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Risk factors for alcohol misuse: Examining heart rate reactivity to alcohol, alcohol sensitivity, and personality constructs

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Abstract

Objective: Heart rate reactivity to alcohol has been conceptualized as an index of alcohol-induced reward and has been associated with a sensation seeking personality profile. The goal of this study is to expand on previous findings regarding the significance of heart rate reactivity to alcohol while examining convergent lines of research on alcohol sensitivity, the rewarding effects of alcohol, and personality constructs.
Methods: Participants (N=47) were heavy drinkers who completed an intravenous alcohol challenge protocol.
Results: Analyses revealed a significant negative relationship between heart rate reactivity and alcohol-induced sedation and subjective intoxication. Heart rate reactivity was positively related to self-reported alcohol-induced vigor and to impulsivity and sensation seeking scores.
Conclusions: Taken together, these results suggest that individuals with heightened heart rate reactivity to alcohol appear to be more sensitive to the invigorating properties of alcohol, while being less sensitive to the sedative and unpleasant effects of alcohol intoxication. These findings have implications to the conceptualization of heart rate reactivity to alcohol as a biobehavioral marker of alcohol sensitivity.

Keywords: Heart rate; Alcohol; Intoxication; Sensitivity; Personality

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1. Introduction

A number of risk factors for the development of alcohol use disorders have been identified to date. Examples include cognitive (e.g. alcohol expectancies; Brown, 1993), behavioral (e.g. quantity and frequency of drinking), genetic (e.g. family history of alcohol use disorders; Heath & Phil, 1995), personality (e.g. experience seeking; Finn, Earleywine, & Pihl, 1992), and physiological (e.g. level of response to alcohol; Schuckit & Smith, 1996) variables, all of which have been associated with increased risk for alcohol misuse. Enhanced heart rate reactivity to alcohol has also been examined as an indicator of risk for alcohol pathology (Conrod, Pihl, & Vassileva, 1998). Heart rate reactivity during alcohol intoxication has been widely used in alcohol challenge studies, particularly in the context of: (1) stress response dampening research (for a review see Sayette, 1993); (2) alcohol and aggression (Asaad, Pihl, & Seguin, 2003; Hoaken, Campbell, Stewart, & Pihl, 2003) and (3) the psychomotor stimulant theory of addiction (Conrod, Peterson, & Pihl, 2001; Conrod, Peterson, Pihl, & Mankowski, 1997).

According to the psychomotor stimulant theory, substances with high abuse potential produce psychomotor stimulation. The theory posits that the stimulatory and rewarding effects of a vast range of addictive substances share an underlying biological mechanism (Wise & Bozarth, 1987). Consequently, individuals who experience greater alcohol-induced reward are thought to be more likely to develop alcohol problems. In this context, heart rate reactivity to alcohol is thought to serve as a psychophysiological index of alcohol-induced reward (Conrod et al., 2001; Fowles, 1983a, 1983b). Studies have shown that an increase in baseline heart rate during alcohol intoxication is associated with (1) changes in mood associated with the stimulant properties of alcohol (e.g. energetic–tired dimension) (Conrod et al., 2001); (2) enhanced sensitivity to reward (Brunelle et al., 2004); (3) higher scores on sensation seeking and reward seeking personality scales (Brunelle et al., 2004); (4) increased risk for gambling (Brunelle et al., 2003); and (5) higher self-reported alcohol consumption among non-alcoholic men (Peterson, Pihl, Seguin, Finn, & Stewart, 1993; Pihl, Giancola, & Peterson, 1995). Furthermore, a study by Reed and Hanna (1986) has suggested that heart rate reactivity to alcohol is under moderate genetic control.

In addition to studies of heart rate reactivity to alcohol, researchers have examined the relationship between heart rate reactivity and responses to appetitive stimuli, such as monetary rewards (Fowles, 1983a, 1983b). Specifically, heart rate reactivity was studied in the context of Gray's (1975) behavioral theories of appetitive versus aversive motivational systems. A series of studies by Fowles (1983a, 1983b) revealed that heart rate reactivity was more closely associated with appetitive motivational states than aversive ones, such that greater heart rate reactivity may indicate greater appetitive motivation. These earlier findings are consistent with recent research suggesting that individuals with greater alcohol-induced heart rate reactivity score higher on measures of sensitivity to reward, which in turn suggests an overactive behavioral activation system (Brunelle et al., 2004).

Support for the notion that alcohol-induced heart rate reactivity constitutes a risk factor for alcoholism comes from research suggesting that individuals with a multigenerational family history of alcoholism experience greater alcohol-induced heart rate reactivity during the rising limb of breath alcohol concentration, than individuals without a family history of alcoholism (Conrod et al., 1997). The same was true of highly aggressive sons of male alcoholics (Asaad et al., 2003). Interestingly, heart rate reactivity to alcohol has also been linked to an enhanced memory consolidation for positive stimuli (Bruce, Shestowsky, Mayerovitch, & Pihl, 1999). In summary, a number of studies have used heart rate

reactivity to alcohol as an index of alcohol-induced reward (e.g. Asaad et al., 2003). Furthermore, a paper by Conrod et al. (2001) has suggested that increases in heart rate during the ascending limb of BAL constitute a reliable and valid index of sensitivity to the stimulant effects of alcohol, as measured by mood states such as the energetic–tired dimension of the Profile of Mood States (POMS) (Conrod et al., 2001).

Nevertheless, several of the aforementioned studies suffer from methodological limitations, such as (1) samples comprised exclusively of male participants (Brunelle et al., 2004; Conrod et al., 2001, 1997); (2) the lack of a specific measure of alcohol-induced stimulation (Brunelle et al., 2004; Conrod et al., 2001, 1997); and (3) the lack of a direct measure of sensitivity to the rewarding effects of alcohol, such as "liking" of the alcohol exposure (Conrod et al., 2001). Furthermore, to the best of our knowledge, no study to date has concomitantly examined the relationship between heart rate reactivity to alcohol and alcohol sensitivity, reward, and personality structures within a single sample.

The primary goal of this study is to expand on previous findings regarding the significance of heart rate reactivity to alcohol while examining convergent lines of research on alcohol sensitivity, the rewarding effects of alcohol, and personality constructs. Specifically, this study will address three main research questions. First, it will examine the relationship between heart rate reactivity to alcohol and self-report measures of alcohol sensitivity, such as subjective intoxication, alcohol-induced stimulation, sedation, and changes in mood states. Second, heart rate reactivity to alcohol will be compared to self-reported "liking" of the exposure to alcohol, given that the latter constitutes a more direct measure of sensitivity to the rewarding properties of alcohol. Third, this investigation will examine the association between heart rate reactivity to alcohol and personality constructs associated with increased sensitivity to appetitive stimuli, namely sensation seeking and impulsivity. Consistent with the prior literature based on male-only samples, it is hypothesized that heart rate reactivity to alcohol will be positively associated with alcohol-induced stimulation and to impulsivity and sensation seeking. Conversely, heart rate reactivity is expected to be negatively associated with alcohol-induced sedation and subjective intoxication. Finally, individuals with higher levels of heart rate reactivity are expected to report greater "liking" of the exposure to alcohol, which is consistent with the conceptualization of heart rate reactivity as an index of sensitivity to the rewarding properties of alcohol.

2. Methods

2.1. Participants

Participants were 47 men and women (23 females) whose ages ranged from 21 to 29. Data on 38 of these subjects were presented in a previous investigation of genetic factors associated with individual differences in response to alcohol (Ray & Hutchison, 2004). Inclusion criteria were the following: (1) a score of 8 or higher on the Alcohol Use Disorders Identification Test (AUDIT), indicating a heavy drinking pattern (Allen, Litten, Fertig, & Babor, 1997); (2) self-reported drinking frequency of 3 or more drinks (2 for women) at least twice per week; (3) no history of adverse reactions to needle puncture; (4) successfully completing a physical health exam. In addition, all female subjects tested negative for pregnancy prior to the alcohol administration, and all subjects were required to have a breath alcohol level (BAL) of zero before each session.

2.2. Procedure

Telephone interviews assessed eligibility. Eligible participants were invited to the laboratory for a screening session. Upon arrival at the lab, participants provided informed consent, a saliva sample for DNA analyses, and completed a series of self-report measures of demographics, personality (IMPSS, see below), and drinking behavior. Based on the results from DNA analyses, participants were invited to the alcohol infusion session. Participants were selected on the basis of their allele status for the A118G SNP of the OPRM1 gene, such that groups were balanced on genotype (for details see Ray & Hutchison, 2004). A total of 101 participants (44 females) were screened in the laboratory, 54 took part in the physical exam, 49 of whom were eligible and willing to complete the alcohol infusion session. Complete heart rate reactivity data were available for 47 (23 females) of the 49 individuals who participated in the alcohol challenge.

During the experimental session, participants sat in a recliner chair and the IV was inserted in their non-dominant arm. Participants completed baseline assessments, which included the Subjective High Assessment Scale (SHAS), the Biphasic Alcohol Effects Scale (BAES), and the Profile of Mood States (POMS) (see measures below), before receiving any alcohol. In addition, baseline heart rate was collected before alcohol administration, at which time participants were asked to "relax" in their recliner chair. After completing the baseline assessment, participants received intravenous doses of alcohol. Participants then completed the SHAS, BAES, POMS, and "alcohol liking" assessments at each of the following points in the ascending curve of breath alcohol level: .02, .04, and .06. After the infusion, participants were debriefed, given a meal, and asked to stay in the lab until their BAL was below .02. All participants complied with this request and BAL was monitored periodically until it was safe for participants to leave the lab (i.e., when BAL $<$ .02). Participants were unaware of their blood alcohol level throughout the experimental procedure. The experimental sessions started between 10 am and 2 pm, in order to minimize experimental variability due to time of day.

2.3. Alcohol administration

A number of studies have highlighted the importance of effectively controlling blood alcohol levels in order to reduce experimental variability induced by individual differences in the pharmacokinetics of alcohol (Li, Yin, Crabb, O'Connor, & Ramchandani, 2001; O'Connor, Morzorati, Christian, & Li, 1998; Ramchandani, Bolane, Li, & O'Connor, 1999). This is particularly important when examining participants' sensitivity to the effects of alcohol. Therefore the intravenous alcohol administration paradigm was used. The alcohol infusion sessions took place at the General Clinical Research Center at the University of Colorado. The alcohol administration procedures were performed by registered nurses under the direct supervision of a staff physician.

The ethanol infusion was performed using a 5% alcohol IV solution. An infusion rate algorithm was developed, taking into account participants' gender and weight. Target breath alcohol concentrations were as follows: .02, .04, and .06. The following are the means and standard deviations for each of the target levels of intoxication: .02, M = .022, SD = .003; .04, M = .0404, SD = .002; and .06, M = .0602, SD = .002. Participants took an average of 18.69 min (SD = 7.34) to reach a BAL of .02 (and complete the assessments), 25.02 min (SD = 8.16) to go from a BAL of .02 to .04, and finally, 32.54 min (SD = 10.7) to reach the last target BAL of .06. In summary, these results suggest that the alcohol

infusion design yielded highly controlled and reliable levels of alcohol intoxication at all three trial points. For a more detailed description of the alcohol infusion procedure see Ray and Hutchison (2004).

2.4. Measures

The following measures were used to test the relationship between heart rate reactivity to alcohol and (1) sensitivity to the effects of alcohol intoxication (SHAS, BAES, POMS); (2) responses to the rewarding properties of alcohol (liking of the exposure to alcohol); and (3) personality traits (IMPSS).

2.4.1. Heart rate (HR)

Participants' heart rate was collected by a registered nurse once at baseline and once at each time point in the trial (BAL: .02, .04, and .06) using a Dinamap apparatus, produced by Critikon, which is designed to collect heart rate and blood pressure in medical settings. The importance of considering limb of alcohol intoxication has been highlighted in previous studies of the biphasic effects of alcohol (Conrod et al., 1997; Martin, Earleywine, Musty, Perrine, & Swift, 1993), suggesting that the stimulatory effects of alcohol are restricted to the ascending limb. The following measure of heart rate reactivity was computed to address the research questions proposed in this study: a difference score was calculated by averaging the three heart rate readings collected during the ascending limb of BAL, and subtracting the baseline heart rate. Collapsing across the three heart rate collections during the challenge (.02, .04, and .06) was done to increase the reliability of the index of alcohol-induced heart rate reactivity. For the purpose of this investigation, and in accordance with previous studies (e.g., Brunelle et al., 2004), participants were divided into two groups based on a median split on heart rate reactivity (Median score = − .67). Participants scoring at or above the median were classified as "high heart rate responders" ($n = 23$, *Mean* heart rate reactivity = +3.33, SD = 3.23) while participants scoring below the median were classified as "low heart rate responders" ($n = 24$, *Mean* heart rate reactivity = − 7.96, SD = 7.13).[1]

2.4.2. Subjective High Assessment Scale (SHAS)

The SHAS was used to assess subjective feelings of alcohol intoxication. This measure has been adapted by Schuckit (1984) and has since been used in alcohol challenge studies. Participants rated their feelings of intoxication on a 10-point Likert scale ranging from "not at all" to "extremely", and sample items included: "trouble concentrating," "drunk," and "slurred speech."

2.4.3. Biphasic Alcohol Effects Scale (BAES)

The BAES was used to collect information on self-reported stimulation (e.g. energized, excited) and sedation (e.g. sedated, sluggish) after alcohol administration. The BAES has been shown to be reliable and valid in studies of sensitivity to the pharmacological effects of alcohol (Earleywine & Erblich, 1995;

[1] We have labeled these groups in keeping with the conventional nomenclature in the literature (e.g., Brunelle et al., 2004) so that our results might be considered in light of similar research. It has been pointed out to us however, that "high HR responder" may be a misnomer in regards to our data given that the so-called "low HR responder" group showed a greater magnitude of change from baseline. Accordingly, from a stress–response dampening (SRD) point of view, the group we have termed "low HR responders" might be considered those with high SRD responses. The difference between an SRD and a psychomotor stimulant conceptualization may be a function of the biphasic effects of alcohol (i.e., psychomotor stimulant properties predominating on the ascending limb of BAL and SRD on the descending). The slower rate of alcohol administration in our study makes direct inference in this regard difficult (i.e., at a slower rate of alcohol administration, sedative effects may have an influence before the peak BAL is reached).

Martin et al., 1993). The BAES is composed of 14 items, 7 of which form the *stimulation subscale* and 7 items that make up the *sedation subscale*.

2.4.4. Profile of Mood States (POMS)

The short version of the POMS is a 40-item questionnaire, used in this study to assess changes in mood following alcohol consumption (McNair, Lorr, & Droppleman, 1971). The following subscales of the POMS were utilized in this study: *vigor*, *tension*, *positive* and *negative mood*. These scales were chosen on the basis of prior research (Conrod et al., 2001).

2.4.5. Liking of the exposure to alcohol

Liking of the alcohol was assessed using the following question: "Overall, how pleasant was it during the time that you were exposed to alcohol?" A 10-point Likert scale ranging from "not at all pleasant" to "very pleasant" was used to score responses.

2.4.6. Impulsivity and sensation seeking scale (IMPSS)

This measure consists of a total of 19 true/false items assessing impulsivity and sensation seeking (Zuckerman, 1996). Items included: "I often do things on impulse" and "I like doing things just for the thrill of it."

2.4.7. Rutgers Alcohol Problem Index (RAPI)

The RAPI was used to assess alcohol-related problems. This scale consists of 23 items that examine the impact of alcohol on social and health functioning over the past year. The RAPI has high reliability and validity, with an internal consistency of .92 (White & Labouvie, 1989).

3. Results

3.1. Pre-test comparisons

Prior to testing the research questions proposed in this study, the experimental groups (i.e. high and low heart rate responders) were compared across a number of potential confounding variables. No significant group differences were found with regard to gender, race, family history of alcohol problems, drinking frequency and quantity, and alcohol-related problems (see Table 1 for details). The null findings with regard to gender differences on heart rate reactivity to alcohol ($\chi^2(1) < 1.0$, ns) are particularly interesting given that this is the first study, to examine heart rate reactivity in a sample that included female participants. Likewise, there were no group differences with regard to alcohol-related problems, measured by the RAPI ($t(47) < 1$, ns). These results may be partially due to the relative homogeneity of our sample in terms of drinking patterns. Table 2 presents the results of pre-test comparisons of the experimental groups on the dependent measures of interest in this study, measured at baseline. Results revealed that "low heart rate responders to alcohol" had higher heart rate at baseline and reported higher levels of tension, measured by the Tension Subscale of the POMS ($p < .05$).

Additionally, given that participants were selected on the basis of their genotype on the A118G locus of the OPRM1 gene (see Ray & Hutchison, 2004), and in order to ensure that the selection process did not bias the results obtained in this study, the genotype used for participant selection was tested for its

Table 1
Pre-test differences between high versus low heart rate responders

Variable[a]	Low HR ($n=23$)	High HR ($n=24$)	Test for the difference
Change in heart rate from baseline	−7.96 (7.13)	3.33 (3.23)	$t(45)=-6.94$; $p<.0001$
Gender (% male)	56.52	45.83	$\chi^2(1)<1$, ns
Race (% Caucasian)	95.45	95.45	$\chi^2(2)=2.0$; $p=.37$
Family history of alcohol problems (% family history positive)	45.45	47.62	$\chi^2(1)<1$, ns
Age	22.30 (2.0)	21.63 (1.38)	$t(45)=1.36$; $p=.18$
Alcohol problems (Rutgers Alcohol Problem Index — RAPI) (possible range of scale: 0–92)	19.74 (14.82)	23.04 (14.23)	$t(45)<1$, ns
Frequency of drinking occasions in the past year (possible range of scale: 0–11; 6 = twice a week)	6.26 (1.10)	6.04 (1.85)	$t(45)<1$, ns
Average number of drinks per drinking occasion (in the last year)	3.85 (1.42)	4.63 (1.96)	$t(45)=-1.55$; $p=.13$

[a] Standard deviations appear in parentheses below the means of continuous variables.

association to heart rate reactivity to alcohol. Results did not support an association between genotype (A118G SNP or the OPRM1 gene) and heart rate response to alcohol ($\chi^2(1)<1.0$, ns), as well as heart rate at baseline ($t(45)<1.0$, ns), suggesting that the selection procedure did not bias the study results. Lastly, although breath alcohol levels were tightly controlled in this study, individual differences in the pharmacokinetics of alcohol could impact the rate at which target BALs were reached. Consequently, the experimental groups (high vs. low heart rate responders) were compared on how much time it took them

Table 2
Pre-test differences at baseline between high versus low heart rate responders

Variable[a]	Low HR ($n=23$)	High HR ($n=24$)	Range	Test for the difference
Baseline heart rate	72.74 (12.02)	65.96 (8.05)	50–93	$t(45)=2.28$; $p<.05$
SHAS	6.65 (12.61)	7.71 (9.48)	0–62	$t(45)<1$, ns
BAES: Stimulation subscale	14.35 (14.63)	15.75 (13.96)	0–49	$t(45)<1$, ns
BAES: Sedation subscale	5.36 (8.82)	7.71 (9.48)	0–40	$t(45)=-1.01$, ns
POMS: Vigor subscale	1.45 (1.0)	1.41 (0.76)	0–3.4	$t(45)<1$, ns
POMS: Tension subscale	1.2 (0.71)	0.82 (0.43)	0–2.6	$t(45)=2.14$; $p<.05$
POMS: Positive mood subscale	2.06 (0.85)	2.12 (0.69)	0.8–3.8	$t(45)<1$, ns
POMS: Negative mood subscale	0.43 (0.34)	0.55 (0.38)	0–1.7	$t(45)<1$, ns

[a] Standard deviations appear in parentheses below the means.

to reach each target BAL. Results revealed no significant group differences across trial ($F(1,45)<1.0$, ns), nor a group by trial interaction ($F(2,90)<1.0$, ns), suggesting that rate of intoxication is not a confounding variable in the present investigation. The experimental groups also did not differ on BAL across trial ($F(1,45)=1.08$, $p=.30$) and there was no group by trial interaction with regards to BAL ($F(2,90)=1.35$, $p=.26$).

3.2. Overview of analyses

The study hypotheses regarding differential alcohol sensitivity were tested using a series of 2×3 mixed design analyses of covariance in which heart rate group was a two-level between-subject factor (high versus low heart rate responders), trial was a three-level within subject factor (trial 1, BAL=0.02; trial 2, BAL=0.04; and trial 3, BAL=0.06), and baseline scores on the corresponding measure of interest were used as covariates. The overall goal of these analyses was to test for differences in sensitivity to alcohol between high and low heart rate responders across levels of intoxication (i.e. trial). In addition, the hypothesis regarding differences in personality profiles was tested by a Student's *t*-test comparing high and low heart rate responders on IMPSS scores.

3.3. Heart rate reactivity and alcohol-induced stimulation and sedation

Analyses revealed a significant main effect of heart rate group (high vs. low) on alcohol-induced sedation, measured by the sedation subscale of the BAES. Results were such that low heart rate responders reported higher levels of sedation during the alcohol challenge, as compared to high heart rate responders, after controlling for baseline sedation scores ($F(1,43)=6.41$, $p<.05$) (see Fig. 1). In addition, there was a main effect of trial, such that self-reported sedation increased across levels of BAL,

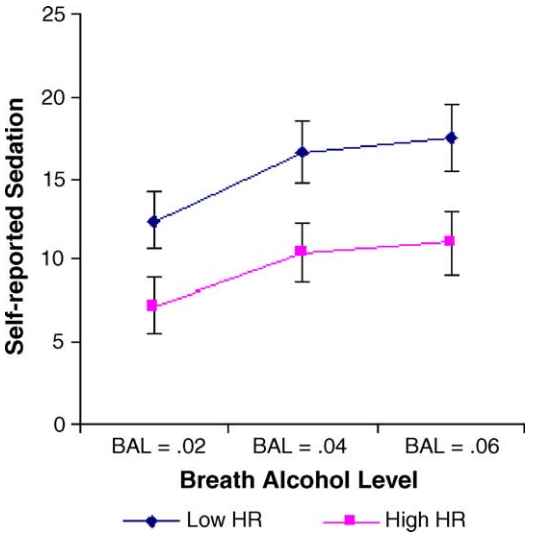

Fig. 1. Unadjusted Mean and SE self-reported alcohol-induced sedation for high and low heart rate responders. Analyses indicated that overall, high heart rate responders reported lower levels of sedation as compared to low heart rate responders ($p<0.05$), after controlling for baseline sedation scores.

$F(2,86)=6.08$, $p<.05$. Regarding alcohol-induced stimulation, there was no main effect of heart rate group on the stimulation subscale of the BAES, $F(1,44)<1.0$, ns. There was however, a main effect of trial, such that stimulation increased across levels of BAL, $F(2,88)=6.52$, $p<.01$. There were no significant group × trial interactions with regards to sedation or stimulation.

3.4. Heart rate reactivity and subjective intoxication

There was a main effect of heart rate group with regards to scores on the Subjective High Assessment Scale (SHAS), $F(1,44)=4.88$, $p<.05$. As shown in Fig. 2, high heart rate responders scored lower on the SHAS, during the alcohol challenge, as compared to low heart rate responders. In addition, there was a main effect of trial, such that subjective intoxication increased across levels of BAL, $F(2,88)=33.69$, $p<.0001$. No significant measure × trial interaction was found, $F(2,90)<1.0$, ns.

3.5. Heart rate reactivity and mood states

There was a significant main effect of heart rate group on the Vigor subscale of the POMS, such that high heart rate responders reported greater overall alcohol-induced Vigor, as compared to low heart rate responders, and after controlling for baseline scores on the Vigor subscale of the POMS, $F(2,42)=8.56$, $p<.01$ (see Fig. 3). There was no significant effect of trial or group × trial interaction with regards to Vigor, $F(2,84)<1.0$, ns. In addition, there was a trend towards a main effect of heart rate group on Tension, such that high heart rate responders scored higher on the Tension subscale of the POMS, after controlling for baseline tension scores, $F(1,42)=3.17$, $p=.08$. There was no significant effect of trial or group × trial interaction with regards to self-reported Tension, $F(2,84)<1.0$, ns. There was no main effect of heart rate group on positive mood (Happiness Subscale of the POMS; $F(1,42)<1.0$, ns) or

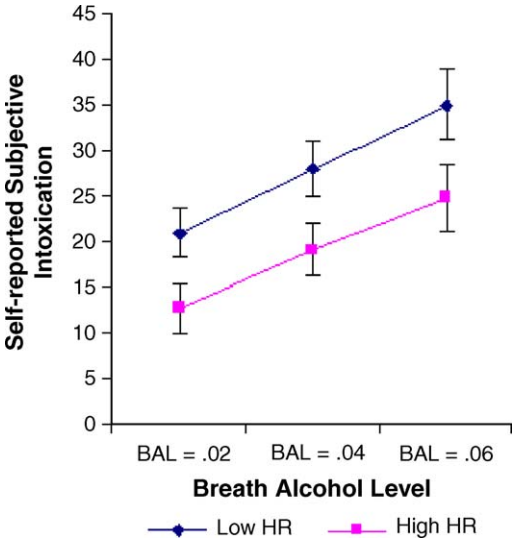

Fig. 2. Unadjusted Mean and SE self-reported alcohol-induced subjective intoxication (measured by the SHAS) for high and low heart rate responders. Analyses indicated that overall, high heart rate responders scored lower on the SHAS as compared to low heart rate responders ($p<0.05$), after controlling for baseline scores on the SHAS.

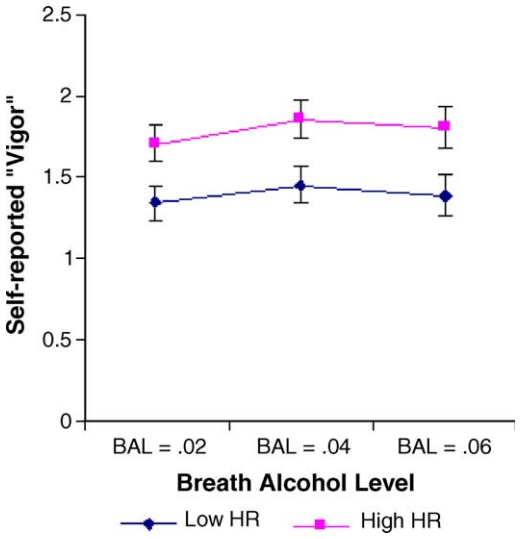

Fig. 3. Unadjusted Mean score and SE on the Vigor subscale of the POMS for high and low heart rate responders. Analyses indicated that overall, high heart rate responders scored higher on alcohol-induced vigor as compared to low heart rate responders ($p<0.05$), after controlling for baseline vigor scores.

negative mood (Depression Subscale of the POMS; $F(1,42)<1.0$, ns) during the alcohol challenge. There was no significant effect of trial on positive mood but there was a trend toward an increase in negative mood across levels of BAL, $F(2,84)=2.69$, $p=.07$. There were no significant group × trial interactions.

To ensure that the difference on baseline heart rate between the groups was not driving the effect of heart rate reactivity (i.e., HR after drinking minus HR at baseline), we repeated the analyses using a median split on baseline HR. Baseline heart rate by itself was unrelated to measures of sensitivity to alcohol during the trial, such as stimulation, sedation, subjective intoxication, and tension ($p>.05$).

3.6. Heart rate reactivity and "liking" the exposure to alcohol

Participants were asked the following question at each time point in trial: "Overall, how pleasant was it during the time that you were exposed to the alcohol?" Results revealed no significant main effect of group with regards to "liking" of the alcohol exposure, $F(1,43)<1.0$, ns. There was however, a significant effect of trial, such that "liking" of the exposure to alcohol increased across levels of BAL ($p<.0001$). There was no significant group × trial interaction.

3.7. Heart rate reactivity and personality profile

High and low heart rate responders were compared on their scores in the impulsivity and sensation seeking scale (IMPSS) using a Student's *t*-test. Results revealed that high heart rate responders scored significantly higher on the IMPSS (Mean=12.83; SD=3.60) than low heart rate responders (Mean=10.30; SD=2.70), $t(45)=-2.72$, $p<.01$.

4. Discussion

This study tested the relationship between heart rate reactivity to alcohol and measures of sensitivity to the effects of alcohol (i.e. stimulation, sedation, subjective intoxication, and mood states), responses to the rewarding properties of alcohol (i.e., "liking" of the exposure to alcohol), and a priori personality constructs (i.e., sensation seeking and impulsivity). The primary goal of this study was to replicate and expand previous findings on the significance of heart rate reactivity to alcohol while examining convergent lines of research on alcohol sensitivity, the rewarding effects of alcohol, and personality structures.

Results revealed that heart rate reactivity to alcohol intoxication was negatively associated with self-reported subjective intoxication and alcohol-induced sedation. In short, individuals who experienced heightened heart rate reactivity to alcohol intoxication reported lower levels of subjective intoxication and lower sensitivity to the sedative properties of alcohol. These findings are consistent with those of Conrod et al. (2001), who found that heart rate reactivity was inversely related to scores on the Subjective High Assessment Scale (SHAS). As suggested by Conrod et al. (2001), enhanced sensitivity to the invigorating properties of alcohol may be a parallel process to decreased sensitivity to the sedative effects of alcohol and subjective intoxication. The relationship between heart rate reactivity to alcohol and subjective intoxication, measured by the SHAS, is an important one given that the latter is a well-established biobehavioral risk factor for the development of alcohol use disorders (Schuckit & Smith, 1996). In light of this line of research, the present findings suggest that high heart rate responders are behaviorally similar to what Schuckit and Smith describe as "low responders" to alcohol (Schuckit & Smith, 1996).

Conversely, heightened heart rate reactivity during the challenge was positively associated with scores on the Vigor subscale of the POMS and there was a trend toward a positive association with scores on the Tension Subscale of the POMS. These findings are consistent with prior research, conducted with male-only samples, demonstrating a positive association between alcohol-induced heart rate reactivity and measures of mood (e.g. energetic-tired dimension) associated with the stimulant properties of alcohol (Conrod et al. 2001). Results regarding self-reported stimulation however, did not support the original hypothesis, such that alcohol-induced stimulation was not associated with heart rate response to alcohol.

These results must be interpreted in the context of methodological considerations. Specifically, prior research on heart rate reactivity to alcohol consisted of alcohol challenge protocols in which target breath alcohol levels were considerably higher than in this study (e.g., Target BAL=.1 in Conrod et al., 1997). In addition, the rate at which alcohol is consumed has been shown to impact heart rate reactivity, particularly among individuals with a family history of alcoholism (Conrod et al., 1997), such that a faster rate of consumption led to greater heart rate increases among those with a family history positive. In the present study, the rate of alcohol administration was considerably slower and steadier than most oral administration studies such that in the intravenous administration protocol, blood alcohol levels kept rising for an average of approximately 75 min. Methodological differences in target blood alcohol concentration and rate of alcohol administration may partially account for the lower levels of alcohol-induced heart rate reactivity observed in this study, as well as the lack of an association between self-reported stimulation and heart rate reactivity. Notwithstanding, our results suggest that high and low heart rate responders differed in their sensitivity, or acute tolerance (see Morzorati, Ramchandani, Flury, Li, & O'Connor, 2002), to alcohol even when blood alcohol concentrations were relatively low and rate

of alcohol administration was slow in comparison to most alcohol challenge paradigms that rely on an oral ethanol administration.

An additional novel contribution of this study is the fact that participants were asked about their "liking" of the exposure to alcohol, which evaluates their subjective responses to the hedonic and rewarding properties of alcohol. Results did not support the initial hypothesis that high heart rate responders would report greater liking of the alcohol exposure. Additional studies with larger samples and a more comprehensive assessment of responses to the rewarding properties of alcohol are needed to evaluate whether heart rate reactivity to alcohol captures individual differences in responses to the rewarding properties of alcohol (Conrod et al., 2001).

In accordance with the study's hypothesis, there was a positive association between the personality constructs of sensation seeking and impulsivity, and heart rate response to alcohol intoxication. High heart rate responders scored higher on the impulsivity and sensation seeking scale (IMPSS), than low heart rate responders. These findings are consistent with those of Brunelle et al. (2004), showing that individuals with a reward seeking personality profile experienced higher cardiac response to alcohol and suggesting that high heart rate responders may be characterized by an overactive behavioral activation system. Moreover, three findings obtained in the context of pre-test comparisons of the experimental groups deserve further consideration. First, no differences between male and female participants were noted with regards to heart rate reactivity. This finding is particularly important given that this is the first study to include females in its sample. Second, low and high heart rate responders did not differ on the Rutgers Alcohol Problems Inventory (RAPI), or on measures of drinking frequency and quantity. A possible explanation for the lack of a relationship between heart rate reactivity and drinking variables is that the present sample is highly homogeneous in terms of drinking behaviors (see inclusion criteria for details). It is possible that a range restriction with regard to drinking behaviors and alcohol-related problems may be obscuring the relationship between heart rate reactivity and drinking measures, given prior studies have lent support to the association between heart rate reactivity and alcohol use (Peterson et al., 1993; Pihl et al., 1995). Third, low heart rate responders to alcohol had significantly higher baseline heart rate and self-reported feelings of tension, as compared to high heart rate responders. However, additional analyses excluded the possibility that baseline HR, rather than HR reactivity, was driving the findings noted in the present study.

In summary, the present findings replicate and expand on the current knowledge about the usefulness of heart rate response to alcohol as an index of risk for alcohol misuse. Heightened heart rate response to alcohol intoxication in the laboratory was associated with: (1) increased self-reported alcohol-induced feelings of "vigor" and a tendency toward higher scores on "tension"; (2) lower sensitivity to the sedative properties of alcohol; (3) lower scores on the Subjective High Assessment Scale (SHAS); and (4) higher scores on a personality measure of impulsivity and sensation seeking (IMPSS). Taken together, these results suggest that heightened heart rate response to alcohol represents an important biobehavioral marker of alcohol sensitivity. In addition, this study has examined how heart rate reactivity to alcohol relates to other important risk factors for alcohol misuse, namely alcohol sensitivity and personality constructs. Specifically, individuals with a heightened heart rate response to alcohol intoxication appear to be more sensitive to the invigorating properties of alcohol, while being less sensitive to the sedative and subjective feelings of intoxication. Furthermore, those individuals appear to be characterized as more impulsive and as having a greater drive to seek rewarding experiences. Prior research has demonstrated that such characteristics are individually associated with greater alcohol consumption and increased risk for the development of alcohol-related problems.

The present study has a number of strengths and limitations. The alcohol administration paradigm confers tight control over breath alcohol levels, which is an important advantage of this study, although this methodological strength is obtained at the expense of external validity. Additionally, the present sample was comprised of both males and females, as opposed to most prior studies in this area, which have relied on male-only samples. This study is also the first to consider heart rate reactivity to alcohol in conjunction with alcohol sensitivity, reward, and personality variables within a single sample. Study limitations include the relatively small and homogeneous sample, primarily with regard to drinking behaviors, the lack of correction for Type I error due to multiple tests, and the absence of a placebo-control condition. Moreover, given the absence of a placebo control and a more naturalistic alcohol administration, this study cannot adequately address the effects of alcohol expectancies or cue reactivity on heart rate stimulation or on alcohol sensitivity as a whole. Nevertheless, this study adds to the literature by examining the purely pharmacological effects of alcohol. Another study limitation is the quasi-experimental nature of association studies, which precludes true random assignment and raises the possibility of unmeasured third variables influencing the relationships of interest. Consequently, our sample is unbalanced in terms of the selection genotype. Finally, the ideal methodological design for the assessment of risk factors for alcohol use disorders consists of longitudinal investigations such as those involving individual differences in levels of response to alcohol (Schuckit & Smith, 1996).

In conclusion, the present findings replicate and expand the current understanding of heart rate reactivity as a biobehavioral marker of alcohol sensitivity, while providing indirect support for its role as a potential risk factor for alcoholism. Further research is necessary to elucidate the specific pathways through which heightened heart rate response to alcohol intoxication may moderate the risk for alcohol use disorders. And most importantly, additional research is needed to explain how different physiological and behavioral risk factors interplay.

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