Ecological momentary assessment of daily stress and blood alcohol concentration in healthy drinkers: A feasibility study

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Abstract

Rationale: Hazardous drinking presents a global health risk and if chronic, can escalate into an alcohol use disorder. The causal mechanisms for the transition from controlled alcohol use to uncontrolled misuse and dependence are complex, and it is not presently possible to accurately predict those most at-risk of misusing alcohol, or of developing AUD.

Objectives: We investigated the feasibility of using ecological momentary assessments, specifically related to daily stress and alcohol use, to study risk factors for hazardous drinking. We tested the hypothesis that in a sample of healthy drinkers, risk-taking would modulate the impact of daily self-reported stress on alcohol use.

Methods: We characterised impulsivity/risk-taking in 23 participants (12 female; mean age = 24.59 [SD = 5.34]) using a battery of questionnaires and computer tasks. We then collected daily behavioural and physiological data related to self-reported stress levels and blood alcohol concentration consumption for 30 days.

Results: Attrition and missing data rates were low, with an overall response rate of 92.6%. We found support for our hypothesis, with higher risk-taking and impulsive participants drinking more following daily stressors. However, the picture was not clear, with participants drinking greater volumes of alcohol at weekends, and the interactions of stress x personality trait often differing on weekdays.

Conclusions: This feasibility study demonstrated the potential for using ecological momentary assessments, such as, digital biomarkers to assess risk factors for alcohol misuse is a viable option for investigating the effects of neurocognitive endophenotypes and stress on alcohol misuse on a longitudinal basis.

Introduction

Despite decades of knowledge that hazardous drinking (both acute and chronic) and associated morbidities present a significant risk to global health (Connor, Haber, & Hall, 2016; Leon & McCambridge, 2006; Lieber, 1995; Rehm et al., 2009; Wang, Fan, Zhang, Gao, & Wang, 2014), little progress has been made in the way of creating and implementing efficacious curative or preventative interventions for alcohol use disorders (AUDs), perhaps due to the complex aetiology of both alcohol misuse and dependence (Harris & Koob, 2017). Irrespective of the current guidelines, i.e. to avoid consuming more than 14 units per week (where one unit is defined as 8g 100%v/v ethanol), 20% of the population are estimated to drink at hazardous and harmful levels regularly (McManus, Bebbington, Jenkins, & Brugha, 2016). Hazardous drinking can lead to alcohol-related hospital admissions, which currently exceed one million per year in the UK (HSCIC, 2015), and cost the National Health Service in excess of £21 billion per year (Home Office, 2012). Hazardous and harmful drinking can, in some users, escalate into state of dependence (Skinner & Allen, 1982), classically characterised by withdrawal symptoms in the abstinence of alcohol, compulsive alcohol seeking, anhedonia and social/familial problems (American Psychiatric Association, 2013).

Previous work has highlighted several risk factors for alcohol misuse, one of which is psychosocial stress. Chronic hazardous drinking causes neuroadaptations in stress pathways, most notably the hypothalamic pituitary adrenocortical (HPA) and sympathetic adrenomedullary (SAM) axes (Sinha, 2012), recognised as cortisol response dysregulation (Kreek & Koob, 1998) and deficits in emotional regulation (Sinha, 2001). In turn, these neuroadaptations leave AUD patients at a greater risk of stress induced relapse. However, there are inconsistent findings in terms of predicting the latency to, and likelihood of, relapse using stress alone, owing to large individual differences and inconsistent findings between patient groups (Sinha et al., 2011). Also, how these stress-pathway adaptations affect the early development of AUD, or indeed differences in hazardous alcohol use and misuse more generally, is not well characterised.

An established risk factor for AUD is the propensity to act impulsively. Here, impulsivity is defined as the tendency to proceed without foresight and take risks, despite potential adverse consequences (Dalley, Everitt, & Robbins, 2011). Trait impulsivity represents a neurocognitive endophenotype of AUD, i.e., a sub-clinical 'intermediate' phenotype that is state-independent, and observed in at-risk individuals (and their first-degree relatives) even when the full-blown disease is absent (Gottesman & Gould, 2003). In at-risk individuals, addiction develops following a shift from controlled voluntary substance use to a habitual, compulsive (addicted) state (Everitt and Robbins, 2005). Human studies show that trait impulsivity is linked both to addiction and to relapse; addicts have higher levels of impulsivity, as do their (non-addicted) first degree relatives (Bowden-Jones, McPhillips, Rogers, Hutton, & Joyce, 2005; Lawrence, Luty, Bogdan, Sahakian, & Clark, 2009). In pre-clinical (rodent) studies, impulsivity has a causal relationship with compulsive drug-seeking (Belin, Jonkman, Dickinson, Robbins, & Everitt, 2009).

Stress has been shown to modulate the shift between goal-directed and habitual responding, potentially as a result of stress activating the amygdala, which then influences the shift to habitual behaviour (Koob, 2008), and there are links between risk-taking and reported alcohol use in social drinkers (Fernie, Cole, Goudie, & Field, 2010). In our previous work we have demonstrated that risk-taking and risky-decision-making (individual tendencies closely related to impulsivity) influence psychosocial stress-induced craving (Clay et al., 2018) and consumption (Clay & Parker, 2018) of alcohol, respectively, in social drinkers. We also found results suggesting that variances in stress reactivity i.e. individuals with faster reactivity and slower recovery to stress tend to consume a greater amount of alcohol following psychosocial stress (Clay & Parker, 2018). Poor vagal tone inhibits the management of allostatic load (Ingjaldsson, Laberg, & Thayer, 2003; Rechlin, Orbes, Weis, & Kaschka, 1996; Shively et al., 2007; Thayer & Sternberg, 2006), thus leaving individuals more at risk of alcohol craving (Koob & Le Moal, 2001). Therefore, this neurocognitive endophenotype theory predicts that in healthy individuals, higher rates of stress-induced drinking will be observed in those

impulsive/risk-taking tendency (or that those with high impulse control will show more resilience to stress-induced craving/consumption).

Much of the work described above, including our own, was conducted in the laboratory. While laboratory work presents obvious advantages, such as, precise control of extraneous variables and an ease of replicability, laboratory studies are often limited in terms of ecological validity. In contrast, ecological momentary assessment (EMA) allows researchers and clinicians to make repeated observations surrounding a participants symptoms, affect, behaviour, and cognitions in close to real-time (Moskowitz & Young, 2006; Shiffman, Stone, & Hufford, 2008). Unfortunately, however, these methods are often go unutilised in the field of psychopharmacology (Moskowitz & Young, 2006). Yet, coupled with longitudinal methods, this novel approach will overcome many of the shortfalls of classical laboratory-based assessment, allowing for exciting new inferences about neuropsychiatric disorders.

Biomarkers are measurable indices of disease-state that can give insight into both the biological mechanisms that underlie the disease and/or risk-status for the disease (Pletcher & Pignone, 2011), and there is wide acceptance of the clinical importance of the discovery of biomarkers for the diagnosis and treatment of neuropsychiatric disorders such as AUD (e.g. Baskaran, Milev, & McIntyre, 2012; Domany et al., 2018; Niemelä, Niemelä, & Onni, 2016; Rosman & Lieber, 1994; Volkow & Baler, 2013). Digital biomarkers allow researchers and clinicians to use EMA to facilitate the investigation of putative, or the discovery of *de novo*, risk-factors and/or interventions for neuropsychiatric disorders, by interrogating a variety of data derived from smart phones and other portable devices; for example, physiological (e.g. heart rate); cognitive (e.g. cognitive tests delivered via smartphone); behavioural (e.g. movement patterns via the Global Positioning System (GPS)); self-report questionnaires (Torous, Rodriguez, & Powell, 2017). So far, potential digital biomarkers have been discovered and documented for several neuropsychiatric disorders including, for example, depression (Baskaran, Milev, & McIntyre, 2012), schizophrenia (Domany et al., 2018), and AUD (Skipper et al., 2014). However, to date, no contributions have been made investigating the potential of digital biomarkers to identify *risk factors* for alcohol misuse in normative populations. It is possible, for example, that digital biomarkers could prove useful in predicting those most at risk of misusing alcohol and subsequent AUD development.

In the present study, our primary aim was to test the feasibility of using EMA and digital biomarkers, specifically related to daily stress and alcohol use, to study who is most at risk of hazardous drinking. Secondly, we aimed to explore the external validity of previously identified putative risk-factors for alcohol misuse. Based on our previous laboratory research, we predict that stress-induced alcohol consumption is mediated by risk-taking. Therefore, the primary objective of this study was to test the hypothesis that, in a sample of healthy (social) drinkers, those with higher levels of risk-taking would consume a greater volume of alcohol following daily stress. To test this hypothesis, we first characterised trait risk-taking in participants. We also collected data on other personality factors (impulsivity, stress reactivity). We then collected daily self-reported stress levels and blood alcohol concentration (BAC) using digital breathalysers for 30 days.

Methods

Study design

This study employed a prospective semi-longitudinal design, following participants over 30 days. The dependent variable (DV) was daily alcohol consumption (assessed via BAC and self-reported units/day consumed). There were several explanatory variables regressed against the DV including measures of prior alcohol use behaviour, neurocognitive measures, a measure of subjective stress reactivity and daily assessments of perceived stress.

Participants

Initially thirty-two participants (15 female; mean age = 23.71 [SD = 4.54]) were recruited using opportunity sampling from the community of staff and students at the University of Portsmouth. Participants were recruited via online (social media) advertising and through word of mouth. An advert placed on our laboratory's social media (Facebook) page informed participants that we were interested in investigating factors that are associated with high risk of alcohol misuse; however, specific details of the hypotheses were withheld from potential participants to limit demand characteristics. Potential participants expressing an interest in taking part were asked to email the lead researcher. Following this, participants were sent a participant information sheet and consent form, issued with a unique identification (ID) number (to maintain anonymity) and sent a link to an online screening questionnaire programmed and implemented using PsyToolkit (Stoet, 2010, 2017) via email. Inclusion criteria included age ≥ 18 or ≤ 55 years; normal or corrected to normal vision; regular alcohol consumption prior to the study i.e. regularly consuming at least one alcoholic beverage/week. Exclusion criteria included present or previous diagnosis (past 6 months) and/or treatment for a psychiatric disorder (not specified); present or previous diagnosis and/or treatment for alcoholism (at any time in the past), other substance use disorders (SUDs), or any related disorder/disease e.g. alcohol liver disease (at any time in the past). For female participants, we excluded anyone who was currently pregnant or planned/expected to get pregnant over the course of the study. Furthermore, as a secondary screening of undiagnosed alcohol dependency and/or anxiety and/or depression, all participants completed the Patient Health Questionnaire for Depression and Anxiety (PHQ-4; Kroenke, Spitzer, Williams, & Löwe, 2009) and the Alcohol Use Disorders Test (AUDIT; Bush, Kivlahan, McDonell, Fihn, & Bradley, 1998). Any participant that score >5 on the PHQ-4 or >20 on the AUDIT was excluded. Participant attrition due to exclusion and withdrawal following the commencement of data collection (e.g., not completing questionnaires or regularly failing to produce samples), left us with a final sample size of twenty-three (12 female; mean age = 24.59 [SD = 5.34]). Participants received a £40 payment for their participation following completion of the study and return of the breathalyser. The study was approved by the University of Portsmouth Science Faculty Ethics Committee (ref: SFEC 2018-042).

Prior alcohol use behaviour

Alcohol use and drinking behaviour prior to the study was assessed using three subjective assessments: 1) self-reported units/week consumed assessed through a single question: "*How many units do you typically consume in a week? [Please note you cannot just count each drink as a unit of alcohol. The number of units depends on the different strength and size of each drink, so it can vary a lot. Here are some examples: Single shot of spirits (25ml, ABV 40%) = 1 unit; Alcopop (275ml, 5.5%) = 1.5 units; Small glass of wine (125ml, ABV 12% = 1.5 units); large glass of wine (250ml, ABV 12% = 3 units); bottle of beer/cider (330ml, 5% ABV) = 1.7 units; can of beer/cider (440ml, ABV 5.5%) = 2 units; pint of lower strength beer/cider (ABV 3.6%) = 2 units; pint of higher strength beer/cider (5.2%) = 3 units]*". In the UK, one alcohol unit is defined as 8g of 100%v/v alcohol. 2) The AUDIT: The English version of the AUDIT, originally developed by the World Health Organisation (Babor, Higgins-Biddle, Saunders, & Monteiro, 2001; Saunders, Assland, Babor, De La Fuente, & Grant, 1993), was designed to rapidly assess AUD disorders in a primary health care setting and has been shown to have good psychometric properties (Saunders et al., 1993; Stockwell, Murphy, & Hodgson, 1983). The AUDIT is scored on a scale from 0-40; scores >20 suggest alcohol dependency, and score >30 suggesting severe dependency. 3) The Binge Drinking Questionnaire (BDQ); adapted from the

AUDIT-C (Bush et al., 1998) is a 3-item assessment of binge drinking, scored out of 12, with scores >3 indicating the participant is a binge drinker. In the UK binge drinking is defined as consuming >3 drinks in a single session, based on the NHS guidelines of binge drinking i.e. consuming >6 units in a single session (the mean unit/drink in the UK is 2).

Neurocognitive measures

A battery of questionnaires (explicit assessment) and computer tasks (implicit assessment) were chosen to assess personality traits including and related to impulsivity i.e. risk-taking, sensation seeking, and decision-making. The Balloon Analogue Risk Task (BART) was programmed and implemented using PsychoPy software (Peirce, 2007, 2008). All other computer tasks and questionnaires were programmed and executed using the online version of the PsyToolkit software (Stoet, 2010, 2017).

Impulsivity: Impulsivity was measured using the Barratt Impulsiveness Scale (explicit; BIS-11; Patton, Stanford, & Barratt, 1995) and a Stop-Signal computer task (implicit; SST; Logan, Schachar, & Tannock, 1997), allowing both explicit and implicit assessment of the trait. The BIS-11 has previously been shown to have good psychometric properties in clinical environments and research (Stanford et al., 2009). Likewise, the SST has previously been successful in quantifying impulsivity in clinical (e.g. attention deficit hyperactivity disorder) and normative populations (Lipszyc & Schachar, 2010; Solanto et al., 2001). Here, participants are required to respond to an arrow centralised on a screen, pointing either left or right with the 'b' and 'n' keys respectively within 500ms. A white circle encompassing the arrow (go-signal) denotes that participants should respond. Should the arrow be surrounded by a red circle (stop-signal), participant should cease their responses. The SST started with a block of practice trials continued until either the participant completed a total of 50 practice trials or the participant completed 20 practice trials without mistake. Following the practice trials, participants completed 50 critical trials. There are three DVs measured in this task: response time (ms); errors of omission (i.e. failing to respond on a go-signal); errors of commission (i.e. responding on a stop-signal).

Risk-taking: Risk-taking was assessed explicitly using the Domain-Specific Risk-Taking Scale (DOSPERS; Blais & Weber, 2006). The DOSPERT is a scale designed to assess five sub-domains of real world risk-taking: E, ethical; F, financial; H, health; R, recreational; S, social and has been shown to be a reliable and valuable assessment of risk-taking via questionnaire (Highhouse, Nye, Zhang, & Rada, 2017). We also administered the Balloon Analogue Risk Task (BART; Lejuez et al., 2002) to the participants as a means of quantifying implicit 'real world' risk-taking. Here, participants are required to inflate an onscreen balloon using the spacebar. Each spacebar press equates to a single pump and a £0.05 increase in virtual currency earned; 'earnings' could be banked by pressing the enter key. There was a total of twenty balloons (trials) in each administration of the task, each with a randomly set tolerance. Over inflation of a balloon would cause it to be burst and the earnings for that trial to be lost. We were able to analyse early (pre-experience) responses, as well as, learn responses due to the inflation threshold being withheld from participants. The DV in the BART is the average number of pumps on unexploded balloons.

Sensation seeking: Sensation seeking, a trait closely related to impulsivity and risk-taking (Magid, MacLean, & Colder, 2007), was measured using the Arnett Inventory of Sensation Seeking (AISS; Arnett, 1994). The AISS uses a 4-point Likert scale (1 = does not describe me at all: 4 = describes me very well) to assess 20 statements related to sensation seeking which can be split into two 10-item subscales; novelty and intensity. The AISS has been shown to have good psychometric properties in several studies (e.g. Desrichard, Vos, Bouvard, Dantzer, & Pagnon (2008) and Roth & Herzberg (2004)).

Decision-making: Decision-making was measured via the Iowa Gambling task (IGT; Bechara, Damasio, Damasio, & Anderson, 1994). In this task, participants start with a 'loan' of £2000 and are presented with four on-screen choices 'A', 'B', 'C' and 'D'. After making a choice, participants are given feedback about their profit/losses. Choices 'A' and 'B' always yield £100 and choices 'C' and 'D'

always yield £50. Furthermore, with each choice there is a 50% chance of making a loss. The loss for choices 'A' and 'B' is always £250, whereas, the loss for choices 'C' and 'D' are always £50; therefore, choices 'C' and 'D' are more advantageous over the long-term. There was a total of 100 trials (choices) in this task. There are two independent variables: 'A-tendency' i.e. the tendency to choose 'A' and 'B' and 'B-tendency' i.e. the tendency to choose 'C' and 'D'. The literature suggests that individuals with higher impulsivity levels tend to discount the value of delayed rewards (Burdick, Roy, & Raver, 2013; Wittmann & Paulus, 2008) and will therefore have a greater A-tendency.

Stress reactivity: Stress reactivity was assessed using the 23-item Perceived Stress Reactivity Scale (PSRS; Schlotz, Yim, Zoccola, Jansen, & Schulz, 2011). The PSRS has is a standalone scale with five subscales: Prolonged Reactivity (PrR); Reactivity to Work Overload (RWO); Reactivity to Social Conflict (RSC); Reactivity to Failure (RFa); Reactivity to Social Evaluation (RSE). The psychometric properties of the PSRS has been established in several countries, with scores correlating with numerous stress related disorders (Schlotz et al., 2011).

Daily alcohol consumption

Daily alcohol consumption during the study period was assed using both self-report (estimation) and physiological measures. The self-report measure used simply asked participants to record, at the end of the day, the number of units consumed in that day (i.e., '*Please estimate the number of each type of drink that you have consumed today*'). The estimation was on a 12-point scale (0 drinks : >10 drinks) for each drink type. Drink types were: 1) Pint of beer/Cider; 2) ½ pint of beer/cider; 2) large glass of wine (250ml); 3) small glass of wine (125ml); single measure (25ml) of spirits (e.g. Vodka, Whisky, Rum); Alcopop (e.g. WKD, VK, Smirnoff Ice). This allowed participants to estimate the drinks consumed without calculating the units consumed, and was included as a means of reducing burden. Units/day were then calculated *post-hoc* using typical alcohol beverage unit contents derived from the NHS choices website (2018). Here a pint of beer/cider = 2.5 units; ½ a pint of beer/cider = 1.25 units; a large glass of wine (250ml) = 3 units; a small glass of wine (125ml) = 1.5 units; a single measure of spirits = 1 unit; and an alcopop = 1.5 units. Physiological data pertaining to alcohol use was measured using *AlcoSense Lite* breathalysers (Now Group, UK). *AlcoSense Lite* have an accuracy of $\pm 0.2\%$ blood-alcohol content (BAC) at the drink drive limit (35 $\mu\text{g}/100\text{ml}$ of breath; UK Government, n.d.) up to 1 decimal place and a maximum reading of 1.2% BAC.

Daily stress

Daily stress was assessed using the Daily Perceived Stress Scale (DPSS; adapted from the PSRS; Annex A). The DPSS is a 10-item questionnaire where participants use a 4-point Likert Scale (1 = disagree completely: 4 = agree completely) to rate statements related to their daily stress. Further details of the DPSS can be seen in Annex A.

Procedure

Phase 1: Laboratory Session. Once participant's suitability was confirmed following the pre-screening process described in the participants section of this manuscript, participants were invited to attend a single laboratory session lasting approximately 30 minutes. Before the laboratory session began, participants were given the opportunity to re-read the previously emailed participant information sheet and ask any questions and asked to re-confirm consent to take part. Following information and consent, participants completed the BDQ, unit/week question, BIS-11, SST, BART, DOSPERT, AISS, IGT and the PSRS. The order of the administration of questionnaires and computer tasks were counterbalanced to eliminate order effects. Participants were then trained on how to use the breathalysers and how to upload their daily data.

Phase 2: Daily data collection. Participants were required to provide daily alcohol use (units consumed/day and BAC) and stress (DPSS) data for 30 days immediately prior to going to bed. Participants were sent a link every day to the PsyToolKit website where they could log in with their unique ID number and fill out the required information/questionnaires. If a participant had not uploaded their data by 22:00 they were sent a follow up email reminding them to do so. If a participant

missed a day they were sent a second follow up email on the subsequent day to ensure all was well, and to remind them to take part.

Data preparation and statistical analysis

All data were analysed using R (version 3.4.4) for Windows®. For all parametric analyses, studentized residuals were examined for normality. DOSPERT E and DOSPERT H scores were non-normally distributed; however, a natural log transformation restored normality. A single score for the IGT was calculated (IGT score = b tendency – a tendency; where higher scores = more advantageous decision-making). As the *AlcoSense Lite* breathalysers denote the minimum reading of 0 with “Low” and the maximum reading of 1.2 with “High” we replaced these values with 0 and 1.2 respectively in our data. The percentage of missing data was calculated for each EMA variable i.e. daily alcohol use and daily stress (percentage of missing data = number of days of missing data / number of days * 100). To test the reliability of our measures we compared each group our variables using Pearson’s correlations, except BAC and unit/day (these variables were highly positively skewed, and could not be corrected with transformation, and thus were treated as gamma distributed for analyses) which were compared using Kendall’s Tau correlations. All variables were then compared for sex differences using independent samples t-tests. We also compared units/week participants estimated that they consumed *prior to* the study with units/week consumed *during* the study using a paired samples t-test.

To examine variables that predict alcohol consumption we used the “lme4” library to fit a series of generalized linear mixed models (GLMMs). Initial null models with BAC as the outcome variables confirmed that the studentized residuals were gamma distributed, which was accounted for in future models using the gamma distribution option (as units/day and BAC had ‘0’ values we first added 0.001 to each score). We then ran several null models to determine the best combination of nested random effects by comparing AIC values (where lowest is best). This process revealed that accounting for individual (i.e. ID number) as a random effect produced the best fit. We reasoned that drinking may differ during the week and at weekends, and we next fitted models with ‘weekend’ as a covariate. This model revealed that, as expected, alcohol consumption was significantly greater at weekends (Friday - Sunday). To account for this in future models, we split our data into two data frames (i.e. weekend and weekday) and analysed each separately. To examine which variables affected alcohol consumption, we grouped covariates into several categories: 1) descriptive variables (age and gender); 2) daily stress (DPSS); 3) previous alcohol and poly-drug use (AUDIT, BDQ, smoking, vaping, poly-drug use); 4) impulsivity (BIS-11 and SST); 5) risk-taking (BART and DOSPERT); 6) sensation seeking (AISS); 7) risky decision-making (IGT); 8) stress reactivity (PSRS). To test the hypothesis that impulsivity and related traits would modulate stress induced alcohol consumption, we added a daily stress as an interaction term for all models including covariates related to impulsivity (i.e. impulsivity, risk-taking, sensation seeking and risky decision-making). To remove noise, we employed a backwards elimination technique by sequentially removing non-significant predictor variables with the largest p-values ($p_s > .06$) until only significant terms remained ($p_s < .05$). There are three link functions that can be used with Gamma distributed GLMMs: inverse, identity and log. We ran each model with each of these link functions, and compared the AIC for each prior to backwards elimination, again choosing the model with the lowest AIC. Beta values were all unstandardized. Descriptive statistics are reported as mean $\pm$ SEM. All data are freely available via the Open Science Framework (<https://osf.io/yt93s>).

Results

Sample characteristics

[Table 1]

Sample characteristics in terms of descriptive statistics, alcohol use, personality traits and stress are reported in Table 1. Significant sex differences were found for four variables. DPSS was greater in females ($M = 16.63$, $SD = 3.61$) than males ($M = 14.62$, $SD = 3.87$), $t(620.29) = 6.74$, $p < .01$, Cohen's $d = .54$ [95% CI of difference = 1.42, 2.59]. PSRS RFa was also greater in females ($M = 0.58$, $SD = 1.08$) than males ($M = -0.73$, $SD = 1.01$), $t(20.99) = -3.0$, $p < .01$, Cohen's $d = 1.25$ [95% CI of difference = -2.22, -.40]. PSRS RSC was greater in female ($M = 5.67$, $SD = 2.23$) than males ($M = 2.36$, $SD = 2.25$), $t(20.79) = -3.35$, $p < .01$, Cohen's $d = 1.48$ [95% CI of difference = -5.25, -1.36]. PSRS RSE was greater in females ($M = 6.42$, $SD = 1.73$) than males ($M = 4.09$, $SD = 2.39$), $t(18.13) = -2.66$, $p = .02$, Cohen's $d = 1.12$ [95% CI of difference = -4.16, -0.49].

Participant engagement

[Figure 1]

Participant engagement was high with an overall response rate (response rate = 100 – percentage of missing data) of 92.66%. A detailed breakdown of the percentage of missing data for each day can be seen in Figure 1.

Bivariate analyses

[Table 2]

We examined intercorrelations between variables to assess the reliability of our measures of alcohol consumption, personality traits, prior alcohol use and stress. Both self-report-estimation and BAC measures of alcohol consumption during the study were strongly intercorrelated ($r_t = .71$, $p < .01$). As shown in Table 2, many of the assessments of personality traits were intercorrelated. Our assessments of prior alcohol use i.e. AUDIT, BDQ and units/week prior to the study taking place, and units/week during the study were all positively intercorrelated (all $r_s > .29$, all $p_s < .01$; data not shown). Our assessments of daily stress (DPSS) and stress reactivity (PSRS subscales) were also all positively intercorrelated (all $r_s > .11$, all $p_s < .01$; data not shown).

Self-report assessments of alcohol consumption reliability check

A paired samples t-test assessed the reliability of self-report measures of alcohol consumption revealed that self-reported alcohol consumption (units/week) during the study ($M = 22.7$, $SD = 14.57$) was 100% greater than estimated units/week prior to the study taking place ($M = 10.25$, $SD = 6.57$), $t(21) = -4.35$, $p < .01$, Cohen's $d = -.093$ [95% CI of difference = -19.33, -6.83]. This analysis suggested that estimated consumption was likely to be a poor representation of alcohol consumed. Therefore, despite the fact that estimated units/day was correlated with units consumed (BAC), we reasoned that the self-report was likely to be unreliable and was omitted from further analysis.

Alcohol consumption

Gamma distributed GLMMs were fitted to determine which covariates best predicted alcohol consumption (BAC). The details of model and each step of backwards elimination can be seen in the Annex B. In total we ran 9 models. In our first model, we found that the volume of alcohol consumed was significantly greater during weekends ($M = .32\%$, $SD = .46\%$) than during weekdays ($M = .24\%$, $SD = .41\%$), $\beta = .34$, S.E. $\beta = .17$, $t = 2.02$, $p = .04$. To account for this in subsequent models, we split the data into two subsets for 'weekend' and 'weekday' and ran future models on each subset. Our second model tested the effects of age and gender on alcohol consumption, and revealed no effects on daily BAC. Daily stress (DPSS) was the only covariate in our third model. Our fourth model examined the effects of reported alcohol-related behaviour on alcohol consumption during the study. This model showed that AUDIT significantly predicted a greater alcohol use at the weekend, $\beta = .13$, S.E. $\beta = .05$, $t = 2.41$, $p = .02$.

[Table 3, 4, 5, 6]

The next four models examined the effects of personality traits on alcohol consumption. Due to the large number of personality trait assessments, we grouped these covariates into four categories depending on what each variable was assessing: (i) impulsivity; (ii) risk-taking; (iii) sensation seeking; (iv) decision-making. To test the hypothesis that in impulsive/risk-taking individuals increases in alcohol intake would be predicted by daily reported stress, we added a trait x daily stress (DPSS) as an interaction term for each personality trait in each model. Table 3 displays the results of the final step of our model for covariates related to impulsivity following backwards elimination. On weekdays, SST commission errors predicted a decrease in drinking. On weekdays, greater BIS-11 motor, BIS-11 nonplanning and BIS-11 attentional scores predicted an increase in alcohol consumption. During the weekend, there were several interactions with SST performance and daily stress. For example, sub-categories of SST performance interacted with daily stress (DPSS) at weekends (SST RT) and weekdays (SST commission errors) to predict and increase in alcohol consumption. Furthermore, a greater number of SST omission errors at weekends, independent of stress, predicted a decreased level of drinking, however, interacted with stress to predict an increase in drinking. Table 4 displays the results of the final step of the model of covariates related to risk-taking. In this model we found BART and daily stress interacted to predict a greater volume of alcohol consumed at both weekends and on weekdays. BART, independent of stress, however, was associated with a *decrease* in drinking during weekdays.

Several DOSPERS subscales was associated with changes in drinking on weekdays. DOSPERS E and DOSPERS R were associated with decreased drinking and DOSPERS H was associated with an increase in drinking. Additionally, DOSPERS E, H and R all interacted with stress to predict an increase in alcohol consumption. Table 5 shows the final step of the model of covariates related to sensation seeking. At the weekend AISS intensity predicted an increased drinking. During the week, an AISS intensity x stress interaction was associated with a decrease in drinking. Table 6 displays the results for the final step of our model of covariates related to decision-making. On weekdays, more advantageous decision making (IGT score) predicted an increase in drinking. We also found more advantageous decision making assessed using the IGT interacted with stress to predict an increase in drinking at weekends; whereas during the week, a less advantageous decision-making x stress interaction was associated with increased alcohol consumption.

[Table 7]

To test the hypothesis that greater stress reactivity would increase alcohol consumption, our final model included our assessment of stress reactivity i.e. PSRS as a covariate. We also added a stress reactivity x daily stress interaction term for each subscale of the PSRS in the model to examine how stress induced alcohol consumption may be modulated by differences in stress reactivity. Table 7 shows the results of our final model. We found that, on weekends, a greater PSRS PrR score was associated with a decrease in alcohol consumption. Furthermore, we found PSRS PrR to interact with daily stress on weekdays to also predict a decrease in drinking.

Discussion

The primary aim of this study was to examine whether the use of ecological momentary assessments of alcohol use and stress are feasible to further study what leave some susceptible to alcohol misuse and potential subsequent addiction. Our data suggest that the use of daily assessments of stress and BAC measured via breathalyser, do indeed present a practicable and efficacious alternative to laboratory-based methods. There are, however, some limitations in the use of this novel technique which are outlined below. In addition, we aimed investigate whether the findings of our previous laboratory-based work could be replicated and generalised to a naturalistic environment. Towards this aim, we tested the hypothesis that in a sample of healthy drinkers, those with a greater level of impulsivity/risk-taking would consume a greater volume of alcohol following daily stress. We found support for our hypothesis, with higher risk-taking and impulsive participants drinking more following daily stressors. However, the picture was not clear, with participants drinking greater volumes of alcohol at weekends, and the interactions of stress x personality trait often differing between weekends and weekdays. The data support and extend our previous research, where we have found, using a laboratory stress-induction protocol, that risky decision-making predicts alcohol consumption in social drinkers (Clay & Parker, 2018). Our earlier research has also found that social drinkers with the propensity to take risks tend to have a higher craving following stress (Clay et al., 2018). Others have also demonstrated links between risk-taking and reported alcohol use in social drinkers (Ferne et al., 2010), as well as establishing that AUD patients show deficits in their decision-making ability (Fein, Klein, & Finn, 2004). Conversely, the relationship between impulsivity and alcohol consumption is less clear. Both our previous work (Clay & Parker, 2018) and a study conducted in a semi-naturalistic 'mock bar' environment, which aimed to investigate the role that impulsivity plays in stress induced alcohol consumption found no evidence that implicit impulsivity predicts stress-induced drinking (McGrath, Jones, & Field, 2016). Nevertheless, this could be due to differences between laboratory-induced and naturalistic stressors.

Previous research suggests that drinking motives (DM) are the most central component for consumption (Cooper, 1994), which act as a gateway less proximal influences, such as, personality traits (Cooper, Agocha, & Sheldon, 2000), which may explain why our data appear to suggest that neurocognitive endophenotypes have less influence on alcohol consumption at the weekend in comparison to weekdays. The literature supports the idea that DMs are temporally-influenced, with the motivation to drink on weekends apparently differing from the motivation to drink on weekdays. For example, many studies suggest that the motivation to drink during the week is often associated coping motives, such as the desire for stress-reduction (Lau-Barraco, Braitman, Linden-Carmichael, & Stamates, 2016; Studer et al., 2014). Conversely, weekend drinking is often associated with social pressures, such as those exuded by peers and family members, the opportunity to socialise and/or the desire to 'fit in' (Lau-Barraco et al., 2016; Oostveen, Knibbe, & De Vries, 1996; Studer et al., 2014). Others suggest that environment (e.g. private vs public setting), the number of intoxicated people present, and/or the frequency of attendees of the opposite sex present at the event (Thrul, Labhart, & Kuntsche, 2017; Trim, Clapp, Reed, Shillington, & Thombs, 2011) all play an important role in predicting heavy episodic drinking episodes. Thrul, Labhart, & Kuntsche (2017), for example, found the gender composition of drinking groups to be more important when predicting number of drinks consumed per hour than the size of the drinking group. Furthermore, within individuals that binge drink at weekends, the need to seek out fun and excitement is a key DM (Grittner, Kuntsche, Gmel, & Bloomfield, 2013) and sensation-seeking has been shown to significantly influence DMs and future alcohol use (Magid et al., 2007). We found support for this in our sample where participant's desire for intensity (quantified using the AISS intensity subscale) significantly predicted an increase in alcohol consumption at the weekend. Clearly the motivation and factors associated with drinking at weekends are highly complex and multifaceted, and require fractionating in order to establish their unique contribution. However, it appears that the modulation by risk-taking and impulsivity of responses to daily stress and personality may explain some of the variance associated with drinking.

Craving is thought to be one of the most important predictors for the onset of alcohol consumption (i.e. relapse), and in clinical populations there is a large body of work in support of this claim (e.g. Koob, 2008; Kwako & Koob, 2017; Litt et al., 2000; Robinson & Berridge, 1993; Schneekloth et al., 2012; Sinha, 2012; Sinha et al., 2011). It is also thought that stress is the key risk-factor for the onset on craving (Sinha, 2001; Sinha, 2009; Sinha & Li, 2007) and relapse (Sinha et al., 2011; Sinha, 2012). Therefore, it is assumed that stress levels increase proportionally to craving, in turn, acting as the causative factor for subsequent consumption. This process has been demonstrated, in both translational (animal) studies (Cleck & Blendy, 2008; Koob, & Kreek, 2007; Koob et al., 2004; Rasmussen, Wilkinson, & Raskind, 2006) and human studies (Clay et al., 2018; Field & Quigley, 2009; McGrath et al., 2016). Moreover, the literature suggests that adaptations in neural pathways related to stress (e.g. the HPA and SAM axes) in response to chronic alcohol are the underlying explanatory factors of this mechanism (Sinha et al., 2011; Sinha, 2012) - which can be characterised, for example, by cortisol dysregulation (Kreek & Koob, 1998). Surprisingly, in our data, stress alone did not predict alcohol consumption either at the weekend or on weekdays. Instead, we found that the risk of stress increasing alcohol consumption was mediated by several personality traits to significantly increase the volume of alcohol consumed by individuals. Specifically, our data suggests that both implicit (BART and IGT) and explicit (DOSPERT E, H, R) risk-taking and implicit impulsivity (SST commission errors) interact with stress to increase drinking during the week and implicit impulsivity (SST RT), risk-taking (BART), and explicit sensation seeking (AISS intensity) interact with stress to predict drinking at weekends. We also found risky decision-making (IGT), motor impulsivity (BIS-11 motor), non-planning (BIS-11 non-planning) impulsivity, risk-taking surrounding health (DOSPERT H) to significantly predict an increase in alcohol consumption independent of stress on weekdays. These findings are in accord with previous research that has highlighted the links between high levels of trait impulsivity/risk-taking and alcohol consumption in both social drinkers (Clay & Parker, 2018; Granö, Virtanen, Vahtera, Elovainio, & Kivimäki, 2004; Henges & Marczinski, 2012) and alcoholic populations (Czapla et al., 2016; Dom, Hulstijn, & Sabbe, 2006; Evren, Durkaya, Evren, Dalbdak, & Cetin, 2012). Collectively, it could be hypothesised that for an individual to experience alcohol craving intensely enough to elicit alcohol consumption/relapse, high levels of trait impulsivity must be present; i.e. both social drinkers with high levels of trait impulsivity and AUD patients (who tend to be more impulsive due to alcohol induced neuroadaptations) tend to crave more intensely and subsequently misuse alcohol more often. However, the proportion by which phenotypic impulsivity are effected by aetiology (genetics) or environment (alcohol induced neuroadaptations) is currently not clear; thus, future research should aim to investigate this topic.

Unexpected results

There were several unexpected results in our data. Our assessment of subjective daily stress (DPSS) alone did not predict alcohol consumption. As far as we can tell, this is a novel finding in the literature, which may be present due to the use of the subjective stress report being unreliable. However, using the present data, it is currently impossible to reliably infer this. Here we suggest that future research in this area should incorporate daily physiological assessments of stress alongside the subjective to allow for a reliability check between measures to be performed. Likewise, although many studies rely on self-reported measures of alcohol use, our results show that unit consumed/week was dramatically greater while the study was taking place when compared self-reports taken prior to the longitudinal data collection. Furthermore, when we compared our physiological measure of daily alcohol consumption (BAC) with reported alcohol use we found a correlation coefficient of only $r_t = .71$, suggesting that self-report assessments of alcohol use may fall victim to response-bias. Therefore, self-report alcohol use was omitted as a DV in our current analysis in favour of the physiological BAC reading. In future we will aim to use physiological biomarkers for the quantification of alcohol use as they have been shown to be reliable and have good participant uptake over a longitudinal basis in this study and in prior research (Skipper et al., 2014). Several assessments of impulsivity (SST commission errors) and risk-taking (BART, DOSPERT E and DOSPERT R), when tested independently from stress, significantly decreased drinking on weekdays. To the best of our

knowledge we are the first to demonstrate this effect; thus, we can only speculate the cause. One hypothesis might be that the construct of impulsivity is multifaceted with three core components i.e. risk-taking, response inhibition and impulsive decision-making (Courtney et al., 2012). Several of our assessments of these separate but related personality dimensions predict decreases in drinking when considered independently from stress, but predict increases in drinking when added as an interaction factor with stress, this suggests that those higher in impulsivity/risk-taking, when their perceived stress increases, show subsequent increases craving and consumption. However, our findings do appear to suggest that higher levels of impulsivity/risk taking may *reduce* alcohol consumption in the absence of stress, which was surprising and unexpected. To further understand this paradigm, future research should focus on investigating whether high levels of impulsivity/risk are indeed a protective factor against alcohol misuse in the absence of stress and/or whether low levels of impulsivity/risk-taking act as a protective factor generally.

Limitations

Findings from the current study should be interpreted in the context of several limitations. It is worth noting that the IGT has received criticism surrounding the reliability of the task to detect decision-making in healthy populations as the results are often heterogeneous (Steingroeverz, Wetzelsa, Horstmannb, & Neumannb, 2013). Our data suggest that this heterogeneity may be useful in explaining variability in alcohol consumption amongst social drinkers. However, it is important to note that not all measures of risky decision making were found to interact with stress to explain alcohol consumption. This should be considered when assessing the generalizability of the findings to risk-taking phenotypes in general. In addition, we also found evidence that attentional deficits, namely a greater number of commission errors during weekends and a greater BIS-11 attentional subscale score on weekdays, predicted a decrease in alcohol consumption. The literature suggests that heavy drinkers tend to show poorer attention overall (Thoma et al., 2011), therefore, we would expect alcohol consumption and attention deficits to have a positive relationship. Finding data that shows an inverse relationship could be a one-off, perhaps due to sampling error, however, as others have found that the number of past year hangover symptoms to be predictive of deficits in attention and executive function (Parsons & Stevens, 1986; Squeglia, Spadoni, Infante, Myers, & Tapert, 2009; Wagner, Parsons, Sinha, & Stevens, 1988), it could be suggested that the relationship between alcohol use and deficits in attention is a function of alcohol withdrawal severity and frequency. Therefore, we suspect that our sample did not experience hangover symptoms as frequently or intensely enough for alcohol to be the causal factor for the observed attentional deficit. Instead, the attentional deficit was present in the individuals prior to their initial alcohol use i.e. a genetic predisposition for poorer attention. On the other hand, as post-drinking symptoms are independent of the quantity of alcohol consumed and this study did not collect data on hangover frequency and severity, it is impossible for us to infer support for this hypothesis using our data. Interestingly, however, we did find attentional deficits (SST commission errors) to interact with stress at weekends to predict an increase alcohol consumption.

An alternative hypothesis may be then, that in a similar manner to our findings for impulsivity/risk-taking, both neurocognitive endophenotypes (including impulsivity, risk-taking and attentional deficits) and stress must be present for the risk of alcohol consumption to increase. As illustrated above, several trait assessments seem to act as protective factors until stress occurs. As these are indeed novel findings, future research should aim to first replicate them and then, should they be replicated, strive to characterise and understand the underlying biological mechanisms by which they occur. There were several additional interactions that deserve discussion. For example, implicit impulsivity (the BIS-11 non-planning subscale) sensation-seeking (AISS intensity) and decision-making (IGT) interacted with stress during weekdays to predict a decrease in alcohol consumption. Again, it may be that the nuanced differences between subtypes of impulsivity are dissociable, each with complex and varying effects of alcohol consumption, especially when interacting with stress. It is unclear at this stage what processes underlie the disparity between the effects of personality on mediating alcohol consumption at weekends and during the week, and this will require further research to clarify.

As this was a feasibility study, our sample size was relatively small. Although the sample size was calculated *a priori*, power analyses should be carried out in the light of our new findings to appropriately design follow-up studies to ensure sufficient statistical power to detect subtle effects. Furthermore, due to our sample being recruited from a pool of staff and students at the University of Portsmouth, our results may not be generalisable to other populations. Future studies should aim to recruit from a more diverse range of socioeconomic and sociocultural backgrounds. The generalizability of our data may be limited by the fact that the AUDIT and BDQ scores in our data suggests that our sample were predominantly hazardous drinkers. This may be cultural, as previous literature has emphasised the binge drinking culture in the UK (Kuntsche, Kuntsche, Thrul, & Gmel, 2017; Twigg & Moon, 2013), especially amongst young adults (Gill, 2002; Measham & Brain, 2005).

Again, as this was a feasibility study, we chose to use the commercially available (and relatively inexpensive) *AlcoSense Lite* breathalyser which outputs a maximum reading of 1.2%. Therefore, we may have limited the detection of outcomes in very heavy drinkers or heavy drinking episodes owing to ceiling effects. Additionally, the use of breathalysers in ecological momentary assessment research are limited in terms of the consistency at the time at which BAC was recorded. In other words, there is no way of certifying whether any given BAC reading was provided during the ascending or descending limb of intoxication. Previous research suggests that there are differences, in terms of executive functioning, between the ascending and descending limbs of intoxication (e.g. Pihl *et al.*, 2003), however, this body of work is generally inconclusive as more recent studies in naturalistic settings find no difference in executive function between limbs (Lyvers & Tobias-Webb, 2010). Nevertheless, it would be ideal to assess and control for differences (if they are found) in executive function, namely risk-taking behaviour, at different time points during drinking episode. Although this is not impossible to achieve using breathalysers, getting participants to comply in providing multiple breathalyser results per day, some of which must be provided during a drinking episode (perhaps while the participants is in public instead of in the privacy of their home) may prove difficult. Furthermore, there was also no way to control the time at which participants uploaded their BAC readings. For example, there may be both between-subject and within-subject differences in the time at which participants went to bed and thus uploaded their reading. One may suggest that we could avoid this by instructing participants to upload their data at a set time every day, however, participants may have not consumed any alcohol prior to the set time and may decide to start consuming alcohol after the deadline to upload their data, therefore, we would miss crucial episodic drinking data. Herein, we recommend that future studies should employ alternative equipment with a larger, more precise range of measurement in order to capture temporal variability and very high drinking episodes. One such piece of equipment may be one of the recently developed continuous transdermal alcohol monitors, such as, SCRAM CAM (Scram Systems, USA), WrisTAS, (Giner Labs, USA), BACtrack Skyn (BACtrack, USA). These monitors allow for real-time monitoring of alcohol use with little input from the participant, with one significant caveat: the cost.

Conclusion

In conclusion, this study was the first to demonstrate that using digital biomarkers and ecological momentary assessment to assess risk factors for alcohol misuse is a viable option, with exciting potential, for investigating the effects of neurocognitive endophenotypes and stress on alcohol misuse on a longitudinal basis. We have shown that impulsivity predicts stress-induced alcohol consumption in social drinkers in a naturalistic environment, replicating findings from our previous work carried out using laboratory induced stress. These findings highlight the growing importance for future research to investigate the specific mechanisms by which impulsivity/risk-taking interacts with stress to influence drinking. Future research in this area may ultimately allow for more accurate early identification of those most at risk of alcohol misuse and AUD. In addition, giving people the option to identify personal risk factors may help to empower those at risk to reduce their risk level by making positive behavioural change. Future research may examine the efficacy of this using a biomarker approach. Perhaps focusing characterising digital biomarkers for alcohol misuse through the use of smartphones. In the UK, approximately 66% of the population currently use smartphones, a number

that has been increasing year-on-year (Ofcom, 2017), allowing future research to be conducted and (potential) future treatments to be delivered, in a vast and growing proportion of the population.

Figure titles

Figure 1. Percentage of missing data for each day of the study.

Note: BAC, blood alcohol concentration; DPSS, Daily Perceived Stress Scale. 1 unit of alcohol = 8g 100% v/v ethanol. Percentage missing data = number of days of missing data / total number of days * 100.

Table titles

Table 1. Demographic characteristics of sample and raw data.

Note: PHQ-4, Patient Health Questionnaire for Depression and Anxiety; AUDIT, Alcohol Use Disorders Test; BDQ, Binge Drinking Questionnaire; BAC, blood-alcohol content; BIS-11, Barratt Impulsiveness Scale; SST, Stop Signal Task; DOSPERT, Domain Specific Risk-taking Scale [E, ethical; F, financial; H, health; R, recreational; S, social]; BART, Balloon Analogue Risk Task; AISS, Arnett Inventory of Sensation Seeking; IGT, Iowa Gambling Task; DPSS, Daily Perceived Stress Scale; PSRS, Perceived Stress Reactivity Scale [RWO, Reactivity to Work Overload; RFa, Reactivity to Failure; RSC, Reactivity to Social Conflict; RSE, Reactivity to Social Evaluation; PrR, Prolonged Reactivity]. * $p < .05$, ** $p < .01$, † $p < .08$

Table 2. Inter-correlations (Pearson's R values) of personality trait assessments.

Note: BIS-11, Barratt Impulsiveness Scale; SST, Stop Signal Task; DOSPERT, Domain Specific Risk-taking Scale [E, ethical; F, financial; H, health; R, recreational; S, social]; BART, Balloon Analogue Risk Task; AISS, Arnett Inventory of Sensation Seeking; IGT, Iowa Gambling Task. * $p < .05$, ** $p < .01$

Table 3. Summary of the final step of the generalized linear mixed model of variables related to impulsivity as covariates and alcohol consumption (BAC) as the outcome variable following backwards elimination.

Note: BIS-11, Barratt Impulsiveness Scale; SST, Stop Signal Task; DPSS, Daily Perceived Stress Scale. † $p < .10$, * $p < .05$, ** $p < .01$

Table 4. Summary of the final step of the generalized linear mixed model of variables related to risk-taking as covariates and alcohol consumption (BAC) as the outcome variable following backwards elimination.

Note: DOSPERT, Domain Specific Risk-taking Scale [E, ethical; F, financial; H, health; R, recreational; S, social]; BART, Balloon Analogue Risk Task; DPSS, Daily Perceived Stress Scale. ** $p < .01$

Table 5. Summary of the final step of the generalized linear mixed model of variables related to sensation seeking as covariates and alcohol consumption (BAC) as the outcome variable following backwards elimination.

Note: AISS, Arnett Inventory of Sensation Seeking. * $p < .05$, ** $p < .01$

Table 6. Summary of the final step of the generalized linear mixed model of variables related to decision making as covariates and alcohol consumption (BAC) as the outcome variable following backwards elimination.

Note: IGT, Iowa Gambling Task; DPSS, Daily Perceived Stress Scale. * $p < .05$, ** $p < .01$

Table 7. Summary of the final step of the generalized linear mixed model of our assessment of stress reactivity (PSRS) as a covariate and alcohol consumption (BAC) as the outcome variable following backwards elimination.

Note: PSRS PrR, PSRS, Perceived Stress Reactivity Scale Prolonged Reactivity. ** $p < .01$

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