UNIVERSITY OF CALIFORNIA,
IRVINE

Resting Heart Rate Variability and Self-Reported Substance Use: An Emphasis on Potential Gender and Racial Differences

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Psychological Science

by

Enoch S. Kwon

Dissertation Committee:
Assistant Professor DeWayne P. Williams, Chair
Professor Jodi A. Quas
Distinguished Professor Julian F. Thayer
Associate Professor Alyson K. Zalta

2024

DEDICATION

To

First and foremost, God. Everything I have ever accomplished and achieved is only possible through God's will.

My Wife, Pauline, who has seen both the best and worst of me and continues to love and support me in all circumstances. Thank you for making me a better person each and every day.

My Son, Ethan, I look forward to all of the cherished memories we will make together.

My Family, as they are my absolute rock and foundation. Throughout all of the struggles we have been through together, I could not be where I am today without the love and support of my parents and my brother.

My Friends, who have supported me through all of the highs and lows of life, and have been a great reminder that life is best lived amongst others.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

I would like to extend my deepest gratitude to my committee chair, Dr. DeWayne Williams, for his exceptional guidance and support throughout my PhD journey. In a relatively short period of time, Dr. Williams has transitioned from being merely my research advisor to a mentor in various facets of life. His ability to foster my growth as a researcher has been instrumental, and his positive influence in both my personal and professional life is undeniable. Dr. Williams is someone I hold in high regard and will continue to look up to for inspiration and advice.

I am also deeply thankful to my dissertation committee members for their invaluable contributions to my research and academic development. Dr. Jodi Quas, Dr. Julian Thayer, and Dr. Alyson Zalta have provided me with insightful feedback, encouragement, and expertise that have greatly enhanced the quality of my work. Their commitment to excellence and their willingness to share their knowledge have been pivotal in shaping my dissertation. I am grateful for their guidance and support throughout this journey.

I also want to express my gratitude to the other graduate students who have been incredibly helpful, answering my questions and providing support along the way. Their contributions, no matter how small, have been crucial to the completion of this dissertation and my success in the graduate program.

Finally, I would like to express my gratitude to Frontiers for granting permission to reference my previous publication, originally published in *Frontiers in Psychiatry*. Additionally, I extend my thanks to the University of California, Irvine, for providing financial support, which has been instrumental in allowing me to pursue my personal and academic goals. The support and resources offered by the University have been vital in my academic journey.

VITA

Enoch S. Kwon

2014	B.S. in Psychobiology (Neuroscience), La Sierra University
2014-16	Research Assistant, College of Human Ecology, Cornell University
2016	M.A. in Human Development (Psychology), Cornell University
2020	M.A. in Social Ecology, University of California, Irvine
2018-24	Teaching Assistant, Department of Psychological Science, University of California, Irvine
2020-24	Research Assistant, IEQP Psychophysiology Lab, University of California, Irvine
2023-24	Ph.D. Candidate in Psychological Science, University of California, Irvine

FIELD OF STUDY

Health Psychology

PUBLICATIONS

Kwon, E. S., Kittaneh, A. A., Gerardo, G. M., Koenig, J., Thayer, J. F., & Williams, D. P. (2022). Resting Heart Rate Variability, Perceived Emotion Regulation, and Low-Risk Drug Use in College-Aged Adults: Gender as a Moderator. *Frontiers in Psychiatry*, *13*. https://doi.org/10.3389/fpsyt.2022.885217

ABSTRACT OF THE DISSERTATION

Resting Heart Rate Variability and Self-Reported Substance Use: An Emphasis on Potential Gender and Racial Differences

By

Enoch S. Kwon

Doctor of Philosophy in Psychological Science

University of California, Irvine, 2024

Assistant Professor DeWayne P. Williams, Chair

This dissertation investigates the relationship between resting heart rate variability (HRV) and substance use, including the potential moderating roles of gender and race. Study 1 analyzes data from the Midlife in the United States Study (MIDUS) to examine cross-sectional associations between resting HRV and substance use, exploring potential gender differences and mediation effects involving emotion regulation (ER). Results indicate that men reported higher emotion control, alcohol consumption, and cigarette smoking compared to women. Higher resting HRV was associated with increased alcohol consumption, particularly in women, while no significant link was found between resting HRV and cigarette smoking. Mediation and moderation models did not yield significant findings. Study 2 utilizes data from the Augusta Heart Study to examine associations between resting HRV in late adolescence and substance use in early adulthood, again while considering gender and race. Results show that men and European Americans used more substances than women and African Americans, respectively. However, resting HRV did not predict substance use. Among African Americans, the slope between resting HRV and cigarette smoking was more positive in women than in men. These findings suggest that resting HRV may not be a particularly strong predictor of substance use but could still hold relevance in specific

contexts or subgroups. Further research is needed to explore the complex interplay of factors influencing substance use behaviors. This dissertation highlights the importance of understanding various motivations for substance use and emphasizes the need for ongoing research targeting individualized treatments based on marginalized identities.

INTRODUCTION

The Substance Abuse and Mental Health Services Administration (2014) posits that early substance use (e.g., smoking, alcohol, non-prescription drugs) can lead to addiction, a chronic, relapsing disorder characterized by compulsive substance seeking and use despite adverse consequences (American Psychiatric Association, 2013; NIDA, 2020). Substance use that leads to abuse has been linked to poor psychological and physiological health and well-being. Consequently, understanding the biological and social underpinnings of recreational substance use becomes essential and justified for promoting overall well-being and longevity.

Substance use elicits intense emotions, ranging from remarkably high states and pronounced euphoria, to severe negative states that cause disruptions in homeostasis (Koob, 2015). Repetitive substance use also produces abnormal activation of incentive salience/reward systems. For example, it can trigger the release of dopamine and opioid peptides in the extended amygdala, both of which play crucial roles in guiding behavior toward high-value incentives in the environment (Koob, 2015). Abnormal release can lead to an overemphasis on drug-related rewards at the expense of natural rewards, potentially altering the brain's reward circuitry. Consequently, the neurophysiological pathways underlying emotional states might be disrupted, as the brain becomes increasingly reliant on substance-induced stimuli to regulate emotions. Such disruption is indicative of poorer emotion regulation (ER), defined as an individual's ability to modify their emotional experiences, expressions, and subsequent physiological responses to appropriately respond to ever-changing environmental demands (Aldao, 2013). In other words, ER functions as a mechanism that enhances coping with environmental demands (Jarymowicz, 2002; Jarymowicz & Imbir, 2015). In the case of substance use, poorer or ineffective ER may be linked with increased recreational substance use, in part as an additional form of self-regulation.

Neurophysiological Mechanisms of Emotion Regulation and Substance Use

Self-regulation, often reflected via inhibition, has the potential to diminish strong internal predispositions or external temptations, enabling individuals to choose the most appropriate and necessary response (Diamond, 2013; Williams et al., 2015). From a neurophysiological perspective, cortical brain regions, such as the prefrontal cortex, exert inhibitory control over subcortical structures, such as the amygdala, facilitating adaptive responses to environmental demands and enabling effective self-regulation, including emotion regulation (ER) when needed (Thayer et al., 2012). In a resting state, active cortical brain regions may indicate higher flexibility in inhibitory control, thus promoting self-regulation (Thayer and Lane, 2000; Thayer et al., 2012). Importantly, converging evidence suggests that one way of indexing the activity of cortisol regions and hence self-regulation, is in autonomic nervous system activity (Thayer et al., 2012).

Specifically, Thayer and Lane (2000) proposed that characteristic beat-to-beat variability in the heart rate time series—heart rate variability (HRV)—serves not only as an index of healthy heart function (Thayer & Lane, 2007) but also as a readily available index and measure of inhibitory control, emotion regulation (ER) ability (Williams, 2015; Visted et al., 2017), and overall self-regulatory abilities (Thayer et al., 2012). Several neuroimaging and pharmacological studies have identified the link between inhibitory executive brain regions and cardiac parasympathetic activity as indexed by resting HRV (Ahern et al., 2001; Lane et al., 2009; Thayer et al., 2012). The Neurovisceral Integration Model proposes that HRV is an index of parasympathetic activity, and thus resting HRV serves as a readily available biomarker of self-regulatory (e.g., emotional and cognitive control) abilities. For instance, individuals with higher resting HRV have demonstrated more effective behavioral responses (e.g., faster response times

and better accuracy) on executive cognitive tasks (Hansen et al., 2003) as well as more flexible and adaptive emotional responding relative to individuals with lower resting HRV (Ruiz-Padial et al., 2003; Thayer et al., 2009), both of which are believed to reflect better self-regulation. In contrast, individuals with lower resting HRV exhibit hypoactive prefrontal brain activation, which results in hyperactive subcortical structures believed to contribute to maladaptive cognitive and poor emotional self-regulation (Thayer et al., 2012). Overall, a reciprocal cortico-subcortical inhibitory neural circuit may serve as the structural link between psychological processes such as ER and health-related physiological processes, and this circuit can be indexed by resting HRV (Thayer et al., 2012).

As it relates to substance abuse, converging evidence suggests that lower HRV, which itself is reflective of poorer self-regulation, is linked to increased alcohol abuse (Eddie et al., 2021; Ralevski et al., 2019), cravings for alcohol, and associated negative mood (Ingjaldsson et al., 2003). Additionally, chronic alcohol and cigarette use are associated with reduced resting HRV (Guo et al., 2022; Koshiken et al., 1994; Ryan & Howes, 2022). Prior research has also explored the potential use of HRV biofeedback intervention, added to a traditional 28-day substance abuse disorder inpatient treatment program, as an effective tool for reducing substance cravings (Eddie et al., 2014). Specifically, the study revealed that decreased resting HRV, indicating poorer self-regulation, was associated with an increase in cravings, while increased resting HRV was linked to a more substantial decrease in cravings from the beginning to the end of treatment (Eddie et al., 2014). Experimental studies have shown that interventions aimed at increasing HRV, such as HRV biofeedback, can lead to reduced substance use, suggesting a potential causal link (Eddie et al., 2014). Moreover, longitudinal studies indicate that individuals with higher baseline HRV are less likely to develop substance use disorders, providing further

evidence of a causal relationship (Porges, 2011). These findings suggest that lower resting HRV might contribute to increased substance use, further emphasizing the relevance of HRV as a potential target for substance use intervention. Additionally, mechanistic studies have proposed that HRV influences the autonomic regulation of emotional and stress responses, which are critical factors in substance use and relapse (Thayer et al., 2012).

However, little research has linked resting HRV with self-reported history of substance use. This gap is significant, as individual differences in resting HRV appear to be a useful index in identifying individuals' likelihood of engaging in recreational substance use – a potential gateway to substance abuse. My recent report (Kwon et al., 2022) highlighted an indirect association between self-reported substance use (non-prescription drugs) and resting HRV. However, I did not find evidence of a direct association, despite previous evidence suggesting otherwise (e.g., Kroll et al., 2021). Notably, the sample in my study was comprised of relatively young and healthy individuals, with only "low-risk" levels of substance (drug) use. Therefore, it is crucial and necessary to examine the associations between resting HRV and substance use history in a more diverse group of individuals who span varying ages, genders, and races, and who potentially have used a wider range of substances. Such expanded research will provide novel insights into the relationship between resting HRV and early substance use, with potential for future substance abuse.

Marginalization and Substance Use

Social inequities, both structural (e.g., laws and policies, substance accessibility) and individual (e.g., sexism, racism), have been linked with greater substance use, which is particularly problematic for both women and people of color in the U.S. These inequities have been shown to directly elevate substance abuse among at-risk populations. Indeed, marginalized

individuals often seek substance use to decrease stress, which can originate from or be exacerbated by previously mentioned social inequities (Borrell et al., 2006; Clark, 2004; Guthrie et. al, 2002; Landrine & Klonoff, 2000; Mays et al., 2007; Mendrek, 2014). These trends, in combination, highlight the ongoing need to understand resting HRV's links to substance across marginalized groups. Yet to my knowledge, to date, few studies have focused specifically on how such links might vary between marginalized and non-marginalized individuals.

For example, although the gender gap in substance use has been decreasing over the past few decades (Mendrek, 2014), the National Institute on Drug Abuse (NIDA) states that men are still more likely than women to use almost all types of substances (Center for Behavioral Health Statistics and Quality, 2017). Women, however, have faced significant social inequities for centuries compared to men. The motivations for substance use differ between genders: men typically use substances to induce feelings of elation, energy, or focus, whereas women often use substances to alleviate high stress levels, feelings of alienation, depression, anxiety, or post-traumatic stress disorder (Mendrek, 2014). These motivations align with social inequities, meaning that women could be an at-risk group for substance use, especially when emotion regulation (ER) is compromised. My recent article supports this, showing a stronger link between resting HRV, ER difficulties, and low-risk drug use among young women compared to young men (Kwon et al., 2022).

Similarly, there is a substantial difference in the propensity for substance use between African American and European American adolescents. Research indicates that European Americans predominantly initiate substance use (e.g., alcohol and cigarettes) for sensation-seeking purposes (Brown et al., 2004). However, this motivation does not predict substance use among African Americans and even seems to have an opposite effect in some instances (Brown

et al., 2004). Substance use among African Americans might serve as a coping mechanism to deal with stress from social inequities (e.g., experiences of discrimination; Borrell et al., 2006; Clark, 2004; Guthrie et al., 2002; Landrine & Klonoff, 2000; Mays et al., 2007). This disparity is important to consider within the context of gender, as the intersection of being an African American woman can be met with unique and more detrimental social inequities, such as sexism paired with racism (Crenshaw, 2013), shaping more maladaptive substance use behaviors.

In sum, understanding the impact of gender, along with the potentially intricate interplay between race and gender, on the link between resting HRV and substance use can significantly contribute to developing targeted interventions for marginalized individuals. These interventions could better address substance use challenges, promote adaptive stress-related coping mechanisms, and improve health outcomes.

Current Dissertation

This dissertation comprises a two-study investigation that examined the link between resting HRV and self-reported substance use, and importantly, explored whether the link varied based on gender in Study 1, and both gender and race, directly and in combination, in Study 2.

Study 1 aimed to replicate my previous findings (Kwon et al., 2022) using data from the Midlife in the United States Study (MIDUS), which is a comprehensive dataset of middle-aged adults. The current study examined cross-sectional associations between resting HRV and substance use and how these associations varied based on gender. The research also considered the possible mediating effects involving ER, with an emphasis on gender as a potential moderating factor.

In Study 2, data from the Augusta Heart Study was utilized to examine prospective associations between resting HRV and substance use six years later, with a specific focus on

understanding potential differences based on gender and race. The prospective aspect of this study is crucial to the overall theory, suggesting that ER abilities, marked by resting HRV, may influence the likelihood of initial engagement in substance use, particularly for marginalized individuals.

Overall, my dissertation aimed to provide novel insights into the critical association among resting HRV, ER, and substance use. From a clinical perspective, these findings may reveal potential intervention targets, focusing on both objective (i.e., HRV) and subjective (i.e., self-reported) ER processes to reduce the likelihood of substance use and positively impact future substance use behaviors.

STUDY 1

Substance use, specifically cigarette smoking and frequent alcohol consumption, is linked to major causes of death such as heart disease and cancer (Rostron, 2012; CDC, 2024). These behaviors not only lead to tens of thousands of deaths annually but also cost the nation billions of dollars each year. The World Health Organization reports that, as of November 2023, over 8 million people die prematurely from tobacco use each year, with more than 7 million of these deaths resulting from direct tobacco use. Additionally, approximately 1.3 million non-smokers die each year due to second-hand smoke exposure. In the U.S., smoking rates have decreased from 20.9% in 2003 to 11.5%, yet tobacco use remains the leading cause of preventable disease and death, accounting for about one in every five deaths. Furthermore, nearly 178,000 deaths in the U.S. each year are related to excessive alcohol use, with about one-third due to accidents and two-thirds to chronic health conditions resulting from chronic alcohol use. Numerous studies have linked smoking and alcohol consumption to key biomarkers of physiological function and health, such as immune (e.g., white blood cells), inflammation (e.g., c-reactive protein), and cardiovascular (e.g., blood pressure) biomarkers (Shiels et al., 2014; King et al., 2017; Wannamethee et al., 2005; Primatesta et al., 2001). Substance use has shown to predict these metrics prospectively, suggesting a directional impact of smoking on these biomarkers (e.g., Bodin et al., 2017).

While the physiological and health effects of smoking tobacco and alcohol consumption are well-established, the psychological aspects of substance use are more complex. Generally, increased substance use is often associated with higher levels of psychopathology, such as anxiety and depression (Smith & Book, 2008; Quello et al., 2005). High alcohol consumption can lead to poorer ER, which may exacerbate depressive symptoms (Saban & Flisher, 2010).

Similarly, reliance on tobacco may worsen anxiety symptoms. However, it is also believed that psychopathology can predict substance use, with individuals turning to substances as a coping mechanism for stress-related psychological issues (Gilbert, 2014). In this context, maladaptive ER, characterized by poor control over emotions and impulses, is implicated in the tendency to use substances as a form of self-medication.

In a resting state where no objective stressors are present, HRV serves as a marker of both ER abilities and overall risk for disease, especially cardiovascular disease (Thayer & Lane, 2000). As such, research has investigated the link between substance use and resting HRV, generally finding a negative association. For example, lower resting HRV is associated with greater alcohol abuse (Eddie et al., 2021; Ralevski et al., 2019), including cravings for alcohol and associated negative mood (Ingjaldsson et al., 2003). Empirical evidence suggests that both acute and chronic smoking lead to lower HRV. An ecological momentary assessment study found that smoking led to acute decrements in HRV, and resting HRV was lower in smokers compared to non-smokers (Bodin et al., 2017). This result suggests that individuals with poorer ER, as indexed by lower HRV, are more likely to engage in cigarette smoking. However, much of the research continues to focus on biomarkers such as HRV and active substance use, rather than a history of substance use (Kwon et al., 2022).

Furthermore, substance use can lead to abnormal activation of the incentive salience/reward systems, such as dopamine and opioid peptide release in the extended amygdala, which plays a crucial role in guiding behavior toward high-value incentives in the environment (Koob, 2015). Thus, neurophysiological pathways underlying emotional-motivational states may be disrupted in individuals who engage in substance use (Kwon et al., 2022). This disruption is evident in the link between resting HRV, an index of emotional state, and self-reported ER, an

index of motivational state (Williams et al., 2018). In other words, innate ER abilities marked by higher resting HRV may not translate to better ER among individuals who use substances (Kwon et al., 2022). This is problematic, as interventions aimed at increasing HRV and/or ER may not have an equal impact on the opposing metric in those who use substances. In, sum converging evidence links substance use, especially smoking, with death and disease mediated by poor physiological function.

It is therefore not surprising that psychologists and clinicians have worked for decades to implement effective interventions to disrupt the propensity and cravings for such substances. However, the number of substance users remains elevated and problematic for public health, which may be due to research overlooking how the propensity to use substances differs between groups.

Gender Differences

As it relates to brain areas involved with ER, resting HRV, and the cravings underlying addictive substances, a meta-analysis revealed that men typically have a larger amygdala (in volume) compared to women, whereas women have larger frontal brain structures, including the prefrontal cortex (Ruigrok et al., 2014). From a functional perspective, imaging studies have identified gender differences in the upregulation and downregulation of negative emotions; several reports found that women display more activity in the frontal lobe and amygdala (Gardener et. al, 2013) in response to negative stimuli compared to men (see Stevens & Hamann, 2012, for meta-analysis). Taken together, this suggests basic gender differences in the very brain areas responsible for both ER and resting HRV. Likewise, a recent meta-analysis (Koenig & Thayer, 2016) found women to have greater resting HRV despite greater heart rate than do men. This is “paradoxical,” as higher HRV should be associated with lower heart rate and better mood

states such as lower anxiety and depression, yet women generally report higher levels of both anxiety and depression (Leach et al., 2008). From a psychological perspective, one study demonstrated that higher resting HRV had a significant negative association with self-reported difficulties in ER (Williams et al., 2015), and another found this association was strongest among women (Williams et al., 2018).

In addition to gender differences existing in HRV and possibly its associations with ER, gender differences also emerge when considering substance use and the propensity to use substances (Brown et al., 2004). Men use substances more frequently than women, yet women report higher levels of psychopathology, a precursor to substance use. It is interesting to consider that gender differences in HRV and ER might help explain disparities in substance use tendencies. Generally, women have better emotional clarity and awareness, along with higher resting HRV, compared to men. This suggests greater emotional control among women, which aligns with their lower likelihood of having a history of substance use. However, women typically report higher levels of psychopathology, such as depression and anxiety, which aligns with their general propensity to initially use substances. Consequently, such psychopathology might be particularly linked to a history of substance use in women.

This suggests a possibility of gender differences in the relationships between resting HRV and self-reported substance use, however little research has documented such possibilities. Additionally, given the stronger link between resting HRV and ER among women relative to men, substance use might primarily disrupt this link among women relative to men. To my knowledge, only my recent study has explored these possibilities together comprehensively. In my young and largely healthy population, a history of substance use in early adulthood was related to resting HRV more strongly in women relative to men mediated by ER difficulties. My

study was also the first to consider how substance use might alter the link between resting HRV and ER, in which this link was disrupted in women but nonexistent among men. In other words, women who engaged in low-risk drug use relative to women who did not, the link between resting HRV and self-reported drug use was attenuated. The link did not exist in men users or non-users. These findings underscore the importance of considering resting HRV as a potential intervention target for substance use, with a particular emphasis on women, who may be influenced by social inequities that influence the likelihood of substance use. In sum, despite converging evidence of lower HRV to be linked with increased substance use, research has not adequately considered specific groups (e.g., women) for which this association might be the strongest, in addition to the complex role of ER. When considering risk for substance use, such differences signify ER might be a more important factor among specific groups relative to others. More work is needed in this domain.

Current Study 1

Study 1 built upon my previous research (Kwon et al., 2022) by examining a middle-aged adult sample from the Midlife in the United States (MIDUS) dataset. The study aimed to investigate the cross-sectional associations between resting HRV and substance use and to examine how these associations differ between women and men. Additionally, the study explored potential mediation effects of self-reported ER and potential moderation effects of gender.

I hypothesized that lower resting HRV and ER would be independently associated with higher substance use. Consistent with my previous findings (Kwon et al., 2022), I expected the relationship to be more pronounced among women compared to men. I also hypothesized that ER would mediate the relationship between resting HRV and substance use, such that individuals

with more effective ER would exhibit lower levels of substance use, with this relationship being more pronounced among women.

METHOD

Study 1 Sample

The initial sample for this study was drawn from the Midlife in the United States (MIDUS 2) Biomarker Project, conducted between 2004 and 2009. This project aimed to collect biological data from a subset of MIDUS respondents to complement the extensive social, behavioral, psychological, and cognitive data collected in the broader MIDUS study. The biomarker data were gathered to assess various aspects of physical health, including cardiovascular, neuroendocrine, and immune system functioning (Ryff, et al., 2004-2009).

Participants in the Biomarker Project constituted a subsample of the larger MIDUS 2 cohort, which included individuals aged 34 to 84 years. The original biomarker subsample comprised 1,255 individuals who agreed to undergo a comprehensive overnight clinic visit, during which various biological samples (such as blood, urine, and saliva) were collected, and physiological assessments (such as blood pressure and HRV) were conducted (Ryff, et al., 2004-2009).

The demographic composition of the biomarker subsample mirrored that of the larger MIDUS 2 cohort, with a balanced representation of men and women and diverse educational and socioeconomic backgrounds. It should be noted, though, that the sample primarily comprised individuals of European American descent, with limited representation from African American and other racial groups (precluding analyses of race, see Study 2). In addition, due to insufficient biomarker data and incomplete substance use questionnaires, the Milwaukee subgroup was

excluded, as were those in the Twin subgroup. Therefore, the study utilized the main Random Digit Dial biomarker subsample, consisting of 640 individuals.

Data Collection

Data collection for this study included obtaining participants' medical histories through telephone interviews and self-administered questionnaires. Additionally, a comprehensive physical examination was conducted, and biomarkers were measured. See the MIDUS 2: Biomarker Project for a description of consent, recruitment, and session details (Ryff, 2004 - 2009).

Heart Rate Variability (HRV)

Cardiovascular activity was evaluated following an overnight stay at one of three General Clinical Research Centers (at UCLA, University of Wisconsin, and Georgetown University). Participants were instructed to have a light breakfast, excluding caffeinated beverages. The assessment involved continuous monitoring with a 3-lead electrocardiogram (ECG), with electrodes positioned on the left and right collarbones and the left lower quadrant of the abdomen. A respiration band was placed around the participant's chest, and a Finometer beat-to-beat blood pressure cuff was secured around the middle finger of their non-dominant hand. Data were recorded during an 11-minute baseline assessment while the participants were seated, and these data were used for the analysis.

HRV was analyzed using time-domain and frequency-domain indices. In the time domain, indices included the standard deviation of RR intervals and the root mean squared successive differences (RMSSD). In the frequency domain, measures focused on spectral power in the low-frequency (0.04-0.15 Hz) and high-frequency (0.15-0.50 Hz) bands. Spectral analysis was performed using a method similar to DeBoer et al. (1984), involving centering the RR

interval series around zero, applying a Hanning window filter to minimize spectral leakage, and computing power spectral density with Fourier transforms. The resulting spectral power measures, expressed in milliseconds squared ($msec^2$), offer insights into the autonomic modulation of heart rate (Task Force, 1996). LF-HRV reflects a combination of sympathetic and parasympathetic activity, while HF-HRV predominantly indicates parasympathetic (vagal) nervous system activity, with higher values generally associated with better health (Thayer et al., 2010). HF-HRV values were highly correlated with RMSSD, leading to the use of baseline HF-HRV. The mean values of HF-HRV and LF-HRV were calculated (averaged) from two 5-minute epochs. Prior to analysis, the HF-HRV and LF-HRV values were natural-log transformed (ln) (Ryff. 2004 – 2009).

Self-Report Questionnaires

Emotion Regulation

ER tendencies were assessed using the Emotion Control subscale of the Self-Control Scale, consisting of six items measuring participants' ability to control their emotions. Participants responded to each item on a 7-point Likert-type scale, where 1 represents "strongly disagree" and 7 represents "strongly agree." An example item is: "I control my emotions by changing the way I think about the situation I'm in." Four of these six items are adapted from James Gross's Emotion Regulation Questionnaire, designed to assess emotional suppression and cognitive reappraisal. From these items, an index of emotion control was computed by summing them together.

Substance use

Substance use was assessed via self-report, focusing on alcohol and cigarette use. Participants responded to the following questions: (1) "Have you ever smoked cigarettes

regularly, that is, at least a few cigarettes every day?"; (2) "During this period, how many cigarettes did you smoke per day, on average?"; (3) “During the past month, have you had at least one drink of any alcoholic beverage such as beer, wine, wine coolers, or liquor”?; and (4) "During the past month, on the days when you drank, about how many drinks did you drink on average?" Four substance use variables were created, two dichotomous and two continuous. For cigarette use, a dichotomous variable was created to compare individuals who have never smoked with those who have smoked (history of cigarette use). Similarly, for alcohol use, a variable was recoded to compare those who drank in the past month with those who did not drink in the past month (current alcohol use). Continuous variables included the number of cigarettes per day (lifetime) and the number of alcoholic drinks per day (past month), with no use coded as "0."

STATISTICAL ANALYESES

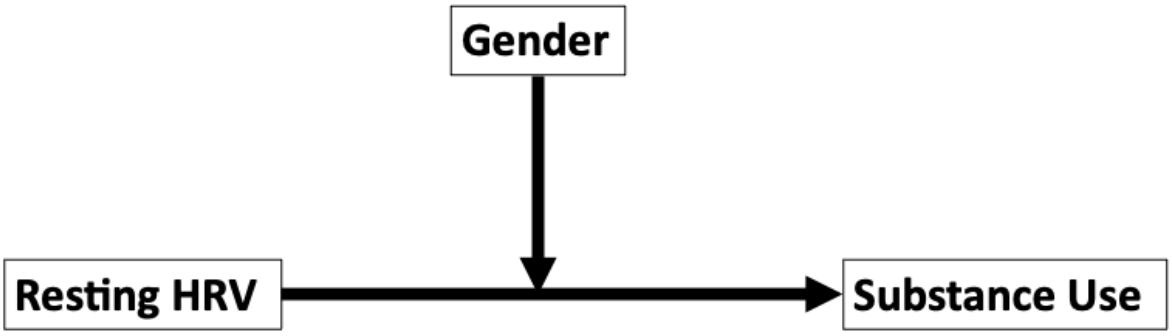
All statistical tests and analyses were conducted using SPSS software (version 29, IBM, Chicago, IL). The significance level (alpha) for all tests was set at 0.05, and two-tailed tests were utilized to assess statistical significance. Sociodemographic analyses were initially conducted to inspect the data and generate specific descriptive statistics for all variables. T-tests were used to determine potential mean differences between women and men on these variables.

Bivariate correlations were run to examine the association between all variables of interest; Spearman's Rho correlations were used for dichotomous and non-normally distributed continuous variables. Partial r correlations were used to adjust for potential covariates including age and body mass index (BMI) in examining associations between ER, HRV, and substance use. These analyses were also conducted stratified by gender group.

To test whether gender moderated the relationship between resting HRV and ER (independently) and dichotomous substance use, the SPSS macro-PROCESS (Hayes, 2022) was utilized. Specifically, PROCESS 'Model 1' was used to test the moderating effect of the independent variable (IV; resting HRV), the conditional effect of the moderator (M; gender), and the interaction effect of the two on the dependent variable (DV; substance use) (**See Figure 1 for conceptual representation**). This analysis allowed for the exploration of whether the relationship between resting HRV and substance use differed depending on gender.

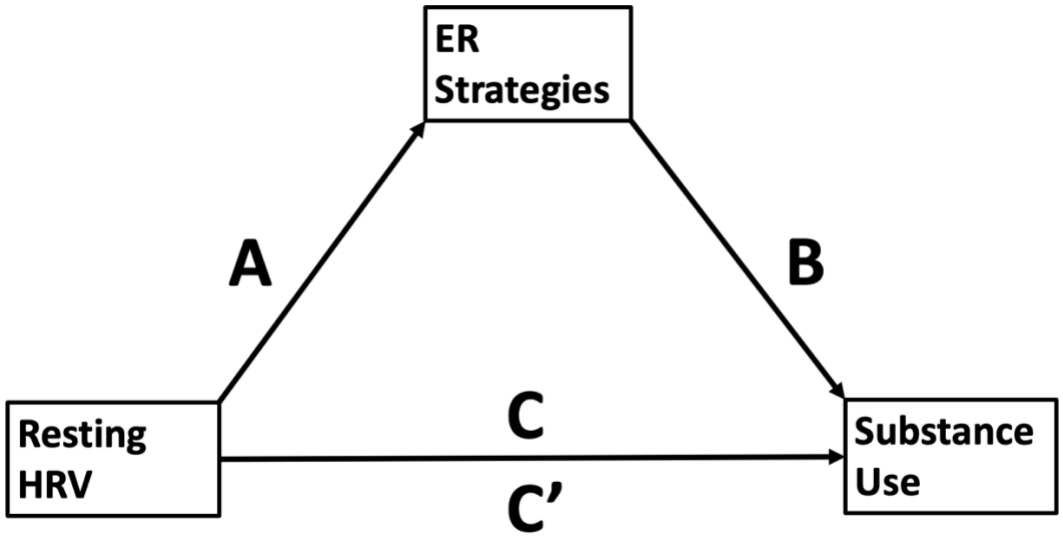
To investigate potential mediation effects of ER strategies on the links between HRV and substance use, PROCESS 'Model 4' was employed. In this analysis, resting HRV served as the independent variable (IV), substance use as the dependent variable (DV), and ER strategies as the mediating variable (**See Figure 2 for conceptual representation.** Additionally, the role of gender as a potential moderating factor was examined using PROCESS 'Model 58,' which is a moderated-mediation model. This entailed exploring whether gender has a moderating effect on the proposed mediation model involving resting HRV, ER strategies, and substance use (**See Figure 3 for conceptual representation**).

FIGURE 1.



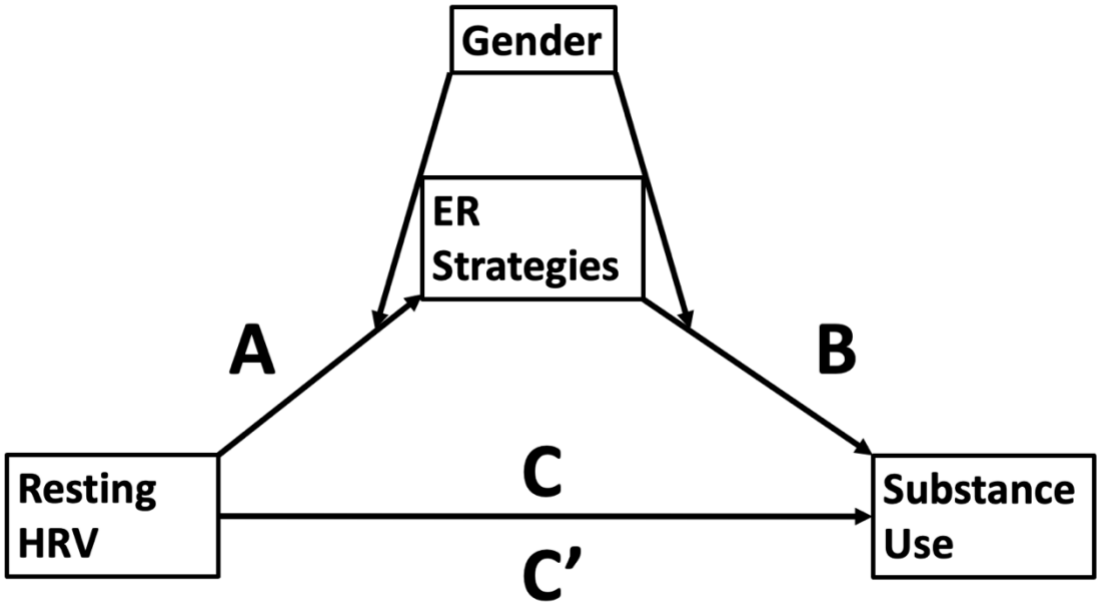
Note. Conceptual Moderation Model for Study 1: This model tests the potential moderating effect of the independent variable (resting HRV), the conditional effect of the moderator (Gender), and the interaction of the two on the dependent variable (dichotomous substance use for both substances).

FIGURE 2.



Note. Conceptual Mediation Model for Study 1: This model tests the potential mediation effects of ER strategies on the relationship between resting HRV and dichotomous substance use (for both substances).

FIGURE 3.



Note. Conceptual Moderated-Mediation Model for Study 1: This model tests the potential moderating effect of Gender on the proposed mediation involving resting HRV, ER strategies, and dichotomous substance use (for both substances).

RESULTS

Participant Demographics

Means and standard deviations for all variables of interest within the full sample (N = 640) are presented in **Table 1**. Additionally, **Table 2** presents means and standard deviations for all variables of interest stratified by gender. Significant gender differences were observed in several variables. Men had significantly higher levels of emotion control (M = 4.78, SD = .71) compared to women (M = 4.60, SD = .81), p = .004. Furthermore, women reported lower past month alcohol consumption (M = 1.50, SD = .78) and lifetime cigarette use (M = 14.49, SD = 11.10) compared to men (alcohol use: M = 2.03, SD = 1.51; cigarette use: M = 19.62, SD = 17.35), with p = .001 for alcohol use and p = .024 for cigarette use. There were no significant

differences between men and women in resting HRV (p = .535), BMI (p = .389), or age (p = .206).

TABLE 1. Sample demographics on variables of interest (Full Sample)

Total (N = 640)	
Age	56.23 (11.80)
BMI	29.56 (6.21)
Resting HRV	4.73 (1.26)
Emotion Control	4.68 (0.77)
Past Month Alcohol Use Cont. (N = 429)	1.77 (1.23)
Lifetime Cigarette Use Cont. (N = 165)	16.98 (14.66)

Note. This Table presents the means and standard deviations (in brackets) on variables of interest in the full sample (N = 640). Alcohol Use Cont. = Past month, on the days when you drank, about how man drinks did you drink on average?; Cigarette Use Cont.= During this period, how many cigarettes did you smoke per day on average?

TABLE 2. Mean differences between men and women on variables of interest

	Men	Women	*p*
Age *(Men: N = 301); (Women: N = 339)*	56.86 (11.99)	55.68 (11.620)	0.206
BMI *(Men: N = 301); (Women: N = 338)*	29.79 (5.19)	29.36 (7.00)	0.389
Resting HRV *(Men: N = 272); (Women: N = 309)*	4.70 (1.30)	4.77 (1.22)	0.536
Emotion Control *(Men: N = 301); (Women: N = 337)*	4.78 (.71)	4.60 (.81)	**0.004***
Past Month Alcohol Use Cont. *(Men: N = 214); (Women: N = 215)*	2.03 (1.51)	1.50 (.78)	**0.001***
Lifetime Cigarette Use Cont. *(Men: N = 80); (Women: N = 85)*	19.62 (17.35)	14.49 (11.10)	**0.024***
Past Month Alcohol Use Dich. *(Men: N = 301); (Women (N = 339)*	215 (86)	215 (124)	**0.035***
Lifetime Cigarette Use Dich. *(Men: N = 301); (Women (N = 339)*	156 (145)	157 (182)	0.178

Note. This Table presents the means and standard deviations (in brackets) on variables of interest stratified by women and men. T-Test statistics include *p* - values. Dichotomous variables present the group who has smoked and used cannabis and those who have not (in brackets). Fisher-Z statistics and associated *p* - values reported for dichotomous substance use variables. HRV = heart rate variability; BMI = body mass index; Cont. = Continuous; Dich. = Dichotomous. Significant differences bolded. *$p < .05$

Zero-Order Correlations Among Variables of Interest

Correlations among variables of interest in the entire sample are presented in **Table 3A.** In the full sample, age was negatively correlated with resting HRV ($r = -.180$, $p < .001$) and alcohol use ($\rho = -.252$, $p < .001$), and positively correlated with emotion control ($r = .133$, $p < .001$). Moreover, resting HRV was positively correlated with past month continuous alcohol use ($\rho = .145$, $p = .004$) (**Figure 4).**

Stratified by gender (**Table 3B**), in men, age was negatively correlated with resting HRV ($r = -.183$, $p = .002$) and past month alcohol use ($\rho = -.272$, $p < .001$), and positively correlated with lifetime cigarette use ($\rho = .228$, $p < .001$). BMI was negatively correlated with resting HRV

(r = -.130, p = .032). In women, age was also negatively correlated with resting HRV (r = -.291, p < .001) and past month continuous alcohol use (ρ = -.259, p < .001), and positively correlated with emotion control (r = .216, p < .001). Moreover, resting HRV was positively correlated with past month continuous alcohol use (r = .212, p = .002) (**Figure 5).**

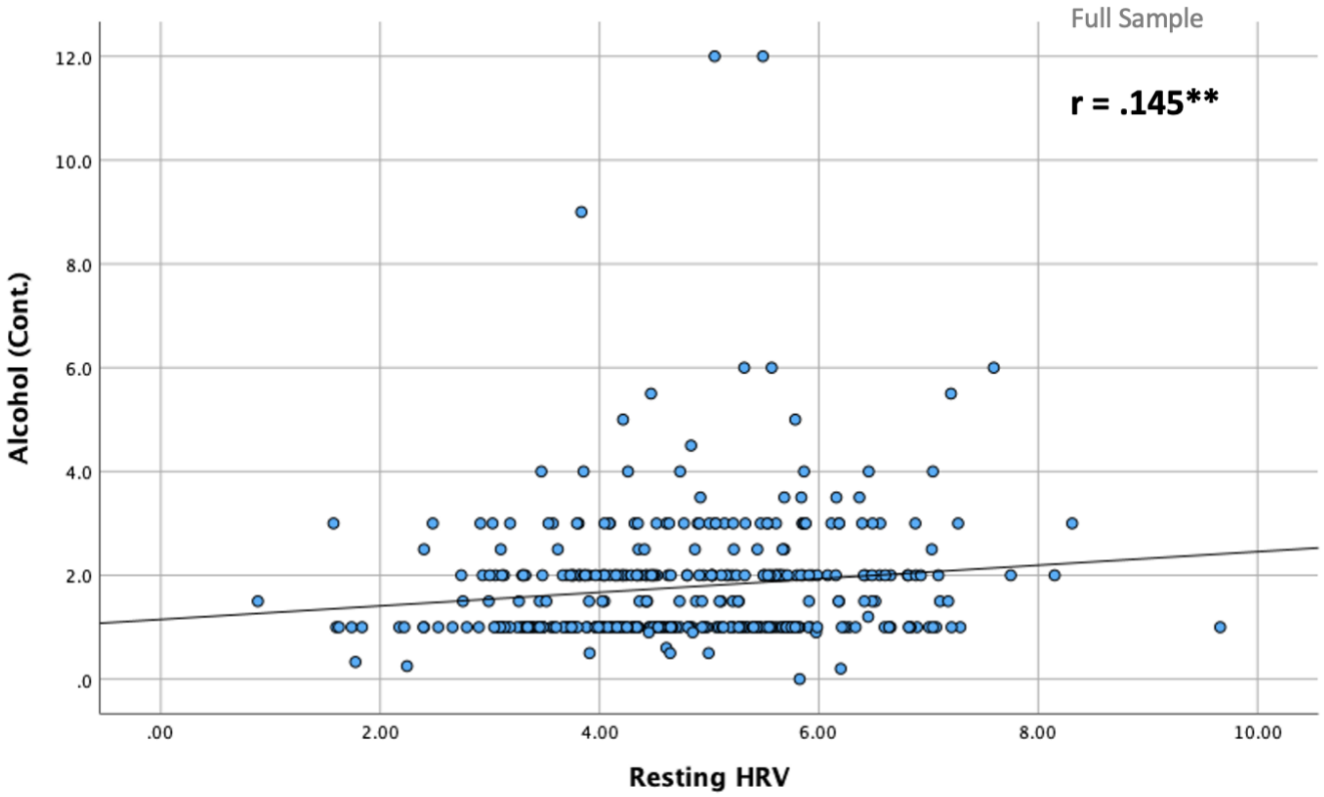
TABLE 3. Correlation coefficients for full sample and stratified by gender

Table 3A (Full Sample)		1	2	3	4	5	6	7	8
1	Age	--							
2	BMI	-.052	--						
3	Resting HRV	**-.239****	-.042	--					
4	EC	**.133****	-.058	-.012	--				
5	Cig. (Cont.)	.130	.086	-.009	.001	--			
6	Alc. (Cont.)	**-.252****	.007	**.145****	-.090	.036	--		
7	Cig. (Dich.)	**.118****	-.016	-.015	-.053	**.296****	**.107***	--	
8	Alc. (Dich.)	.024	-.067	.056	-.010	-.133	.	**.131****	--

Table 3B (Gender)		1	2	3	4	5	6	7	8
1	Age	--	-.017	**-.291****	**.216****	-.010	**-.259****	.016	.005
2	BMI	-.109	--	.020	-.099	-.033	-.038	-.026	**-.138***
3	Resting HRV	**-.183****	**-.130***	--	.039	.096	**.212****	.017	.048
4	EC	.021	-.001	-.067	--	.009	-.100	-.043	-.015
5	Cig. (Cont.)	.202	.112	-.134	-.066	--	-.109	.162	-.059
6	Alc. (Cont.)	**-.272****	-.005	.104	-.124	.140	--	.091	**.**
7	Cig. (Dich.)	**.228****	-.008	-.047	-.078	**.393****	.061	--	**.202****
8	Alc. (Dich.)	.036	.014	.083	-.023	**-.225***	**.**	.038	--

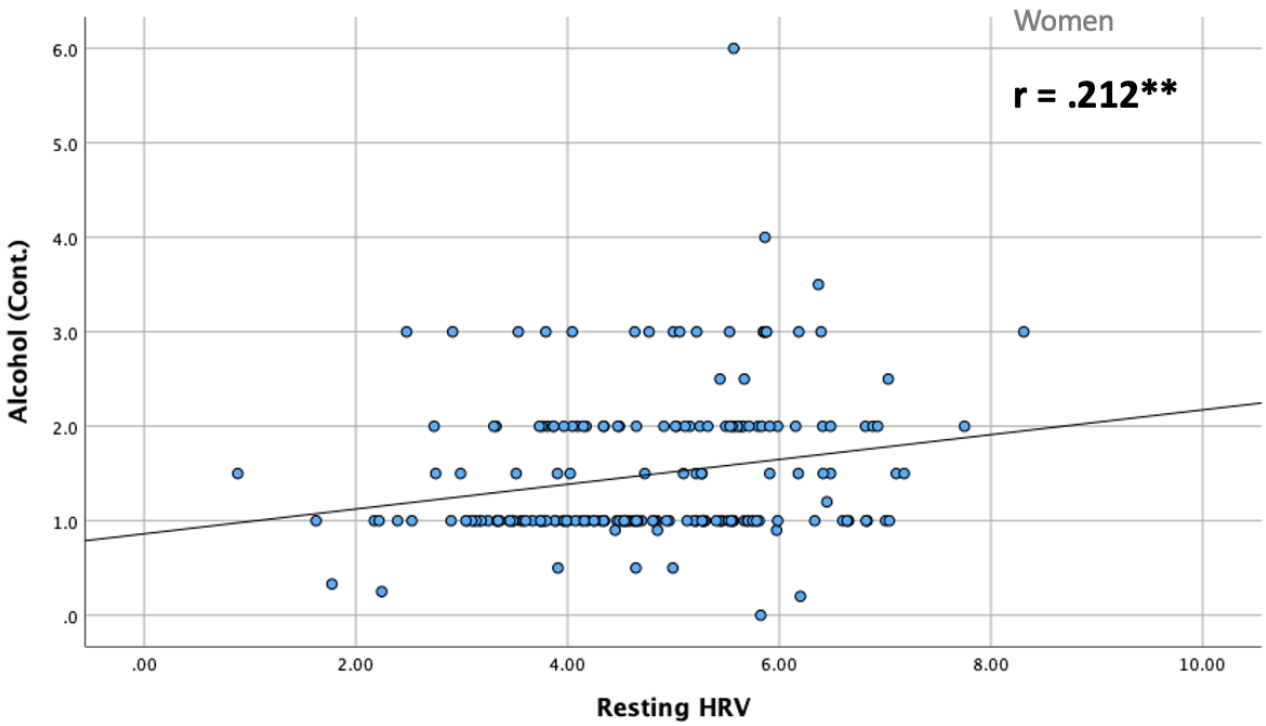
Note. Table 3A represents correlations between variables of interest for the full sample (n = 640). Table 3B represents correlations between variables of interest stratified by gender, with men on the left side of the diagonal and women on the right. HRV = heart rate variability; EC = Emotion Control; BMI = body mass index; Cig = cigarette; Alc. = Alcohol; Cont. = Continuous; Dich. = Dichotomous. Significant correlations bolded. **p* < .05; ***p* < .01

FIGURE 4.



Note. Scatterplot on the association between resting HRV and continuous alcohol use (within the full sample). Statistics reported include Pearson's Correlation Coefficient (r). Cont. = Continuous. Significant correlations bolded. *p < .05, **p < .01

FIGURE 5.



Note. Scatterplot on the association between resting HRV and continuous alcohol use (amongst women only). Statistics reported include Pearson's Correlation Coefficient (r). Cont. = Continuous. Significant correlations bolded. *p < .05, **p < .01

Moderation, Mediation, and Moderated-Mediation Analyses

To test whether gender moderated the relationship between resting HRV and dichotomous substance use, PROCESS Model 1 (a moderation model) was employed. When controlling for age and BMI, moderation analyses showed that gender did not significantly moderate the association between resting HRV and substance use (Cigarette: p = .563; Alcohol: p = .638). **Figure 1** presents the conceptual moderation model, and **Table 4** provides the associated statistics.

To investigate potential mediation effects involving resting HRV, ER, and dichotomous substance use, PROCESS Model 4 (a mediation model) was employed. Emotion control did not significantly mediate the association between resting HRV and lifetime cigarette use [B = -.0027 (.0072), 95% bootstrap CI = [-.0190, .0112]]. However, higher levels of emotion control were significantly associated with less lifetime cigarette use [Path B: B = -.2335 (.1099), 95% bootstrap CI = [-.4488, -.0182], p = .0335]. **Figure 2** presents the conceptual mediation model and **Table 5** provides the associated statistics.

Finally, to investigate the potential role of gender as a moderating factor on the mediating effects involving resting HRV, ER, and dichotomous substance use, we employed PROCESS Model 58 (a moderated-mediation model). Gender did not substantially moderate the mediation model presented in **Figure 2**. The conceptual moderated-mediation model is presented in **Figure 3**, and **Table 6** provides the associated statistics.

TABLE 4. Moderation Results (Associated with Conceptual Figure 1)

	B	SE	95% boot CI	*p*
Cigs. (Dich.)	.0775	.1342	[-.1856, .3405]	.5637
Alc. (Dich.)	-.0688	.1461	[-.3552, .2176]	.6376

Note: Table 4 represents moderation results (associated with conceptual figure 1) on variables of interest moderated by gender. Statistics reported include unstandardized betas (B), standard error (SE), bootstrapping CI's (lower limit, upper limit), and p-values (*p*). Dich. = Dichotomous; Cigs. = cigarettes; Alc. = Alcohol

TABLE 5. Mediation Results (Associated with Conceptual Figure 2)

Mediator:	Emotion Control
Path A [Cigs. (Dich.)]	B = .0116 (.0265), 95% boot CI [-.0404, .0637], *p* = .6607
Path B [Cigs. (Dich.)]	**B = -.2335 (.1099), 95% boot CI [-.4488, -.0182], *p* = .0335***
Path C' [Direct: Cigs. (Dich.)]	B = .0163 (.0695), 95% boot CI [-.1199, .1525], *p* = .8147
Path C [Indirect: Cigs. (Dich.)]	B = -.0027 (.0072), 95% boot CI [-.0190, .0112]
Path A [Alc. (Dich.)]	B = .0116 (.0265), 95% boot CI [-.0404, .0637], *p* = .6607
Path B [Alc. (Dich.)]	B = -.0125 (.1168), 95% boot CI [-.2414, .2164], *p* = .9149
Path C' [Direct: Alc. (Dich.)]	B = .1031 (.0748), 95% boot CI [-.0435, .2496], *p* = .1681
Path C [Indirect: Alc. (Dich.)]	B = -.0001 (.0035), 95% boot CI [-.0080, .0074]

Note: Table 5 represents mediation results (associated with conceptual figure 2) on variables of interest. Statistics reported include unstandardized betas (B), standard error (SE) (in brackets), bootstrapping CI's (lower limit, upper limit), and p-values (*p*). Dich. = Dichotomous; Cigs. = cigarettes; Alc. = Alcohol; HRV = Heart Rate Variability. Significant effects bolded. *$p < .05$

TABLE 6. Moderated-Mediation Results (Associated with Conceptual Figure 3)

Mediator:	Emotion Control
Path A [Cigs. (Dich.)]	B = .0790 (.0513), 95% boot CI [-.0217, .1797], *p* = .1240
Path B [Cigs. (Dich.)]	B = .0158 (.2245), 95% boot CI [-.4242, .4559], *p* = .9438
Path C' [Direct: Cigs. (Dich.)]	B = .0177 (.0698), 95% boot CI [-.1192, .1545], *p* = .8001
Path C [Indirect: Cigs. (Dich.)]	B = -.0194 (.0184), 95% boot CI [-.0606, .0112]
Path A [Alc. (Dich.)]	B = .0790 (.0513), 95% boot CI [-.0217, .1797], *p* = .1240
Path B [Alc. (Dich.)]	B = -.0124 (.2426), 95% boot CI [-.4878, .4630], *p* = .9592
Path C' [Direct: Alc. (Dich.)]	B = .1084 (.0756), 95% boot CI [-.0397, .2565], *p* = .1514
Path C [Indirect: Alc. (Dich.)]	B = -.0029 (.0130), 95% boot CI [-.0309, .0226]

Note: Table 6 represents moderated-mediation results (associated with conceptual figure 3) on variables of interest (moderated by gender). Statistics reported include unstandardized betas (B), standard error (SE) (in brackets), bootstrapping CI's (lower limit, upper limit), and p-values (*p*). Dich. = Dichotomous; Cigs. = cigarettes; Alc. = Alcohol; HRV = Heart Rate Variability. Significant effects bolded. *$p < .05$

DISCUSSION

In my previous research (Kwon et al., 2022), I found an indirect relationship between resting HRV and substance (drug) use, mediated by self-reported ER. The aim of Study 1 was to replicate these findings in an older sample, focusing on cigarette and alcohol use instead of illicit drug use. The current study yielded several important findings. First, consistent with my hypotheses and previous research (Brown et al., 2004), women reported lower past month alcohol and lifetime cigarette use than men. Surprisingly, no significant differences were observed in resting HRV between women and men.

A potential reason for the lack of significant differences in resting HRV could be due to the specific types of substance use (lifetime cigarette and past month alcohol use) rather than illicit drug use. Different substances impact the body in various ways, and their effects on the autonomic nervous system (which controls resting HRV) can vary. For instance, chronic use of illicit drugs might lead to more pronounced alterations in autonomic function compared to the use of alcohol and cigarettes, which might not produce such stark differences in HRV. Moreover, the physiological effects of alcohol and nicotine might not be as acute or pervasive as those caused by certain illicit drugs, potentially leading to less variation in HRV measures across genders.

Additionally, the patterns of use and associated behaviors differ between substances. Alcohol and nicotine use might be more integrated into social and cultural contexts, potentially mitigating their impact on physiological measures like HRV. In contrast, illicit drug use is often accompanied by more severe health and lifestyle consequences that could more substantially alter resting HRV. Thus, the type of substance use being investigated in this study likely influenced the observed outcomes, underscoring the importance of considering the specific

substances when examining physiological measures like HRV. As such, these findings might also suggest that other factors, such as health status or lifestyle factors, could have a more substantial impact on resting HRV than gender alone within this particular sample.

Furthermore, contrary to my hypothesis, men reported higher emotion control compared to women. This could be related to social or cultural factors that influence self-reported measures of emotion regulation. Specifically, men may be socialized to view and report themselves as having greater control over their emotions due to traditional gender roles that value stoicism and emotional restraint in men. Thus, men might have a tendency to report higher emotion control because they perceive it as a desirable trait or due to a bias in self-assessment, where they may overestimate their ability to regulate emotions.

The emotion control subscale used in the MIDUS, which includes items from the James Gross Emotion Regulation Questionnaire which assess both emotion suppression and cognitive reappraisal, was the only substantial measure of emotion regulation in the study. While both suppression and reappraisal are ER techniques, their adaptiveness varies, with suppression generally considered maladaptive and reappraisal more adaptive. Men may attempt to "control" emotions more than women, who might use a variety of ER strategies. This is supported by James Gross's ER Model, which differentiates between "response-focused" and "antecedent-focused" ER. Women, with higher emotion awareness, are likely more "antecedent-focused" in their ER.

With respect to the relationship between HRV and substance use, higher resting HRV was associated with more alcohol consumption in the past month, particularly among women. A potential reason for the association between higher resting HRV and increased alcohol consumption, particularly among women, could be related to the social and psychological

contexts in which alcohol consumption occurs. Women may use alcohol in social situations or as a coping mechanism for stress (Mendrek, 2014), which could temporarily enhance their parasympathetic nervous system activity, leading to higher HRV. Additionally, the metabolic and hormonal differences between men and women (Mumenthaler et al., 1999; Thomasson, 2002) could also play a role in how alcohol consumption affects the autonomic nervous system and HRV. However, further research is needed to explore these potential possibilities and understand the underlying mechanisms fully.

There was no significant relationship between resting HRV and lifetime cigarette smoking in the full sample, nor when stratified by gender. Models examining emotion control as a meditator resting HRV and substance use, did not reveal significant findings, potentially due to different measures of emotion regulation. It is important to note that my previous study focused on difficulties in ER, rather than emotion control. However, the direct link between emotion control and a history of cigarette use was significant, indicating higher emotion control was associated with more lifetime cigarette use.

It is surprising that no moderation, mediation, or moderated mediation tests yielded significant results, as had been observed in the previous study. Age might play a significant role in accounting for the differences, as the average age of MIDUS participants was approximately 56 years, compared to 19 years in the previous study. Age was significantly correlated with lifetime cigarette smoking, HRV, and emotion control. Further research is needed to understand how a history of substance use might influence psychophysiology in later adulthood, as this remains an underexplored area.

Perhaps one of the most surprising findings of Study 1 was that higher resting HRV was associated with greater alcohol consumption, particularly among women. The average alcohol

consumption for women was about 1.5 drinks per day, which does not reach the level of over-consumption. This moderate level of alcohol consumption might be linked to better health and ER, as indicated by higher HRV. This is supported by research suggesting that low to moderate alcohol consumption is associated with a reduced risk of cardiovascular disease. Therefore, the observed positive association is reasonable given the amount consumed. The link is less pronounced in men, who consume about 2 drinks per day on average. Further research is needed to understand the relationship between substance use and physiology in men, while also examining their specific reasons for engaging in substance use (e.g., for feelings of elation).

Although the findings reported here contribute valuable new knowledge regarding how the links between HRV and substance use may operate in women versus men, limitations should also be noted. For one, there was minimal racial diversity in the original MIDUS dataset, which predominantly consists of European American participants (90.1%; N = 4,473) and includes fewer than 50 African American participants with valid HRV measures. This small number precluded analyses of race subgroups, but such is worth exploring in future work (see also Study 2). Also, as mentioned, ER in MIDUS was characterized via a measure of "emotion control." Based on the items, this measure seems to reflect ER strategies used after the perception of negative emotions rather than ER more broadly. Future studies should replicate this research using diverse measures of ER and stress.

Additionally, there was a discrepancy in substance use measurement, with current alcohol use being assessed versus a history of cigarette use, which could affect the comparability of the findings. Notably, single-item measures for substance use, such as asking participants about their average cigarette consumption during a specific period of time, are often insufficient in capturing the full scope of an individual’s substance use history. Thus, this limitation highlights the need

for more comprehensive assessment tools to obtain a more accurate picture of substance use patterns over time."

Finally, correlation does not equal causation, and given the cross-sectional nature of my study, I cannot make strong assertions regarding directionality. Some of these issues were examined in Study 2, which utilizes a more diverse dataset to examine how resting HRV in late adolescence relates to substance use six years later in adulthood.

In conclusion, the results from Study 1 partially support my hypothesis. The relationship between resting HRV, ER, and substance use appears more pronounced in women than in men, likely due to unique social inequities that may motivate women to use substances for stress regulation. However, the impact of substance use on this ER system may vary depending on the type of substance, frequency of use, age of the individual, and how ER is implemented.

STUDY 2

Most studies have considered the relationship between resting HRV and substance use cross-sectionally. Yet, no study has examined how resting HRV in late adolescence might predict substance use in early adulthood. This is extremely important as it would lend directionality to the link between resting HRV and substance use. “Does substance use decrease HRV and activity within associated brain regions?” This question has been answered, and converging evidence suggests that substance use can lead to both acute and chronic decreases in HRV. However, “can resting HRV predict substance use years later?” This question has yet to be sufficiently examined, and my theory to this point is predicated on this question.

Previous research has primarily examined the link between resting HRV and active substance use (Moon et al., 2023), whereas my studies have focused on a history of substance use. Additionally, existing studies are mostly cross-sectional, examining the relationship between substance use and resting HRV at a single point in time, rather than exploring how one predicts the other over a period. There is a pressing need for longitudinal data to explore how early-life resting HRV may predict later-life substance use. My findings suggest that this relationship might be particularly pronounced among women. While women generally have a lower propensity for substance use than men (Slabbert et al., 2019), they may develop substance use as a learned strategy for managing emotions over time (Mendrek, 2014). This contrasts with men, who may use substances for different reasons (e.g., feelings of elation) (Mendrek, 2014), thus not showing the same HRV link. These insights highlight the importance of incorporating gender-specific factors in future research on substance use behaviors.

Research consistently shows racial differences in substance use. For example, African American adolescents are less likely than European American peers to have tried cigarettes

before age 13 (Felton et al., 1999). European American adolescents are more likely to consume alcohol, start drinking at a younger age, drink more frequently and heavily, and associate with peers who consume alcohol (Blum et al., 2000; Brannock et al., 1990; Neff, 1986; Newcomb et al., 1987; Singer, 1987). African Americans typically initiate alcohol use later and exhibit a slower increase in use throughout adolescence, peaking at an older age (Bachman et al., 1991; Duncan et al., 2006; Warheit et al., 1996). Cooper et al. (2008) found that African American adolescents use substances as a coping mechanism to manage stress, often drinking to escape or reduce unpleasant emotions, while European American adolescents are more likely to drink to enhance positive emotions.

Interestingly, the patterns of substance use among African Americans compared to European Americans are similar to the previously outlined gender differences. However, direct research comparing these racial differences is limited. Paradoxically, despite higher mortality and morbidity rates, African Americans exhibit higher resting HRV than European Americans, a phenomenon termed the cardiovascular conundrum (Hill et al., 2015, 2017). This suggests a cardioprotective role of higher HRV in African Americans, though the neurophysiological mechanisms behind this paradox remain underexplored. Given these observations, the relationship between resting HRV and substance use could be particularly pronounced among African Americans, possibly mirroring the gender differences. Further research is essential to confirm these potential parallels.

Of particular relevance to this investigation is the unique impact of being an African American woman, a group often exposed to distinct stressors, including both sexism and racism. These stressors significantly affect health, as documented in the literature. Such stressful

conditions may compromise ER, potentially putting African American women at a greater risk for substance use compared to their counterparts.

Current Study 2

Study 2 utilized data from the Augusta Heart Study, which includes a larger sample of African Americans compared to MIDUS. In this study, I investigated associations similar to those in Study 1, while also examining the potential important influence of race. However, self-reported ER was not available in this dataset, so resting HRV was used as an index of ER abilities, as in Study 1. Additionally, alcohol use data were not available; however, cigarette smoking and cannabis use were assessed. Therefore, the current study focused on these two substances (cigarette and cannabis) use outcomes.

Resting HRV was assessed in late adolescence, and substance use was assessed in early adulthood, with an approximate six-year interval between measurements. Consistent with Study 1, I hypothesized that lower resting HRV would independently predict higher cigarette use six years later. I expected this relationship to be more pronounced among women compared to men, due to higher rates of psychopathology fueled by social inequities, particularly during late adolescence. Comparably, I anticipated that African Americans would show a similar pattern, with the effect being especially pronounced among African American women compared to all other groups. Finally, I hypothesized that cannabis use would follow a similar pattern to cigarette smoking.

METHOD

The participants for this study were drawn from the Augusta Heart Study, a dataset focusing on the cardiovascular well-being of children and adolescents in the Metro Augusta region (Kapuku et al., 2019). Funded by the NIH, the Augusta Heart Study aimed to identify

early indicators and underlying pathological mechanisms contributing to the initial stages of cardiovascular disease, with a particular emphasis on race and family history of essential hypertension and/or premature myocardial infarction (Kapuku et al., 2019).

For my dissertation, I analyzed data from 385 normotensive youths, comprising 207 African Americans (127 women) and 178 European Americans (83 women). These individuals participated in two separate laboratory evaluations, with an average interval of 6.32 years (ranging from 2.1 to 8.2 years). The participants were aged 15-32 years (mean age: 23.16 ± 2.9 years) at the first evaluation.

Key covariates considered in the analysis included age and father's education (as a proxy for socioeconomic status [SES]). Father's education was measured continuously as the number of years spent in formal education; data from time 1 were used due to insufficient responses at time 2. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared. Informed consent was obtained from all participants prior to each study visit.

Heart Rate Variability (HRV)

In the study, heart rate was recorded using a BioZ impedance monitor from Cardio-Dynamics (San Diego, CA). Subjects were instructed to lie down quietly in a supine position for 15 minutes to stabilize their heart rate. Following this, resting HRV was measured for 5 minutes. However, this HRV measurement was only conducted during the first session (time 1).

The raw inter-beat interval data underwent initial screening based on specific criteria: RR-intervals between 300 and 2,000 ms and successive RR-interval ratios between 0.8 and 1.2. Kubios HRV analysis software was then used to derive HRV parameters from the recorded RR intervals. The time domain index of HRV (RMSSD) was available, in addition to the frequency domain measure high-frequency (HF) power, defined as the power between 0.15 and 0.40 Hz,

obtained using Fast Fourier transformation. HF, like RMSSD, is considered a reliable measure of primarily parasympathetic (vagal) influence on cardiac function, and they were highly correlated. For consistency, I used HF- HRV measures as my primary index of HRV, which was available at time 1 only.

Substance Use

At time 2 (six years after HRV data collection), substance use was assessed through self-report, focusing on marijuana and cigarette smoking. The assessment included both dichotomous (yes/no) and continuous (frequency of use) measures. Participants were asked the following questions: (1) "During the past 30 days, on the days you smoked, how many cigarettes did you smoke per day?" and (2) "During the past 30 days, how many times did you use marijuana?" Based on their responses, participants were categorized into substance use groups.

For dichotomous measures (similar to study 1), responses were coded as "1" for "yes" and "0" for "no" regarding past month substance use. For cigarette use, the continuous variable representing the number of cigarettes smoked per day in the past month was recoded into a dichotomous variable, distinguishing between individuals who have never smoked in the past month and those who did smoke in the past month. Similarly, for cannabis use, the continuous variable representing the frequency of cannabis use in the past month was recoded into a dichotomous variable, differentiating between individuals who did use cannabis in the past month and those who did not use cannabis in the past month.

Continuous variables, such as the number of cigarettes smoked per day in the past month and the frequency of cannabis use in the past month, were also analyzed, with non-use coded as "0." This approach enabled a comprehensive assessment of substance use patterns among the study participants.

STATISTICAL ANALYSES

All statistical tests and analyses were conducted using SPSS software (version 29, IBM, Chicago, IL). The significance level (alpha) for all tests was set at 0.05, and two-tailed tests were utilized to assess statistical significance.

The data analysis plan for Study 2 closely resembled that of Study 1. Participants were categorized into gender-based groups according to their self-reported gender, race-based groups according to their self-reported race.

Preliminary analyses were conducted to thoroughly inspect the data and generate specific descriptive statistics for all variables of interest. To examine the linear association between resting HRV and self-reported substance use at the current time point, bivariate correlations were conducted. Pearson correlations were employed to assess the strength and direction of the relationship between these variables, providing insight into how variations in HRV might correspond with substance use behavior.

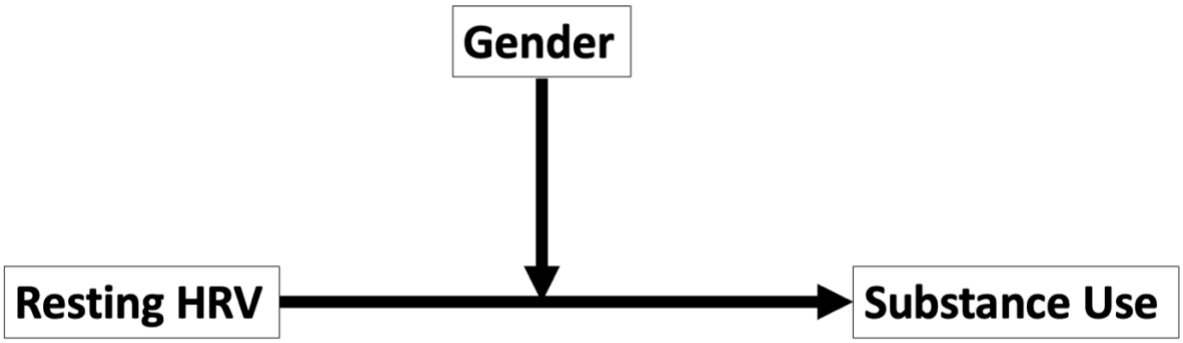
For dichotomous and non-normally distributed continuous variables, Spearman's Rho correlations were utilized to accommodate the non-parametric nature of the data. Additionally, partial r correlations were used to adjust for potential covariates including age and BMI. Father's education was also included as a covariate, specifically, as a proxy measure for socioeconomic status, which is particularly relevant in this relatively young sample. Including this variable helps account for the impact of socioeconomic factors on health behaviors and physiological measures, as higher educational attainment often correlates with better access to resources and healthier lifestyle choices, potentially influencing both HRV and substance use patterns.

The moderating effect of the independent variable (IV; resting HRV), the conditional effect of the moderator (M; gender), and the conditional effect of the moderator via an

interaction on the dependent variable (DV; substance use) were tested using PROCESS ‘Model 1’ (Hayes, 2022) (**See Figure 6 for conceptual representation).** This analysis replicated prior work (Kwon et al., 2022) and the analysis in Study 1. Separately, the moderating effect of the independent variable (IV; resting HRV), the conditional effect of the moderator (M; race), and the interaction effect of the two on the dependent variable (DV; substance use) were also tested using PROCESS ‘Model 1’ (**See Figure 7 for conceptual representation)**.

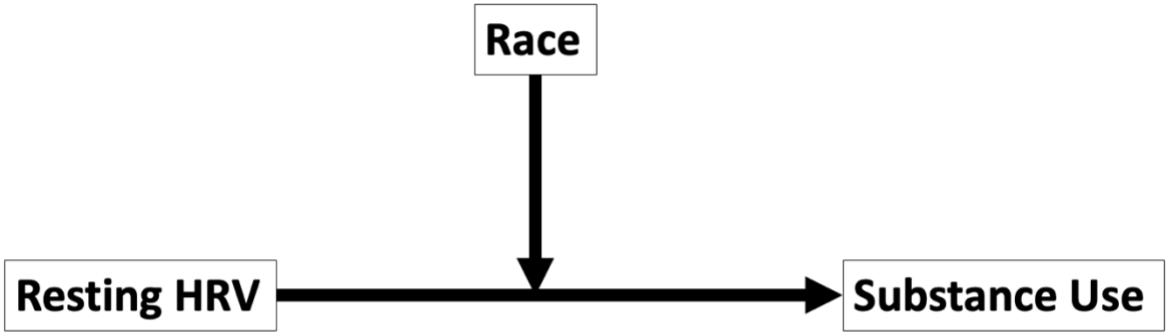
A moderated moderation model was used to examine the interactions between resting HRV, gender, and race concerning substance use. The analysis was performed using the SPSS macro PROCESS (Hayes, 2022) with 'Model 3'. In this model, resting HRV at time 1 was the independent variable, substance use was the dependent variable (DV), and gender served as the primary moderator. Race was the secondary moderator (**see Figure 8 for the conceptual representation**). Covariates included age, BMI, and father's education. Separate models were run for all four dependent measures: two dichotomous (analyzed using logistic regression) and two continuous (analyzed using linear regression).

FIGURE 6.



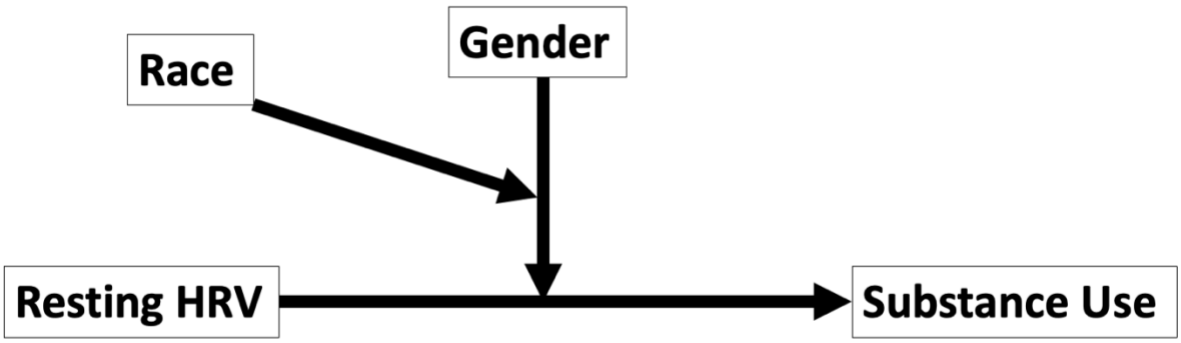
Note. Conceptual Moderation Model for Study 2: This model tests the potential moderating effect of the independent variable (resting HRV), the conditional effect of the moderator (Gender), and the interaction of the two on the dependent variable (dichotomous cigarette use).

FIGURE 7.



Note. Conceptual Moderation Model for Study 2: This model tests the potential moderating effect of the independent variable (resting HRV), the conditional effect of the moderator (Race), and the interaction of the two on the dependent variable (dichotomous cigarette use).

FIGURE 8.



Note. Conceptual Moderated Moderation Model for Study 2: This model was used to examine the interactions between resting HRV, gender, and race concerning dichotomous cigarette use.

RESULTS

Participant Demographics

Means and standard deviations for all variables of interest within the full sample (N = 385) are presented in **Table 7**. Additionally, **Table 8** presents means and standard deviations for all variables of interest stratified by gender. Significant gender differences were observed in several variables. Women had a significantly higher body BMI (M = 29.97, SD = 9.26) compared to men (M = 27.36, SD = 6.99), $p = .002$. Men reported higher continuous cigarette use (M = 3.05, SD = 5.06) and continuous cannabis use (M = 3.36, SD = 8.77) compared to women (Cigarette use: M = 1.54, SD = 3.82; Cannabis use: M = .80, SD = 4.30), with $p = .001$ for cigarette use and $p < .001$ for cannabis use. Notably, due to the limited number of participants reporting cannabis use, detailed analysis of cannabis use patterns was restricted; therefore, no moderation or moderated moderation analyses were conducted on cannabis use. There were no significant differences between men and women in resting HRV, $p = .868$, or father's education level, $p = .227$

TABLE 7. Sample Demographics on Variables of Interest (Full-Sample)

Total (N = 385)	
Age (Time 2)	29.47 (2.96)
BMI (Time 2)	28.79 (8.40)
Resting HRV (Time 1)	7.17 (1.06)
Father's Education (Time 1)	13.45 (2.37)
Cigarette use (Cont.) (Time 2)	1.96 (6.82)
Cannabis use (Cont.) (Time 2)	2.23 (4.49)

Note. This Table presents the means and standard deviations (in brackets) on variables of interest in the full sample (N = 385). Cigarette use (Cont.) = "During the past 30 days, on the days you smoked, how many cigarettes did you smoke per day?"; Cannabis use (Cont.) = "During the past 30 days, how many times did you use marijuana?"

TABLE 8. Differences between men and women on variables of interest

	Men	Women	*p*
Age (Time 2) *(Men: N = 175); (Women: N = 210)*	29.33 (3.12)	29.58 (2.82)	0.398
BMI (Time 2) *(Men: N = 175); (Women: N =210)*	27.36 (6.99)	29.97 (9.26)	**0.002***
Resting HRV (Time 1) *(Men: N = 175); (Women: N = 210)*	7.18 (1.01)	7.16 (1.10)	0.868
Father's Education (Time 1) *(Men: N = 125); (Women: N = 156)*	13.55 (2.63)	13.37 (2.13)	0.227
Cigarette Use Cont. (Time 2) *(Men: N = 169); (Women: N = 203)*	3.05 (5.06)	1.54 (3.82)	**0.001***
Cannabis Use Cont. (Time 2) *(Men: N = 169); (Women (N = 203)*	3.36 (8.77)	.80 (4.30)	**<0.001***
Cigarette Use Dich. (Time 2) *(Men: N = 169); (Women (N = 203)*	73 (96)	47 (156)	**<0.001***
Cannabis Use Dich. (Time 2) *(Men: N = 169); (Women (N = 203)*	45 (124)	21 (182)	**<0.001***

Note. This table presents the means and standard deviations (in brackets) of variables of interest, stratified by women and men. Dichotomous variables indicate the groups who have smoked cigarettes and used cannabis and those who have not (in brackets). T-test statistics include p-values. Fisher-Z statistics and associated p-values are reported for dichotomous substance use variables and exercise. HRV = heart rate variability; BMI = body mass index; Cont. = Continuous; Dich. = Dichotomous. Significant differences are bolded. *p < .05.

Mean differences in variables of interest between race groups are presented in **Table 9**. African American participants were slightly older (Age: M = 29.93, SD = 2.91), $p < .001$, and had a higher BMI (M = 30.27, SD = 9.35), $p < .001$, compared to European American participants (Age: M = 28.93, SD = 2.94; BMI: M = 27.06, SD = 6.77). European American participants smoked more cigarettes (continuous) (M = 3.14, SD = 5.50), $p < .001$, and had fathers with higher education levels (M = 14.05, SD = 2.44), $p < .001$, compared to African American participants (Cigarette use: M = 1.42, SD = 3.15; Father's education: M = 12.93, SD =

2.18). There were no significant differences between European American and African American participants in resting HRV, $p = .475$, or continuous cannabis use, $p = .252$.

TABLE 9. Differences between racial groups on variables of interest

	EA	AA	*p*
Age *(EA: N = 175); (AA: N = 210)*	28.93 (2.94)	29.93 (2.91)	**<0.001***
BMI *(EA: N = 175); (AA: N =210)*	27.06 (6.77)	30.27 (9.35)	**<0.001***
Resting HRV *(EA: N = 175); (AA: N = 210)*	7.13 (1.11)	7.21 (1.00)	0.475
Father's Education *(EA: N = 175); (AA: N = 210)*	14.05 (2.44)	12.93 (2.18)	**<0.001***
Cigarette Use Cont. *(EA: N = 175); (AA: N = 210)*	3.14 (5.50)	1.42 (3.15)	**<0.001***
Cannabis Use Cont. *(EA: N = 175); (AA: N = 210)*	2.39 (8.02)	1.58 (5.54)	0.252
Cigarette Use Dich. *(EA: N = 175); (AA: N = 210)*	64 (110)	56 (142)	0.095
Cannabis Use Dich. *(EA: N = 175); (AA: N = 210)*	33 (141)	33 (165)	0.588

Note. This table presents the means and standard deviations (in brackets) of variables of interest, stratified by racial group. Dichotomous variables indicate the groups who have smoked cigarettes and used cannabis and those who have not (in brackets). T-test statistics include p-values. Fisher-Z statistics and associated p-values are reported for dichotomous substance use variables. EA = European American; AA = African American; HRV = heart rate variability; BMI = body mass index; Cont. = Continuous; Dich. = Dichotomous. Significant differences are bolded. *p < .05.

Zero-Order Correlations Among Variables of Interest

Correlations among variables of interest in the entire sample are presented in **Table 10A**. In the full sample, age was positively correlated with BMI ($r = .257$, $p < .001$) but negatively correlated with resting HRV ($r = -.180$, $p < .001$) and father's education ($r = -.189$, $p < .001$). Moreover, BMI was negatively correlated with father's education ($r = -.221$, $p < .001$). Resting

HRV was not significantly correlated with any variables of interest at a bivariate level. Father's education was negatively correlated with continuous cannabis use (ρ = -.106, p < .001), and continuous cigarette use was positively correlated with continuous cannabis use (ρ = .410, p < .001).

Stratified by gender (**Table 10B**), in men, age was positively correlated with BMI (r = .294, p < .001) and negatively correlated with father's education (r = -.289, p < .001). Father's education was negatively correlated with BMI (r = -.210, p = .005), continuous cigarette use (ρ = -.163, p = .034), and continuous cannabis use (ρ = -.205, p = .008). Continuous Cannabis use was positively correlated with continuous cigarette use (ρ = .403, p < .001). In women, age was positively correlated with BMI (r = .233, p < .001) and negatively correlated with resting HRV (r = -.226, p < .001). Father's education was negatively correlated with BMI (r = -.235, p < .001). Continuous Cannabis use was positively correlated with continuous cigarette use (ρ = .357, p < .001).

Stratified by racial group (**Table 10C**), in European American individuals, age was positively correlated with BMI (r = .314, p < .001), and negatively correlated with resting HRV (r = -.158, p = .035) and father's education (r = -.180, p = .016). BMI was negatively correlated with father's education (r = -.272, p < .001). Continuous cigarette use was positively correlated with continuous cannabis use (ρ = .413, p < .001). In African American individuals, age was positively correlated with BMI (r = .186, p = .007) and negatively correlated with resting HRV (r = -.218, p = .002). Continuous cigarette use was positively correlated with continuous cannabis use (ρ = .412, p < .001).

Correlations amongst variables of interest were also stratified by gender and racial group, with correlations for European American individuals presented in **Table 10D** and for African

American individuals in **Table 10E**. Among European American men, BMI was positively correlated with age (r = .301, p = .003) and negatively correlated with father's education (r = -.325, p = .001). Continuous cannabis use was negatively correlated with father's education (ρ = -.242, p = .020) and positively correlated with continuous cigarette use (ρ = .421, p < .001). Among European American women, age was positively correlated with BMI (r = .313, p = .004) and negatively correlated with resting HRV (r = -.338, p = .002). BMI was negatively correlated with father's education (r = -.225, p = .041) and positively correlated with continuous cigarette use (ρ = .224, p = .043). Continuous cigarette use was also positively correlated with continuous cannabis use (ρ = .393, p < .001).

Among African American men, age was positively correlated with BMI (r = .227, p = .043) and negatively correlated with resting HRV (r = -.320, p = .004) and father's education (r = -.278, p = .012). Continuous cigarette use was negatively correlated with father's education (ρ = -.227, p = .047) and positively correlated with continuous cannabis use (ρ = .392, p < .001). Among African American women, BMI was positively correlated with age (r = .180, p = .043) and negatively correlated with father's education (r = -.212, p = .017). Continuous cigarette use was also positively correlated with continuous cannabis use (ρ = .314, p < .001).

TABLE 10. Correlation coefficients for full sample and stratified by Gender and Race

Table 10A (Full Sample)		1	2	3	4	5	6	7	8
1	Age	--							
2	BMI	**.257****	--						
3	Resting HRV	**-.180****	-.059	--					
4	Father's Education	**-.189****	**-.221****	.019	--				
5	Cigarette (Cont.)	-.002	.067	-.040	-.061	--			
6	Cannabis (Cont.)	.049	.003	-.059	**-.106***	**.410****	--		
7	Cigarette (Dich.)	.009	.049	-.025	-.068	**.977****	**.413****	--	
8	Cannabis (Dich.)	.053	.000	-.062	**-.104***	**.398****	**.994****	**.402****	--

Table 10B (Gender)		1	2	3	4	5	6	7	8
1	Age	--	**.233****	**-.226****	-.073	-.097	.008	-.090	.012
2	BMI	**.294****	--	-.058	**-.235****	.135	.090	.117	.087
3	Resting HRV	-.126	-.061	--	.010	.022	-.050	.033	-.047
4	Father's Education	**-.289****	**-.210****	.029	--	.045	.011	.048	.007
5	Cigarette (Cont.)	.103	.026	-.106	**-.163***	--	**.357****	**.990****	**.354****
6	Cannabis (Cont.)	.103	-.033	-.064	**-.205****	**.403****	--	**.353****	**.998***
7	Cigarette (Dich.)	.124	.010	-.088	**-.192***	**.953****	**.413****	--	**.350****
8	Cannabis (Dich.)	.106	-.048	-.078	**-.199****	**.377****	**.985****	**.394****	--

Table 10C (Race)		1	2	3	4	5	6	7	8
1	Age	--	**.186****	**-.218****	-.133	.037	.084	.031	.081
2	BMI	**.314****	--	-.034	-.131	.047	-.032	.032	-.031
3	Resting HRV	**-.158***	-.119	--	.073	.000	-.075	.014	-.086
4	Father's Education	**-.180***	**-.272****	-.013	--	-.091	-.087	-.116	-.083
5	Cigarette (Cont.)	.001	.125	-.068	-.113	--	**.412****	**.984****	**.400****
6	Cannabis (Cont.)	.037	.055	-.044	-.134	**.413****	--	**.422****	**.995****
7	Cigarette (Dich.)	.017	.089	-.060	-.083	**.968****	**.403****	--	**.411****
8	Cannabis (Dich.)	.048	.047	-.038	-.132	**.398****	**.993****	**.391****	--

Table 10D (Gender, EA)		1	2	3	4	5	6	7	8
1	Age	--	**.313****	**-.338****	-.131	-.031	-.009	.001	-.002
2	BMI	**.301****	--	-.162	**-.225***	**.224***	.098	.189	.090
3	Resting HRV	.022	-.045	--	.026	-.082	-.049	-.098	-.031
4	Father's Education	-.200	**-.325****	-.052	--	-.048	.035	-.012	.030
5	Cigarette (Cont.)	.044	.040	-.074	-.177	--	**.393****	**.980****	**.388****
6	Cannabis (Cont.)	.092	.058	-.034	**-.242***	**.421****	--	**.406****	**.998****
7	Cigarette (Dich.)	.043	.002	-.039	-.156	**.955****	**.391****	--	**.401****
8	Cannabis (Dich.)	.106	.052	-.045	**-.237***	**.392****	**.987****	**.368****	--

Table 10E (Gender, AA)		1	2	3	4	5	6	7	8
1	Age	--	**.180***	-.151	-.008	-.161	.032	-.164	.034
2	BMI	**.227***	--	-.011	**-.212***	.109	.098	.096	.101
3	Resting HRV	**-.320****	-.085	--	.016	.129	-.059	.149	-.068
4	Father's Education	**-.278***	-.028	.150	--	.056	-.016	.046	-.019
5	Cigarette (Cont.)	.212	.011	-.147	**-.227***	--	**.314****	**.994****	**.309****
6	Cannabis (Cont.)	.108	-.152	-.106	-.142	**.392****	--	**.303****	**.999****
7	Cigarette (Dich.)	.213	-.007	-.154	**-.289***	**.951****	**.432****	--	**.298****
8	Cannabis (Dich.)	.091	-.178	-.116	-.120	**.371****	**.983****	**.422****	--

Note: Table 10A presents correlations between variables of interest for the full sample (n = 385). Table 10B displays correlations stratified by gender, with men on the left side of the diagonal and women on the right. Table 10C shows correlations stratified by racial group, with European American individuals on the left side of the diagonal and African American individuals on the right. Table 10D presents correlations stratified by gender and racial group (European American), with European American men on the left side of the diagonal and European American women on the right. Table 10E represents correlations stratified by gender and racial group (African American), with African American men on the left side of the diagonal and African American women on the right. EA = European American; AA = African American; BMI = body mass index; HRV = heart rate variability; Cont. = Continuous; Dich = Dichotomous. Correlations are bolded if significant at *p < .05 or **p < .01.

Moderation, and Moderated-Moderation Analyses

Moderation analyses controlling for age, BMI, and father's education showed that gender did not significantly moderate the association between resting HRV and continuous cigarette use [B = .2123 (.2213), 95% bootstrap confidence interval (CI) = [-.2215, .6461], p = .3374] **(See Figure 6 for graphical representation)**. Similarly, race did not significantly moderate this association [B = .1227 (.2159), 95% bootstrap CI = [-.3005, .5458], p = .5699] **(See Figure 7 for graphical representation)**.

To explore the interplay between resting HRV, gender, and race in relation to cigarette use, a moderated moderation analysis was conducted **(See Figure 8 for graphical representation)**. The results indicated a marginally significant moderated moderation effect of gender and race on the association between resting HRV and dichotomous cigarette use [B = .9072 (.4643), 95% bootstrap CI = [-.0027, 1.8171], p = .0507].

A test of conditional interactions between resting HRV and the first moderator (gender) for different values of the second moderator (race) revealed that the interaction was significant among African American individuals (B = .7758, p = .0316) but not among European American individuals (B = .1315, p = .6498). Further analyses examined the conditional effects of the independent variable (resting HRV) on the dependent variable (dichotomous cigarette use) for different combinations of the moderators (gender and race), with results presented in **Table 11**.

TABLE 11. Conditional Moderated-Moderation Results (Associated with Conceptual Figure 8)

	B	SE	95% boot CI	*p*
EA Men	-.0425	.2062	[-.4467, .3617]	.8368
AA Men	-.3558	.2522	[-.8500, .1384]	.1582
EA Women	-.1740	.2032	[-.5723, .2244]	.3920
AA Women	.4199	.2618	[-.0931, .9330]	.1086

Note: Table 11 represents moderated-moderation results (associated with conceptual figure 8) between resting HRV and dichotomous cigarette use (moderator 1: gender; moderator 2: race). EA = European American; AA = African American. Statistics reported include unstandardized betas (B), standard error (SE), bootstrapping CI's (lower limit, upper limit), and p-values (*p*).

DISCUSSION

Study 1 explored the complex interplay between resting HRV, ER indexed by emotion control, and a history of substance use (both alcohol and cigarette use) cross-sectionally, and how these associations might be impacted by gender. Study 2 builds on Study 1 by examining the link between resting HRV and cigarette smoking habits six years later in an attempt to provide empirical evidence that resting HRV, as an index of ER abilities, can predict future substance use. I also explored how gender might impact these associations, in addition to the unique intersection of race and gender. Cannabis use was minimally examined due to the limited number of users in this category. Consistent with previous research, results showed men used cigarettes and cannabis more than women. African Americans smoked fewer cigarettes, had higher BMI, and lower SES, as proxied by their father's education, compared to European Americans. However, no gender differences in resting HRV were found, and no differences in resting HRV between African Americans and European Americans were observed. These mean

differences are in line with prior reports on differences between groups in substance use, but no significant differences for resting HRV.

As in my prior report and Study 1, resting HRV did not predict cigarette smoking in the full sample or stratified by gender or race. However, at the intersection of gender and race, lower SES predicted higher substance use only among European American men. Importantly, moderation tests suggested that among African Americans, the slope between resting HRV and cigarette smoking was more positive in women relative to the negative slope in men. In other words, higher HRV better predicted higher cigarette smoking among African American women, and lower smoking among African American men. However, it is important to note, that the relationships between HRV and cigarette smoking were not significant in either African American women or African American men. No notable gender differences were observed among European American participants. While resting HRV did not predict substance use six year later in the full sample, meaningful and opposing slopes among African American women and men suggest that further exploration of mechanisms (e.g., ER) underlying differential HRV-substance use trajectories between African American women and men is needed. This will assist in understanding whether increasing resting HRV or providing additional ER techniques might be more appropriate.

Despite the hypothesized relationships, this study did not find a significant association between HRV and cigarette smoking in any portion of the sample. Furthermore, African Americans reported less cigarette use compared to European Americans. These findings suggest that other factors may play a more significant role in predicting cigarette use. The lack of meaningful relationships could be due to the complex interplay of socio-economic, cultural, and individual factors that were not fully captured in this study. Further research is needed to explore

these potential influences and to understand the mechanisms underlying HRV and substance use behaviors.

While most studies have examined the link between HRV and substance use cross-sectionally, few have investigated how HRV might predict substance use prospectively (Saban & Flisher, 2010). This analysis is crucial for identifying whether resting HRV is a potential target for reducing substance use among marginalized individuals. Despite the potential for a bi-directional association between HRV and substance use, these studies showed weak relationships between HRV and substance use. This suggests that HRV may not be significantly associated with low levels of substance use, but rather with substance abuse or other substances not captured in this study. These findings indicate that other factors might play a more critical role in predicting substance use behaviors. Further research is needed to explore these complex dynamics and to determine the specific conditions under which HRV may influence substance use. Additionally, Study 1 suggests that at lower levels of alcohol consumption, higher resting HRV is associated with more drinks, a counterintuitive finding that warrants further investigation.

Resting HRV has been identified as an endophenotype (Beauchaine & Thayer, 2015), reflecting individual differences in interpreting and responding to various situations. Empirical evidence has linked resting HRV to momentary self-regulation, as indicated by psychological variables such as mood and cognitive performance. It is suggested that physiological self-regulation in the moment, or HRV reactivity, is largely influenced by one's resting HRV (Park et al., 2014; Williams et al., 2016). This implies that resting HRV is more of a trait-like variable, in contrast to reactivity and recovery HRV, which are scenario-specific and tied to individual differences in self-regulation abilities. Therefore, this dissertation posits that focusing on resting

HRV provides a clearer understanding of the connection between trait parasympathetic activity and the risk for substance use. It's important to note that the relationship between resting HRV and substance use is considered bi-directional; while resting HRV might influence the likelihood of engaging in substance use, substance use can also affect HRV over time. Consequently, psychologists and clinicians should consider both aspects of the relationship between resting HRV and substance use to better understand potential health complications.

Future Directions & Limitations

One limitation of the Augusta Heart Study dataset was its restricted racial diversity, including only African Americans (N = 207) and European Americans (N = 178). This limitation prevented the analysis of other racial groups, which could offer additional potential insights. Moreover, the dataset lacked variables related to alcohol use and self-reported emotional regulation (ER), which would have enabled a more comprehensive examination of the potential mediating effects of these factors over time, rather than solely in a cross-sectional manner as in my previous study and Study 1. Another significant limitation was the absence of substance use measurements at time 1, which prevented the study from being truly longitudinal. Without knowing if substances were being used initially at time 1 (six years before time 2), the analysis could not fully account for baseline substance use, which is critical for understanding changes over time.

It is important to highlight that the cardiovascular conundrum, characterized by the paradoxical observation of higher resting HRV in African Americans compared to European Americans despite greater mortality and morbidity, has been primarily identified in the African American population. This phenomenon has not been extensively explored in other racially marginalized groups. Therefore, this study's focus on the African American population within

the context of the cardiovascular conundrum can be considered a strength. For the first time, this research allowed for the examination of the relationship between resting HRV and smoking, a significant behavioral and modifiable risk factor for cardiovascular disease, in the context of this unique paradox.

Conclusion

Overall, findings from both Study 1 and Study 2 suggest that the relationships between emotion-based psychophysiological factors, such as HRV, and substance use are generally weak or non-existent. Although gender and race had some effects on the link between psychophysiological systems underlying ER and substance use, these effects were small and varied based on group and substance type. This indicates that while resting HRV and self-reported ER may not be strong standalone predictors of substance use, they might still hold relevance in specific contexts or subgroups. These results highlight the complexity of factors influencing substance use and suggest that other variables, possibly including social, environmental, and psychological factors, play a more significant role.

Given these findings, future research should focus on exploring other motivations for substance use that are not necessarily driven by stress, such as recreational use or social influences, particularly in men. Additionally, further studies should aim to investigate a broader range of substances and consider longitudinal designs to better understand the potential causal relationships. Identifying and examining these additional factors could provide a more comprehensive understanding of substance use behaviors and inform the development of more effective, individualized intervention strategies.

REFERENCES

Ahern, G. L., Sollers, J. J., Lane, R. D., Labiner, D. M., Herring, A. M., Weinand, M. E., Hutzler, R., & Thayer, J. F. (2001). Heart rate and heart rate variability changes in the Intracarotid Sodium Amobarbital Test. *Epilepsia*, *42*(7), 912–921. https://doi.org/10.1046/j.1528-1157.2001.042007912.x

Aldao, A. (2013). The future of emotion regulation research: Capturing context. *Perspectives on Psychological Science*, *8*(2), 155–172. https://doi.org/10.1177/1745691612459518

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). https://doi.org/10.1176/appi.books.9780890425596

Bachman JG, Wallace JM Jr, O'Malley PM, Johnston LD, Kurth CL, Neighbors HW. Racial/Ethnic differences in smoking, drinking, and illicit drug use among American high school seniors, 1976-89. Am J Public Health. 1991 Mar;81(3):372-7. doi: 10.2105/ajph.81.3.372. PMID: 1994746; PMCID: PMC1405013.

Beauchaine, T. P., & Thayer, J. F. (2015). Heart rate variability as a transdiagnostic biomarker of psychopathology. *International journal of psychophysiology : official journal of the International Organization of Psychophysiology*, *98*(2 Pt 2), 338–350. https://doi.org/10.1016/j.ijpsycho.2015.08.004

Biafora, F., & Zimmerman, R. (1998). Developmental patters of African American adolescent drug use. In.W. A.Vega&A. G. Gil (Eds.), Drug use and ethnicity in early adolescence (pp.149-176). New York: Plenum.

Blum RW, Beuhring T, Shew ML, Bearinger LH, Sieving RE, Resnick MD. The effects of race/ethnicity, income, and family structure on adolescent risk behaviors. Am J Public

Health. 2000 Dec;90(12):1879-84. doi: 10.2105/ajph.90.12.1879. PMID: 11111260; PMCID: PMC1446419.

Bodin, F., McIntyre, K. M., Schwartz, J. E., McKinley, P. S., Cardetti, C., Shapiro, P. A., ... & Sloan, R. P. (2017). The association of cigarette smoking with high-frequency heart rate variability: An ecological momentary assessment study. *Psychosomatic Medicine, 79*(9), 1045-1050.

Borrell LN, Jacobs DR, Williams DR, Pletcher MJ, Houston TK, Kiefe CI. Self-reported racial discrimination and substance use in the coronary artery risk development in adults study. American Journal of Epidemiology. 2007;166:1068–1079.

Brannock, J. C., Schandler, S. L., & Oncley, P. R. (1990). Cross-cultural and cognitive factors examined in groups of adolescent drinkers. *Journal of Drug Issues, 20*(3), 427–442. https://doi.org/10.1177/002204269002000304

Brown, T. L., Miller, J. D., & Clayton, R. R. (2004). The Generalizability of Substance Use Predictors Across Racial Groups. *The Journal of Early Adolescence*, *24*(3), 274–302. https://doi.org/10.1177/0272431604265677

Carnevali L, Barbetti M, Statello R, Williams DP, Thayer JF, Sgoifo A. Sex differences in heart rate and heart rate variability in rats: Implications for translational research. Front Physiol. 2023 Mar 24;14:1170320. doi: 10.3389/fphys.2023.1170320. PMID: 37035663; PMCID: PMC10080026.

Carver CS, Connor-Smith J. Personality and coping. Annual Review of Psychology. 2010; 61:679–704.

Center for Behavioral Health Statistics and Quality. *Results from the 2016 National Survey on Drug Use and Health: Detailed Tables.* Rockville, MD: Substance Abuse and Mental

Health Services Administration; 2017. https://www.samhsa.gov/data/sites/default/files/NSDUH-DetTabs-2016/NSDUH-DetTabs-2016.pdf.

Clark R. Interethnic group and intraethnic group racism: Perceptions and coping in Black university students. Journal of Black Psychology. 2004;30:506–526.

Cohen, S., & Janicki-Deverts, D. (2012). Who's stressed? Distributions of psychological stress in the United States in probability samples from 1983, 2006, and 2009. *Journal of Applied Social Psychology*, *42*(6), 1320–1334. https://doi.org/10.1111/j.1559-1816.2012.00900.x

Cooper, M. L., Krull, J. L., Agocha, V. B., Flanagan, M. E., Orcutt, H. K., Grabe, S., Dermen, K. H., & Jackson, M. (2008). Motivational pathways to alcohol use and abuse among Black and White adolescents. *Journal of Abnormal Psychology*, *117*(3), 485–501. https://doi.org/10.1037/a0012592

Crenshaw, K. (2013). Demarginalizing the intersection of race and sex: A black feminist critique of antidiscrimination doctrine, feminist theory, and antiracist politics. In *Feminist Legal Theories* (pp. 23-51). Routledge.

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*(1), 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Dienberg Love G, Seeman TE, Weinstein M, Ryff CD. Bioindicators in the MIDUS national study: protocol, measures, sample, and comparative context. J Aging Health. 2010 Dec;22(8):1059-80. doi: 10.1177/0898264310374355. Epub 2010 Sep 27. PMID: 20876364; PMCID: PMC2972372.

Duncan SC, Duncan TE, Strycker LA. Alcohol use from ages 9 to 16: A cohort-sequential latent growth model. Drug Alcohol Depend. 2006 Jan 4;81(1):71-81. doi:

10.1016/j.drugalcdep.2005.06.001. Epub 2005 Jul 11. PMID: 16006054; PMCID: PMC1368652.

Eddie D, Barr M, Njeim L, Emery N. (2021). Mean versus variability: disentangling stress effects on alcohol lapses among individuals in the first year of alcohol use disorder recovery. *J Stud Alcohol Drugs.* (2021) 82:623–28. doi: 10.15288/jsad.2021.82.623

Eddie D, Kim C, Lehrer P, Deneke E, Bates ME. A pilot study of brief heart rate variability biofeedback to reduce craving in young adult men receiving inpatient treatment for substance use disorders. *Appl Psychophysiol Biofeedback.* (2014) 39:181–92. doi: 10.1007/s10484-014-9251-z

Felton G, Parsons MA, Ward DS, Pate RR, Saunders RP, Dowda M, Trost S. Tracking of avoidance of alcohol use and smoking behavior in a fifth grade cohort over three years. Public Health Nurs. 1999 Feb;16(1):32-40. doi: 10.1046/j.1525-1446.1999.00032. x. PMID: 10074820.

Gardener, E. K. T., Carr, A. R., MacGregor, A., & Felmingham, K. L. (2013). Sex differences and emotion regulation: An event-related potential study. *PLoS ONE, 8*(10), Article e73475. https://doi.org/10.1371/journal.pone.0073475

Gilbert, D. G. (2014). *Smoking: Individual differences, psychopathology, and emotion.* Taylor & Francis.

Guo, Q., Wang, J., Liu, H., Wu, D., & Liao, S. (2022). Nicotine Ingestion Reduces Heart Rate Variability in Young Healthy Adults. *BioMed Research International*, *2022*, e4286621. https://doi.org/10.1155/2022/4286621

Guthrie BJ, Young AM, Williams DR, Boyd CJ, Kintner EK. African American girls' smoking habits and day-to-day experiences with racial discrimination. Nursing Research. 2002; 51:183–190.

Hansen, A. L., Johnsen, B. H., & Thayer, J. F. (2003). Vagal influence on working memory and attention. *International Journal of Psychophysiology*, *48*(3), 263–274. https://doi.org/10.1016/S0167-8760(03)00073-4

Hayes, A.F. (2022). Introduction to mediation, moderation, and conditional process analysis: A regression-based approach (3rd Edition). New York: The Guilford Press.

Hill, L. K., Hoggard, L. S., Richmond, A. S., Gray, D. L., Williams, D. P., and Thayer, J. F. (2017). Examining the association between perceived discrimination and heart rate variability in African Americans. *Cultur. Divers. Ethnic Minor. Psychol.* 23, 5–14. doi: 10.1037/cdp0000076

Hill, L. K., Hu, D. D., Koenig, J., Sollers, J. J. III, Kapuku, G., Wang, X., et al. (2015). Ethnic differences in resting heart rate variability: a systematic review and meta-analysis. *Psychosom. Med.* 77, 16–25. doi: 10.1097/PSY.0000000000000133

Ingjaldsson JT, Thayer JF, Laberg JC. Craving for alcohol and pre-attentive processing of alcohol stimuli. *Int J Psychophysiol.* (2003) 49:29–39. doi: 10.1016/s0167-8760(03)00075-8

Jackson SJ, Knight KM, Rafferty JA. Race and unhealthy behaviors: Chronic stress, the HPA axis, and physical and mental health disparities over the life course. American Journal of Public Health. 2010; 100:933–939.

Jarymowicz, M. (2002). On the benefits from research on implicit affective information processing. *Polish Psychological Bulletin*, *33*(2), 5–11.

Jarymowicz, M. T., & Imbir, K. K. (2015). Toward a human emotions taxonomy (based on their automatic vs. reflective origin). *Emotion Review*, *7*(2), 183–188.

Kapuku G, Ghosh S, Doshi V, Hall P, Strong W, Treiber F, Pollock D, Pollock J, Harris R, Halbert J, et al. The Augusta Heart study. Journal of Environment and Health. Science. 2019; 5:15–23.

King, C. C., Piper, M. E., Gepner, A. D., Fiore, M. C., Baker, T. B., & Stein, J. H. (2017). Longitudinal impact of smoking and smoking cessation on inflammatory markers of cardiovascular disease risk. *Arteriosclerosis, Thrombosis, and Vascular Biology*, *37*(2), 374-379.

Koenig, J., & Thayer, J. F. (2016). Sex differences in healthy human heart rate variability: A meta-analysis. *Neuroscience and Biobehavioral Reviews*, *64*, 288–310. https://doi.org/10.1016/j.neubiorev.2016.03.007

Kong, A. Y., Golden, S. D., & Berger, M. T. (2019). An intersectional approach to the menthol cigarette problem: what's race (ism) got to do with it?. *Critical Public Health*, *29*(5), 616-623.

Koob, G. F. (2015). The dark side of emotion: The addiction perspective. *European Journal of Pharmacology*, *753*, 73–87. https://doi.org/10.1016/j.ejphar.2014.11.044

Koskinen, P., Virolainen, J., & Kupari, M. (1994). Acute alcohol intake decreases short-term heart rate variability in healthy subjects. *Clinical Science (London, England: 1979)*, *87*(2), 225–230. https://doi.org/10.1042/cs0870225

Kroll SL, Thayer JF, Williams DP, Pfabigan DM, Baumgartner MR, Lamm C, et al. Chronic non-medical prescription opioid use and empathy for pain: does pain make the difference? *Psychophysiology* (2021) 58:e13776. doi: 10.1111/psyp.13776

Kwon ES, Kittaneh AA, Gerardo GM, Koenig J, Thayer JF and Williams DP (2022) Resting Heart Rate Variability, Perceived Emotion Regulation, and Low-Risk Drug Use in College-Aged Adults: Gender as a Moderator. *Front. Psychiatry* 13:885217. doi: 10.3389/fpsyt.2022.885217

Landrine H, Klonoff EA. Racial segregation and cigarette smoking among Blacks: Findings at the individual level. Journal of Health Psychology. 2000; 5:211–219.

Lane, R. D., McRae, K., Reiman, E. M., Chen, K., Ahern, G. L., & Thayer, J. F. (2009). Neural correlates of heart rate variability during emotion. *NeuroImage*, *44*(1), 213–222. https://doi.org/10.1016/j.neuroimage.2008.07.056

Leach, L. S., Christensen, H., Mackinnon, A. J., Windsor, T. D., & Butterworth, P. (2008). Gender differences in depression and anxiety across the adult lifespan: the role of psychosocial mediators. *Social psychiatry and psychiatric epidemiology*, *43*, 983-998.

Mays VM, Cochran SD, Barnes NW. Race, race-based discrimination, and health outcomes among African Americans. Annual Review of Psychology. 2007; 58:201–225.

Mauss D, Jarczok MN, Fischer JE. A streamlined approach for assessing the Allostatic Load Index in industrial employees. Stress. 2015;18(4):475-83. doi: 10.3109/10253890.2015.1040987. Epub 2015 May 15. PMID: 25976030.

Mauss D, Jarczok MN, Fischer JE. The streamlined Allostatic Load Index: a replication of study results. Stress. 2016 Nov;19(6):553-558. doi: 10.1080/10253890.2016.1219718. Epub 2016 Aug 23. PMID: 27483979.

Mauss D, Li J, Schmidt B, Angerer P, Jarczok MN. Measuring allostatic load in the workforce: a systematic review. Ind Health. 2015;53(1):5-20. doi: 10.2486/indhealth.2014-0122. Epub 2014 Sep 13. PMID: 25224337; PMCID: PMC4331190.

Mendrek, A. (2014). [Are there any sex/gender differences in drug use and drug addiction?]. *Sante Mentale Au Quebec, 39*(2), 57–74.

Moon, S. J. E., Schlenk, E. A., & Lee, H. (2023). Heart rate variability in adults with substance use disorder: A comprehensive narrative review. *Journal of the American Psychiatric Nurses Association, 30*(2), 240-251. https://doi.org/10.1177/10783903221145142

Mumenthaler, M. S., Taylor, J. L., O'Hara, R., & Yesavage, J. A. (1999). Gender differences in moderate drinking effects. *Alcohol Research & Health*, 23(1), 55-64. PMID: 10890798; PMCID: PMC6761697.

Neff JA. Alcohol consumption and psychological distress among U.S. Anglos, Hispanics and Blacks. Alcohol Alcohol. 1986;21(1):111-9. PMID: 3954826.

Newcomb MD, Maddahian E, Skager R, Bentler PM. Substance abuse and psychosocial risk factors among teenagers: associations with sex, age, ethnicity, and type of school. Am J Drug Alcohol Abuse. 1987;13(4):413-33. doi: 10.3109/00952998709001525. PMID: 3687899.

NIDA. *NIDA is the Lead Federal Agency Supporting Scientific Research on Drug Use and its Consequences.* Bethesda, MD: NIDA (2020).

Park, G., Vasey, M. W., Van Bavel, J. J., & Thayer, J. F. (2014). When tonic cardiac vagal tone predicts changes in phasic vagal tone: the role of fear and perceptual load. *Psychophysiology*, *51*(5), 419–426. https://doi.org/10.1111/psyp.12186

Porges, S. W. (2011). *The polyvagal theory: Neurophysiological foundations of emotions, attachment, communication, and self-regulation*. New York: W. W. Norton.

Primatesta, P., Falaschetti, E., Gupta, S., Marmot, M. G., & Poulter, N. R. (2001). Association between smoking and blood pressure: Evidence from the Health Survey for England. *Hypertension*, *37*(2), 187-193.

Quello SB, Brady KT, Sonne SC. Mood disorders and substance use disorder: a complex comorbidity. *Sci Pract Perspect.* (2005) 3:13–21. doi: 10.1151/spp053113

Ralevski E, Petrakis I, Altemus M. Heart rate variability in alcohol use: a review. *Pharmacol Biochem Behav.* (2019) 176:83–92. doi: 10.1016/j.pbb.2018.12.003

Rostron, B. (2012). Smoking-attributable mortality by cause in the United States: Revising the CDC's data and estimates. *Nicotine & Tobacco Research*, *15*(1), 238-246.

Ruigrok AN, Salimi-Khorshidi G, Lai MC, Baron-Cohen S, Lombardo MV, Tait RJ, Suckling J. A meta-analysis of sex differences in human brain structure. Neurosci Biobehav Rev. 2014 Feb;39(100):34-50. doi: 10.1016/j.neubiorev.2013.12.004. Epub 2013 Dec 26. PMID: 24374381; PMCID: PMC3969295.

Ruiz-Padial, E., Sollers, J. J., Vila, J., & Thayer, J. F. (2003). The rhythm of the heart in the blink of an eye: Emotion-modulated startle magnitude covaries with heart rate variability. *Psychophysiology*, *40*(2), 306–313. https://doi.org/10.1111/1469-8986.00032

Ryan, J. M., & Howes, L. G. (2002). Relations between alcohol consumption, heart rate, and heart rate variability in men. *Heart*, *88*(6), 641–642.

Ryff, Carol D., Seeman, Teresa, and Weinstein, Maxine. Midlife in the United States (MIDUS 2): Biomarker Project, 2004-2009. Inter-university Consortium for Political and Social Research [distributor], 2022-12-14. https://doi.org/10.3886/ICPSR29282.v10

Saban, A., & Flisher, A. J. (2010). The association between psychopathology and substance use in young people: A review of the literature. *Journal of Psychoactive Drugs*, *42*(1), 37-47.

Seeman TE, Singer BH, Rowe JW, Horwitz RI, McEwen BS. Price of adaptation--allostatic load and its health consequences. MacArthur studies of successful aging. Arch Intern Med. 1997 Oct 27;157(19):2259-68. Erratum in: Arch Intern Med 1999 Jun 14;159(11):1176. PMID: 9343003.

Shiels, M. S., Katki, H. A., Freedman, N. D., Purdue, M. P., Wentzensen, N., Trabert, B., ... & Chaturvedi, A. K. (2014). Cigarette smoking and variations in systemic immune and inflammation markers. *Journal of the National Cancer Institute, 106*(11), dju294.

Singer, M. I., & Petchers, M. K. (1987). A biracial comparison of adolescent alcohol use. *The American Journal of Drug and Alcohol Abuse, 13*(4), 461–474. https://doi.org/10.3109/00952998709001528

Slabbert, I., Greene, M. C., Womersley, J. S., Olateju, O. I., Soboka, M., & Lemieux, A. M. (2020). Women and substance use disorders in low- and middle-income countries: A call for advancing research equity in prevention and treatment. *Substance abuse, 41*(1), 6–10. https://doi.org/10.1080/08897077.2019.1680481

Smith JP, Book SW. Anxiety and substance use disorders: a review. *Psychiatr Times.* (2008) 25:19–23.

Stevens, J. S., & Hamann, S. (2012). Sex differences in brain activation to emotional stimuli: A meta-analysis of neuroimaging studies. *Neuropsychologia, 50*(7), 1578–1593. https://doi.org/10.1016/j.neuropsychologia.2012.03.011

Substance Abuse and Mental Health Services Administration. *Mental and substance use disorders.* https://www.samhsa.gov/disorders. Published June 20, 2014.

Substance Abuse and Mental Health Services Administration. (2022). Key substance use and mental health indicators in the United States: Results from the 2021 National Survey on

Drug Use and Health (HHS Publication No. PEP22-07-01-005, NSDUH Series H-57). Center for Behavioral Health Statistics and Quality, Substance Abuse and Mental Health Services Administration. https://www.samhsa.gov/data/report/2021-nsduh-annual-national-report

Thayer, J. F., Ahs, F., Fredrikson, M., Sollers, J. J., & Wager, T. D. (2012). A meta-analysis of heart rate variability and neuroimaging studies: Implications for heart rate variability as a marker of stress and health. *Neuroscience and Biobehavioral Reviews*, *36*(2), 747–756. https://doi.org/10.1016/j.neubiorev.2011.11.009

Thayer, J. F., Hansen, A. L., Saus-Rose, E., & Johnsen, B. H. (2009). Heart rate variability, prefrontal neural function, and cognitive performance: The neurovisceral integration perspective on self-regulation, adaptation, and health. *Annals of Behavioral Medicine*, *37*(2), 141–153. https://doi.org/10.1007/s12160-009-9101-z

Thayer, J. F., & Lane, R. D. (2000). A model of neurovisceral integration in emotion regulation and dysregulation. *Journal of Affective Disorders*, *61*(3), 201–216. https://doi.org/10.1016/S0165-0327(00)00338-4

Thayer, J. F., & Lane, R. D. (2007). The role of vagal function in the risk for cardiovascular disease and mortality. *Biological Psychology*, *74*(2), 224–242. https://doi.org/10.1016/j.biopsycho.2005.11.013

Thomasson, H. R. (2002). Gender differences in alcohol metabolism. In M. Galanter et al. (Eds.), *Recent developments in alcoholism* (Vol. 12). Springer. https://doi.org/10.1007/0-306-47138-8_9

Visted, E., Sørensen, L., Osnes, B., Svendsen, J. L., Binder, P. E., & Schanche, E. (2017). The association between self-reported difficulties in emotion regulation and heart rate

variability: the salient role of not accepting negative emotions. *Frontiers in psychology*, *8*, 328.

Wannamethee, S. G., Lowe, G. D., Shaper, A. G., Rumley, A., Lennon, L., & Whincup, P. H. (2005). Associations between cigarette smoking, pipe/cigar smoking, and smoking cessation, and haemostatic and inflammatory markers for cardiovascular disease. *European Heart Journal*, *26*(17), 1765-1773.

Warheit, G. J., Vega, W. A., Khoury, E. L., & Gil, A. A. (1996). A comparative analysis of cigarette and illicit drug use among an ethnically diverse sample of Hispanic, African American, and non-Hispanic White adolescents. *Journal of Drug Issues*, 26(4), 399-418.

Williams, D. P., Cash, C., Rankin, C., Bernardi, A., Koenig, J., & Thayer, J. F. (2015). Resting heart rate variability predicts self-reported difficulties in emotion regulation: A focus on different facets of emotion regulation. *Frontiers in Psychology*, *6*. https://doi.org/10.3389/fpsyg.2015.00261

Williams, D.P., Joseph, N., Gerardo, G.M. *et al.* Gender Differences in Cardiac Chronotropic Control: Implications for Heart Rate Variability Research. *Appl Psychophysiol Biofeedback* **47**, 65–75 (2022). https://doi.org/10.1007/s10484-021-09528-w

Williams, D. P., Thayer, J. F., & Koenig, J. (2016). Resting cardiac vagal tone predicts intraindividual reaction time variability during an attention task in a sample of young and healthy adults. *Psychophysiology*, *53*(12), 1843–1851. https://doi.org/10.1111/psyp.12739