought to depend on top-down interactions between prefrontal regions and hippocampus, amygdala and nucleus accumbens (Dalley et al., 2011). Recent evidence from human studies also suggests that heightened waiting impulsivity is associated with lower functional connectivity between subcortical areas such as the subthalamic nucleus and ventral striatum and prefrontal regions such as the subgenual cingulate (Morris et al., 2016).

The neural networks involved in *temporal impulsivity* encompass an even wider range of regions over the whole brain including areas involved in higher-order functions (pre-frontal cortex), in reward sensitivity and emotional experience (limbic regions), motor control (basal ganglia, motor cortices) as well as thalamus, parietal lobe and insular cortex (Frost and McNaughton, 2017). Recent lesion studies revealed that patients suffering from insula lesions show less steep discounting of delayed rewards (decreased temporal impulsivity) compared to patients with lesions in other brain regions and healthy controls (Sellitto et al., 2016), while damage to the medial OFC was related with more myopic (impulsive) decisions (Sellitto et al., 2010), suggesting the particular importance of the insular cortex and medial OFC in delay discounting.

2. Impulsivity as a cause or an effect of alcohol abuse

Impulsivity is thought to be both a determinant of drug use as well as a consequence of compulsive drug seeking (e.g.de Wit, 2009). As behavioural impulsivity is such a heterogeneous concept, it is vital to understand how the different facets of impulsivity contribute to alcohol-abuse and alcohol-use outcomes, as such an understanding may inform prevention and treatment of alcohol misuse. Therefore, to establish the causal role of distinct facets in alcohol use, for this section we only selected studies from which the directionality can clearly be inferred. Specifically, we included longitudinal studies, family history and inbred strains of animals. In order to present studies which demonstrate impulsive behaviours as a consequence of alcohol use, we have included studies of acute alcohol intoxication and impulsivity, again both in animals and humans.

2.1. Impulsivity – a vulnerability factor

Temporal impulsivity: Several lines of evidence suggest that impulsivity is a unique vulnerability factor for alcohol drinking, which further predisposes to increased alcohol use. Longitudinal studies indicate that poor ability to delay gratification at a young age is associated with greater likelihood of substance use and dependence in adulthood (Ayduk et al., 2000; Moffitt et al., 2011). Moreover, a study on teenagers found that delay discounting predicted alcohol involvement across multiple time-points 6 months later (Fernie et al., 2013). A recent study, in which delay discounting was examined in 177 addicts in recovery (Athamneh et al., 2017), found that a parental history of addiction was associated with higher discounting; in fact, individuals with both parents with addictions had significantly higher rates of discounting compared to those with no or only one addicted parent. Contradicting findings were reported by Sanchez-Roige et al., (2016) who did not confirm that temporal impulsivity may be an alcohol use predictor as individuals with family history of alcoholism did not differ from individuals without familiar alcohol abuse history in temporal discounting. Animal studies, however, consistently find that alcohol-naïve inbred and outbred strains of rats show increased temporal impulsivity (Beckwith and Czachowski, 2014; Linsenbardt et al., 2017; Oberlin and Grahame, 2009; Perkel et al., 2015; Wilhelm and Mitchell, 2008). For example, alcohol-naïve rats that show a high preference for smaller immediate rewards over larger delayed ones self-administer larger volumes of alcohol than less impulsive rats (Poulos et al., 1995). Overall, research indicates that temporal impulsivity may be an important vulnerability factor for developing an addiction.

Motor impulsivity: Motor impulsivity measured with SST also appears to be a significant predictor of developing alcohol dependence in heavy drinkers at a 4-year follow-up (Rubio et al., 2008). Similarly, studies with adolescents have indicated that performance on the SST could be a predictor of alcohol use on a 6-months follow-up (Fernie et al., 2013). Research on offspring of alcoholic parents, known to be at elevated risk for alcoholism later in life, also showed that poor motor inhibitory control on the SST might be a vulnerability factor predisposing to problem drinking (Nigg et al., 2004). A recent study, however, reported that individuals with a familial history of alcohol abuse did not differ from those without in performance at SST (Sanchez-Roige et al., 2016). On the contrary, an inbred strain of alcohol-preferring rats, show poorer response inhibition on the SST than outbred rats (Beckwith and Czachowski, 2016), suggesting that heightened motor impulsivity might be a vulnerability factor for developing alcohol-related problems.

Noteworthy, large-scale longitudinal studies start to reveal neural predictors of future BD. For example, a failure to inhibit a motor response elicits higher activity in the right middle, medial and precentral gyri and in the left postcentral and middle frontal gyri in future BD compared to adolescents who do not develop BD (Whelan et al., 2014).

Evidence suggesting the role of pre-existing ‘waiting’ impulsivity as a risk factor for developing alcohol-use problems also comes from research using animal models. Sanchez-Roige et al., (2014) tested alcohol-preferring (C57BL/6J) and alcohol-avoiding (DBA2/J) inbred strains of mice on the rodent version of the 5-CSRTT. Alcohol-preferring mice were more impulsive on the task, and a measure of ‘waiting’ impulsivity was correlated with alcohol preference. The degree of impulsivity also correlated with subsequent alcohol consumption. It is important to note that impulsivity was assessed before any exposure to alcohol, which eliminates the possible impact of the drug itself on impulsivity. Sanchez-Roige and colleagues also reported that BD compared to non-BD showed more premature responses in a homologous task for human subjects. Furthermore, individuals with a familial history of alcohol abuse were found to make more premature responses on the 5-CSRTT than those without, indicating that waiting motor impulsivity could also be a potential predictor for alcohol use (Sanchez-Roige et al., 2016). Although, contradicting findings were reported by (Rubio et al., 2008). Nevertheless, the finding of increased premature responding in young social BD and the ethanol-preferring strain of mice provides evidence for exaggerated waiting impulsivity as a potential endophenotype for the development of alcohol addiction and underlie the importance of the development of homologous behavioural measures in animals and humans (Sanchez-Roige et al., 2014a).

Reflection impulsivity: To our knowledge, there is little evidence for the role of reflection impulsivity as a vulnerability factor. A recent study reported that individuals with a familial history of alcohol abuse showed more conservative behaviour (decreased impulsivity) in the IST than those without such history (Sanchez-Roige et al., 2016). This less efficient behaviour may reflect a global decrease in cognitive functioning in individuals with familial history of alcohol abuse.

Together, research reviewed here suggest that temporal and motor impulsivity should be considered unique predisposing factors for alcohol-related problems. The key features of these studies are presented in Table 1.

2.2. Impulsivity – an effect of alcohol

It is a different matter whether alcohol itself affects impulsivity – either acutely due to its pharmacological effect or long-term due to its effects on the brain tissue. In this section, we review human and rodent studies examining whether alcohol use leads to impulsive behaviours. The studies featured here are summarised in Table 2.

Motor impulsivity: Previous studies from our and others labs have shown that alcohol intoxication acutely impairs motor (stopping) impulsivity (Caswell et al., 2013; Loeber and Duka, 2009a, 2009b; McCarthy et al., 2012; Nikolaou et al., 2013; Sanchez-Roige et al., 2016). On the other hand, acute alcohol administration does not seem to affect impulsive responding on versions of the GNG task in either humans or rodents (Moschak and Mitchell, 2012; Ortner et al., 2003; Reed et al., 2013). These differences between effects of alcohol on stopping impulsivity might derive from the fact that the GNG task is considered easier than SST.

Moreover, neuroimaging studies on social drinkers have shown that low dose of alcohol impairs response inhibition on the SST by evoking changes in neural activity within prefrontal, temporal, occipital and motor cortices. The high alcohol dose additionally evoked changes within subcortical centres including the globus pallidus and thalamus (Nikolaou et al., 2013). Thus, it seems that alcohol ingestion compromises the inhibitory control by modulating the activity of cortical regions engaged in attention, planning and sensorimotor functioning.

Acute alcohol intoxication seems to increase 'can't wait' impulsivity in humans (Dougherty et al., 2008; Reed et al., 2013; Sanchez-Roige et al., 2016). Furthermore, rodent studies indicate that intermittent alcohol exposure during late, but not early adolescence increase premature responding on the 5-CSRTT in adulthood (Sanchez-Roige et al., 2014b; Semenova, 2012). In another study, following acute alcohol challenge, rats exposed to alcohol in adolescence showed increased waiting impulsivity (Semenova, 2012).

Additionally, prolonged, but not short-term, abstinence following intermittent alcohol exposure in adulthood is associated with increased waiting impulsivity (Irimia et al., 2015). Together, evidence gathered here suggests that acute alcohol exposure is associated with increased can't wait impulsivity, while the effects of long-term alcohol use might depend on developmental period.

Temporal impulsivity: Results regarding temporal impulsivity are mixed. While several studies found no effect of acute alcohol ingestion on delay discounting (Adams et al., 2017; Caswell et al., 2013; Richards et al., 1999; Sanchez-Roige et al., 2016), others report increased temporal impulsivity (Dougherty et al., 2008; Olmstead et al., 2006; Reed et al., 2013), or even decreased temporal impulsivity (Ortner et al., 2003) following alcohol ingestion. McCarthy and colleagues reported that drink drivers show increased delay discounting following acute alcohol administration compared to non-drink drivers, suggesting that some individuals may be sensitive to alcohol-induced biases towards immediate rewards (McCarthy et al., 2012). Rodent studies on repeated exposure are equally inconsistent with some reports of increased temporal impulsivity in rats exposed to alcohol during adolescence (Mejia-Toiber et al., 2014), while others showing no effect of adolescence exposure on impulsivity in adulthood (Passos et al., 2015).

Reflection impulsivity: To our knowledge only one study investigated the effects of alcohol on reflection impulsivity, reporting no changes in behaviour (Caswell et al., 2013).

Together, acute alcohol intoxication seems to results in increased motor impulsivity, particularly impairing action cancellation and an ability to wait. The alcohol effects on temporal impulsivity yield particularly inconsistent results, with some studies showing a decrease, some studies showing no effects, and some studies showing an increase following alcohol administration, indicating a need for further research in this area.

Apart from acute changes in brain activity caused by alcohol intoxication, basic animal model studies have established that high blood levels of alcohol can directly induce brain damage (Crews and Nixon, 2009; Crews et al., 2004). These types of alcohol-induced alterations in the brain structure may further cause an increase in impulsivity, promote further alcohol use and neurodegeneration contributing to the severity of alcohol use disorders (for a review see Crews and Boettiger, 2009; Crews et al., 2004).

Human studies also indicate structural grey and white matter abnormalities in the circuitry involved in inhibitory control and emotion regulation in young binge and heavy drinkers compared to low-drinking counterparts (Cservenka and Brumback, 2017; Smith et al., 2017; Sousa et al., 2017; Wilson et al., 2015). Although some studies report increases in grey matter volumes in BD (e.g. Sousa et al., 2017) probably indicating a compensatory mechanism, while other studies indicate reduced cortical volumes in BD (e.g. Wilson et al., 2015), it appeared that neurotoxic effect of heavy alcohol use may result in neural reorganisation independently of pre-existing vulnerabilities and increase a risk of developing alcohol use disorder (Cservenka and Brumback, 2017).

3. Emotional state and alcohol use

Apart from stable impulsive tendencies, it is essential to consider the role of momentary 'state' increases in impulsive behaviour which may drive drinking episodes (de Wit, 2009). Parts of the brain involved in emotional processing and experiencing emotions (Phan et al., 2004, 2002; see Figure 3) overlap largely with parts of the brain involved in impulsive behaviour (see Figure 2). Therefore, to fully understand the relationship between alcohol use and impulsivity it is essential to consider the role of situational factors, one of which may be one's current mood state. For this purpose, we have included papers, which assess the relationship between mood state and impulsivity. These are mainly experience sampling studies or lab-based studies with mood-inductions.

Theory and evidence suggest that people drink alcohol to enhance positive or manage negative emotional state, and reduce tension (Conger, 1956; Cooper et al., 1995; Zack et al., 2002). Moreover, experience of stress, which is associated with increased physiological arousal and negative affect, is considered a major trigger in alcohol relapse. Indeed, stressful events increase the urge to drink and chances of relapse in treated alcoholics (Sinha, 2012; Sinha et al., 2009). Alcohol consumption is then used as a means of managing physiological and emotional states, in accordance with the negative reinforcement theory of addiction.

Further evidence for the impact of the emotional state on alcohol use comes from studies looking at individual daily variabilities in mood state and alcohol consumption. There is a large body of evidence coming from those experience sampling studies, showing that increased positive affect, as well as nervousness, is associated with augmented subsequent alcohol consumption (Dvorak et al., 2016; Peacock et al., 2015; Simons et al., 2010, 2005; Swendsen et al., 2000). Recent findings also indicate that a faster escalation in the volume of use among adolescence was predicted by lower levels of positive affect, suggesting that youth may escalate their drinking to boost positive affect (Lopez-Vergara et al., 2016). Moreover, on a day-to-day basis, increased arousal prior to alcohol consumption predicted the extent of alcohol use (Peacock et al., 2015).

Data from social drinkers suggests that alcohol consumption reduces the effects of stressful emotional stimuli on mood (Van Tilburg and Vingerhoets, 2002). After watching a dramatic movie, participants in the placebo condition reported feeling much more restless and nervous than those who consumed alcohol. This suggests that alcohol indeed reduces the emotional impact of a stressor explaining why certain individuals may use it to manage their emotions. Data from experience sampling studies further corroborate this assumption, showing that alcohol drinking is related to a subsequent decrease in nervousness (Swendsen et al., 2000) supporting the self-medication hypothesis of alcohol use. Importantly, repeated alcohol exposure leads to a negative emotional state enhancing the stress response, resulting in a vicious cycle of alcohol abuse (Garland et al., 2011; Koob and Le Moal, 2008).

Anger and hostility have also been related to increased alcohol use; however, that relationship was true for males only (Harder et al., 2014; Simons et al., 2010), suggesting gender differences in mood state relationship with alcohol drinking. Emotional states that lead to alcohol use may also differ across individuals depending on the alcohol drinking history. For instance, some data suggest that heavy female drinkers are less sensitive to the adverse effects and experience more positive effects of alcohol compared to light female drinkers (Reed et al., 2013).

Long-term alcohol abuse may lead to increase in negative states. Indeed alcoholic patients show significantly higher negative emotions ratings following alcohol cue exposure compared to social drinkers (Sinha et al., 2009). A longitudinal study in heavy alcohol drinkers found that increased alcohol use was related to decreased happiness the following day (Harder et al., 2014). Moreover, these effects were stronger for females than males further indicating the role of gender in how affective states interact with alcohol abuse.

The negative motivational state, to which addiction leads, and which drives addiction further is proposed to be caused by increased amygdala activation (Koob, 2009). More recently, a large-sample study demonstrated that a relative imbalance between threat-related amygdala reactivity and reward-related ventral striatal reactivity (i.e. low amygdala-high ventral striatal reactivity or vice versa) represents a neural risk factor for stress-related problem drinking in young adults (Nikolova et al., 2016). In contrast, a balance between those two regions reactivity (i.e., either both low or both high) was found to be protective against stress-related problem drinking. Importantly, the relative enhancement of the threat-related compared to reward-related reactivity profile may lead to behaviours aiming at negative emotions relief (Nikolova et al., 2016), possibly via maladaptive coping strategies, such as alcohol misuse.

In conclusion, a common motive for drinking is to increase positive emotional states and decrease negative ones. Indeed, alcohol acutely decreases nervousness and increases positive mood state, but after alcohol effects subdue, so does happiness in heavy users. Noteworthy, heavy alcohol users may experience alcohol effects differently, i.e. feel more stimulation, than light users. Moreover, high levels of arousal and activation (elevated state of happiness, nervousness, stress) seem to be related to increased alcohol use. Importantly, some results suggest that there are gender differences in specific emotional states which lead to increased drinking. Notably, increased anger and hostility seem to drive alcohol use in males, but not females. Together, it seems clear that affective state does influence the alcohol consumption, but individual differences, such as alcohol use frequency and gender seem to be moderating factors.

4. Impulsivity (urgency), emotional state, and alcohol use

The notion that certain individuals may be more reactive to intense emotional states is getting increased attention and is referred to as urgency (Whiteside and Lynam, 2001). Some individuals may show a tendency towards impulsive behaviours more when experiencing negative emotions, while others when experiencing positive feelings. These features are referred to as negative and positive urgency respectively (Cyders et al., 2007; Whiteside and Lynam, 2001). Experiencing emotional distress leads people to engage in impulsive behaviours to improve their mood (Tice et al., 2001). Research also suggests that indulging in impulsive drinking may be a strategy used by individuals with high trait urgency to regulate their mood. For example, a recent study on university students has shown that individuals displaying high levels of negative urgency may consume alcohol to ameliorate their emotional distress due to strong desires to increase positive and decrease negative experiences (Anthenien et al., 2017). Cumulative stress has been found to be related to increased hazardous drinking among individuals reporting high levels of trait impulsivity (Fox et al., 2010). Similarly, Simons et al., (2010) reported that the relationship between daily anxiety and alcohol intoxication was stronger for individuals with greater negative urgency. Together, these results suggest that managing emotional distress may be a motivation for drinking in impulsive individuals.

Additionally, some evidence also suggests that high levels of positive urgency may predispose to impulsive actions such as alcohol consumption when experiencing heightened positive mood state. For example, positive urgency predicted increased alcohol consumption on the bogus beer taste test following experimental induction of positive mood (Cyders et al., 2010). These findings were recently further expanded by Dinc and

Cooper (2015) who revealed that this was true only for participants in a high arousal positive mood state. These results indicate that positive urgency might be a risk factor for increased alcohol use especially while individuals experience high arousal and high positive mood state.

Some evidence suggests that not only emotional urgency but impulsivity more generally, mediates the relationship between mood and alcohol use. In a recent study, negative mood state predicted drinks on drinking nights, but only for women with poor response inhibition (Dvorak et al., 2016). Finally, positive mood state was associated with a higher rate of experiencing acute alcohol use disorder symptoms (such as withdrawal, tolerance, loss of control over drinking) among those with poor response inhibition; this relationship was reversed among those with good response inhibition (Dvorak et al., 2016). These results suggest that the moderating role of impulsivity is not limited to trait urgency, but also to behavioural response inhibition.

Why should emotional urgency play such a prominent role? Neuroimaging research on structural correlates of emotional impulsivity revealed that high levels of trait negative urgency were related to decreased grey matter volumes of the brain regions previously implicated in emotion processing, decision-making and reward-sensitivity, namely dorsomedial prefrontal cortex, right temporal lobe and ventral striatum (Muhlert and Lawrence, 2015). Additionally, greater negative urgency among alcohol-dependent individuals and social drinkers has been linked to the heightened reactivity of brain regions involved in reward processing (striatum, ventromedial prefrontal cortex) to alcohol cues (Chester et al., 2016a; Cyders et al., 2014). Some evidence also suggests that negative urgency is associated with greater emotional responsiveness following negative mood inductions. Increased alcohol craving and seeking was found in individuals high in negative urgency following a negative, but not neutral, mood induction (VanderVeen et al., 2016). In agreement, action restraint in the negative versus neutral context on the GNG task evokes greater recruitment of inhibitory brain regions in individuals high in negative urgency than controls (Chester et al., 2016b). Together, these findings imply that individuals high in trait negative urgency may be more susceptible to changes in affective state and may seek alcohol as a maladaptive means of regulating their mood state. Additionally, increased alcohol craving following alcohol exposure related to negative urgency may lead to maintenance of alcohol seeking (VanderVeen et al., 2016). To our knowledge, the relationship between negative emotional urgency and distinct behavioural facets of impulsivity has not been explored. Future studies are needed to reveal such a relationship.

5. Emotional processing and alcohol use

Altered emotional processing is a central characteristic of many mental disorders, including alcohol dependence. In particular, alcohol dependence is associated with emotional dysregulation and aspects of negative emotionality, including rumination, worry and anxiety sensitivity (Boschloo et al., 2013; Garofalo and Velotti, 2015). Moreover, alcohol-dependent individuals show difficulty in perceiving their own emotions (e.g. de Timary et al., 2008), decreased emotional empathy (Martinotti et al., 2009; Maurage et al., 2011) and an inability to recognise emotions expressed in faces (e.g. Kornreich et al., 2002). It is suggested that this type of emotional processing deficits can explain alcoholic individuals' difficulties in interpersonal relationships (e.g. Philippot et al., 2005).

Importantly, such emotional deficits appear to increase with the severity of alcohol abuse (i.e. in BD) and the increase in alcohol dependence associated with an experience of multiple detoxifications. For instance, lower levels of positive mood state were found in BD compared to non-BD (Townshend and Duka, 2005) whereas higher negative emotional sensitivity was present in patients following multiple detoxifications compared with those who had one only previous detoxification (Duka et al., 2002). Similarly, alcoholics show enhanced fear recognition in facial expressions, which has been linked to the number of previous detoxifications, and suggests alternations in amygdala functioning (Townshend and Duka, 2003); in the same study alcoholic patients were found to interpret faces expressing disgust as angry. Interestingly, in another study apart from a general inability to categorise emotional facial expressions, alcoholic patients were also found to interpret sad faces as more angry (Frigerio et al., 2002). Together, these results disclose that alcoholics show impaired emotional processing in facial expression recognition, particularly in the negative domain. Apart from social consequences (misinterpreting reactions of others) such findings also suggest more generally a disrupted functioning of brain areas vital for emotional processing such as amygdala or insula. Indeed, neuroimaging evidence indicates that obsessive compulsive drinking is associated with blunted limbic structures responses to fearful faces in a sample of heavy drinkers (Gowin et al., 2016). In agreement, studies utilising animal models of binge drinking indicate that repeated alcohol consumption and withdrawal impairs fear conditioning, and reduces long-term potentiation in the amygdala, which results in the inappropriate generalisation of learned fear responses (Stephens et al., 2005). BD compared to non-BD as well as alcoholic patients compared to social drinkers as well demonstrate a deficit in a fear-potentiated startle, a task examining fear conditioning (Stephens et al., 2005; Stephens and Duka 2008). Acute alcohol intoxication has also been related to altered facial expression processing, accompanied by diminished insula and amygdala activation during a facial expression perception task (Gilman et al., 2012, 2008;

Padula et al., 2011). Thus, acute intoxication may further disrupt emotional processing essential for appropriate social interaction.

Inability to recognise facial emotional expressions in others may indicate a more general deficit in identifying and describing feelings in self and others, a personality trait known as alexithymia (Taylor, 2000; Taylor et al., 2003). Indeed, frequent intoxications and long-term heavy alcohol use have been associated with alexithymia (Kauhanen et al., 1992) which is reported by up to 78% of alcohol abusing individuals (Rybakowski et al., 1988; Thorberg et al., 2009). Interestingly, it has been suggested that individuals with alexithymia may use alcohol as a coping strategy (Lyvers et al., 2012).

Research also highlights a relationship between alexithymia and urgency in predicting alcohol use and alcohol-related problems in university students, suggesting that urgency may pose a risk factor for developing alcohol-related problems due to its role on emotional processing (Shishido et al., 2013). Similarly, research on moderate to heavy alcohol users has revealed that negative urgency mediates the relationship between negative emotion differentiation and alcohol-related problems (Emery et al., 2014). Thus urgency an emotional trait associated with inhibitory control appears to relate to alexithymia. However, to our knowledge, there are no studies on the relationship between alexithymia and facets of impulsive behaviour associated with the inhibitory control.

Taken together, the findings presented in this section suggest that a reduced ability to identify and differentiate between emotions contribute to behavioural disinhibition, such as engaging in heavy alcohol consumption. This poses implications for treatments and prevention of alcohol abuse, which should focus on emotion recognition and regulation training.

5.1. Emotional processing, interoception and alcohol abuse

Recent research indicates that alexithymia, the inability to identify and describe feelings in self and others, is not only related to altered emotional processing, but also to a more general non-affective impairment in interoception, that is a difficulty in perceiving subtle bodily changes such as sensations from the gut or heartbeat (Brewer et al., 2016; Herbert et al., 2011; Shah et al., 2016). For example, individuals with alexithymia show poorer performance on the heartbeat detection task (Herbert et al., 2011; Shah et al., 2016) and are more likely to confuse bodily sensations such as signals of hunger, arousal, proprioception, tiredness or temperature with affective states (i.e. misinterpret anger as heat, pain or hunger etc.; Brewer et al., 2016). This, of course, may lead to various negative consequences such as inappropriate actions due to misperceived sensations and ineffective management of arousal due to an inability to interpret it. Recent data have corroborated this suggestion. Betka and colleagues (2017) have shown that alexithymia mediates the relationship between sensitivity to bodily sensations and alcohol consumption in social drinkers. The authors claim that alexithymia, which results from impaired processing of bodily sensations (including physiological arousal), underpins the urge to consume alcohol.

Above (section 3 and 4), we described that not merely emotional state as such, but an emotional state with high arousal is associated with increased alcohol drinking particularly in highly impulsive individuals (for example Dinc and Cooper, 2015; Peacock et al., 2015). Arousal is strongly associated with changes in body physiology. It is, therefore, possible that a failure in correctly interpreting bodily states of arousal may be a predisposing factor for alcohol drinking, thus further supporting the link between alexithymia, interoception and alcohol use.

Importantly, individual differences in levels of arousal have long been thought to relate to impulsivity; specifically, it has been hypothesised that some subjects may behave impulsively to adjust to an optimal level of arousal (Zuckerman, 1969).

One part of the brain which is associated with arousal, interoception, impulsivity and addiction is insula (Naqvi and Bechara, 2010). Activity in the insula together with the anterior cingulate cortex and somatosensory cortices reflects a level of sympathetic arousal indicated in changes in electrodermal activity (Critchley et al., 2002). Insula is also a central hub of interoceptive awareness (Craig, 2009; Critchley et al., 2004) and a key region involved in emotional experiences, particularly aversive emotional experiences which evoke visceral sensations (Phan et al., 2004, 2002). Importantly, engaging in interoceptive attention (tracking one's heartbeat) and monitoring one's emotional experience evoke an overlapping activity in the insular cortex (Zaki et al., 2012). Increasingly, the role of the insula is also recognised in decision-making, particularly risky choices and inter-temporal decisions (for example Frost and McNaughton, 2017; Kuhnen and Knutson, 2005; Sellitto et al., 2016; Xue et al., 2010). Apart from impulsive choice, the insula is involved in response inhibition (for example Bari and Robbins, 2013; Boehler et al., 2010; Ramautar et al., 2006). Finally, one of the most striking evidence for the role of the insula in addiction, particularly craving, is the fact that insula lesions in nicotine addicts are related to completely cancelled urge to smoke and cessation of tobacco use (Naqvi et al., 2007).

Indeed, it has been suggested that interoceptive ability is vital for higher-order-cognition, and that atypical interoception may predispose to psychopathology, risky behaviour, as well as poor emotional functioning (Murphy et al., 2017). Recent research on alcohol dependence corroborates this hypothesis. Adolescents with substance use disorders (SUDs;

alcohol and cannabis) show attenuated posterior insula activation during soft touch, indicating hyposensitivity to pleasant interoceptive stimuli (Migliorini et al., 2013). Additionally, the insula activation during pleasant touch was related to higher pleasantness ratings in healthy teenagers, while in the SUDs it correlated with lower pleasantness ratings, indicating altered processing of pleasant interoceptive stimuli. On the contrary, SUDs show increased insular activation during inspiratory breathing load (a measure of aversive interoception), compared with control individuals, indicating altered processing and hypersensitivity to aversive interoceptive stimuli (Berk et al., 2015). Moreover, a negative correlation was found between heartbeat perception task and alexithymia score, indicating that poor interoceptive accuracy is associated with difficulties in identifying feelings (Sönmez et al., 2017). Importantly, alcoholic patients show reduced interoceptive abilities compared with healthy individuals (Ateş Çöl et al., 2016; Sönmez et al., 2017). Also acute alcohol impairs interoceptive accuracy on a heartbeat perception task, although only in men (Abrams et al., 2018). The alcohol attenuation effect was observed both at rest and following aerobic exercise, which improves interoceptive accuracy via increased state of arousal. Interestingly, while objective measure of interoception (task accuracy) was affected, alcohol did not influence subjective confidence in perceived number of heartbeats. Interoceptive awareness and alcohol tension reduction expectancies were also found to interact as predictors of drinking compulsions and obsessions (Schmidt et al., 2013). Together, these results suggest that an inability to take advantage of bodily feedback might be a contributing factor for maintenance of drinking behaviour (Ateş Çöl et al., 2016; Schmidt et al., 2013; Sönmez et al., 2017) and that this effect might be further exacerbated by alcohol ingestion (Abrams et al., 2018). The role of impulsivity and its facets in the relationship between emotional processing, interoception and alcohol use, although partly supported via the arousal hypothesis of impulsivity (Zuckerman 1969), requires further investigation.

5.2. Interoceptive training in alcohol misuse

The literature reviewed here indicates that alcohol misuse is at least partly associated with poor interoceptive abilities which can lead to disrupted emotional processing and regulatory control abilities. It is reasonable therefore to suggest that therapies should target development of better emotional and regulatory skills by focusing in improving perception of bodily states. Interoceptive training, such as mindfulness, that is a non-judgemental awareness of present experiences, has been proposed to be used in therapies of addictions (Paulus and Stewart, 2014; Paulus et al., 2013). The idea that mindfulness, which similarly to impulsivity emphasizes presence in the current moment, can be used as interoceptive training, may sound counterintuitive. However, low trait mindfulness is associated with negative emotions (depression, anxiety, stress ratings), trait impulsivity, alexithymia (Lyvers et al., 2014) as well as increased likelihood of lifetime alcohol use (Robinson et al., 2014). On the other hand, mindfulness training has been shown to lead to beneficial effects on emotional responses, resulting in reduction in emotional reactivity and increasing the ability to engage in tasks despite emotional arousal (Roemer et al., 2015). A brief mindfulness intervention was associated with increased activation in prefrontal regions and reduced activation in the amygdala during the anticipation and perception of negative and potentially negative images (Lutz et al., 2013). Since SUDs show hypersensitivity and altered processing of unpleasant interoceptive stimuli (described above, Berk et al., 2015), mindfulness training may provide an effective way of normalising these responses in addicted individuals. Interestingly, trait mindfulness was negatively correlated with prefrontal and right insular cortex activation during perception of negative pictures, suggesting that mindful individuals required less cognitive resources to implement emotional regulation (Lutz et al., 2013). Mindfulness training was also shown to significantly attenuate right anterior insula and anterior cingulate cortex activation during inspiratory breathing load (aversive interoceptive signal) (Haase et al., 2016). Moreover, 8-week Mindfulness-Based Stress Reduction training resulted in structural and functional changes within regions associated with emotion regulation, memory, decision making and inhibitory control (reviewed in Gotink et al., 2016). Specifically, following the training increased activity in the PFC and hippocampus, and decreased activity in amygdala as well as improved connectivity with PFC were observed, suggesting improvements in emotional regulation. Increased activity of the insula was also reported which may reflect increased awareness of internal bodily states. Even shorter 2-week attention-to breath training was shown to reduce amygdala responses to aversive pictures and increased amygdala-prefrontal cortex connectivity (Doll et al., 2016). Importantly, imbalance between amygdala system, signalling for immediate pleasures and pain, and reflective prefrontal system, signalling for long-term outcomes, has been suggested to underlie impulsive decision-making and inability to cease drug-taking in addiction (Bechara, 2005). Mindfulness training, therefore, targets the key brain regions implicated in alcohol addiction and impulsivity (namely, amygdala, prefrontal cortex and insular cortex), and results in improvement in emotional regulation and processing of emotional stimuli which could provide an efficient therapeutic mechanism for addicted individuals.

In agreement, initial studies of mindfulness training in social drinkers, as well as substance abusers, report promising results. For example, in a recent study, a 4-week mindfulness intervention in BD university students significantly reduced the number of binge episodes and consequences of drug use compared to a control group (Mermelstein and Garske, 2015). Eight-week mindful awareness in body-oriented therapy as an adjunct to women's SUDs (predominantly alcohol abusers) treatment, also found significant improvements in length of abstinence compared to standard treatment alongside with reduction of stress and negative affect reports (Price et al., 2012). Similarly, mindfulness training was shown to reduce stress (Brewer et al., 2009; Garland et al., 2010), craving and risk of relapse (Bowen et al., 2014; Zgierska et al., 2009) in recovering substance dependent individuals. However, it is important to note, that mindfulness as a treatment approach to reduce alcohol craving might not be observed following a single intervention (Caselli et al., 2016; Kamboj et al., 2017; Murphy and MacKillop, 2014; Vinci et al., 2014), but instead could arise from repeated practices. Decreased craving and prolonged alcohol abstinence as a result of long-term practices, further supports the notion that mindfulness benefits occur as a result of plastic brain changes within prefrontal–amygdala circuitry (Doll et al., 2016; Gotink et al., 2016). There is a growing interest in the use of mindfulness for addiction therapies; these few examples from the literature are only aimed to highlight its therapeutic potential.

6. Summary and Conclusions

Binge drinking and alcohol abuse are associated with increased impulsivity understood both as an impulsive personality trait as well as behavioural impulsivity. While increased impulsivity predisposes to frequent alcohol use, acute alcohol intoxication independently diminishes inhibitory control resources, which may lead to even heavier drinking episode. Furthermore, repeated episodes of heavy drinking followed by withdrawal periods and subsequent relapse lead to structural changes in the brain regions associated with emotion processing and higher cognitive functioning, resulting in poorer self-control and impulsive behaviour, further promoting drinking.

The role of emotional states in alcohol consumption is not to be underestimated. Acutely, alcohol results in improved positive and decreased negative emotional states, therefore, individuals may use it as a coping strategy to deal with negative emotions. Also, high arousal emotional states are associated with increased alcohol consumption both in social as well as problem drinkers, particularly in highly impulsive individuals. Arousal plays a vital role in impulsive behaviour, and its perception seems essential for emotional processing. Poor interoceptive abilities are associated with decreased perception of arousal and may lead to an inability in identifying and describing feelings in self and others known as alexithymia, which appears to be common in alcoholism. Reduced ability to sense and interpret subtle physiological and emotional changes, such as emotional arousal, may lead to misinterpretation and misattribution of bodily arousal, further strengthening alcohol use as a coping mechanism.

Given that brain areas, such as prefrontal cortex, ACC, amygdala and insula, involved in impulse-control, decision making, emotional processing as well as interoceptive ability largely overlap, interventions for treatment and prevention of problem drinking should be designed to target functioning of these brain areas. Such interventions may include heart-beat detection, mindfulness and emotion recognition training.

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