

A Multi-Analytic Examination of Race, Sex, and Cigarette Craving among Smokers

by

Eliza Lee Marsh

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This thesis was presented

by

Eliza Lee Marsh

It was defended on

April 18, 2024

and approved by

Dr. Scott Fraundorf, Associate Professor, Psychology

Dr. Sarah Pedersen, Associate Professor, Psychiatry

Thesis Advisor: Dr. Michael Sayette, Psychology

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The current research investigates the relationships among race, sex, and in vivo cigarette craving, aiming to elucidate potential differences across various sociodemographic groups. Leveraging the largest sample size to date in studies utilizing in vivo cigarette cue exposure, this research employed two distinct statistical approaches to assess craving dynamics. Findings revealed that Black female and male smokers exhibited heightened baseline urge ratings and were more prone to experiencing maximal peak-provoked craving during cue exposure compared to White female and male smokers. Additionally, White female smokers demonstrated heightened cue reactivity relative to White male smokers. Methodologically, this study provides compelling evidence for a comprehensive statistical approach to understanding experimentally induced cigarette craving, highlighting the importance of considering intersecting identity factors relationship with varied craving outcome measures. Clinically, these results underscore the necessity of understanding and addressing racial and sex disparities in smoking behavior and health outcomes.

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1.0 Introduction: Background and Significance

Tobacco use and exposure causes approximately one in five deaths, making smoking the leading preventable cause of mortality in the United States (Centers for Disease Control, 2017). Likely because of negative health outcomes, most smokers would like to quit, but often are unsuccessful in their attempts (Babb, 2017). Although tobacco use has decreased in the United States over the past 30 years through intervention and prevention efforts, the negative outcomes associated with tobacco use have not been consistently reduced across groups with different sociodemographic factors (Sheffer et al., 2022). Indeed, many marginalized groups in the United States experience higher rates of smoking-related diseases, despite having overall lower smoking rates than do non-Hispanic White males (Trinidad et al., 2011).

Although many individuals in marginalized communities experience difficulties quitting smoking, most smoking research continues to use a single sociodemographic variable to predict health outcomes (e.g., race or sex), rather than applying a holistic, person-centered perspective considering the intersection of identity factors. Studies indicate, however, that individuals with multiple marginalized identities may have unique and challenging experiences with smoking and cessation (Potter et al., 2021; Tan et al., 2023). There are myriad upstream and downstream factors that drive smoking and cessation disparities in marginalized communities, including both social determinants (e.g., structural inequities, experiences of marginalization and discrimination) and social needs (e.g., health care and housing) (Bosma, 2014). There has been a recent call for tobacco research to use an intersectional framework (Potter et al., 2021). Such research aims to help the field better understand why the previously outlined tobacco-related disparities occur at higher rates for individuals with marginalized sociodemographic identity factors (Bauer, 2014; Potter et al.,

2021; Sheffer et al., 2022). The intersectional framework contends that statistical models should include sociodemographic variables that may contribute to and interact with smoking outcomes. The current project addresses these recent calls to action by analyzing empirical data related to cigarette craving through an intersectional lens considering primary predictor variables of race and sex, while accounting for socioeconomic status (SES). Importantly, it must be noted that the data presented in the current project were collected in the United States. Consequently, the results presented in this document may not necessarily apply to other countries. Because the tobacco industry employs targeted tactics in low and middle-income countries (Lee et al., 2012), there is a pressing need for intersectional and individual difference research to extend beyond the United States.

1.1 Smoking and Marginalized Populations

1.1.1 Smoking Among Black Persons

Black Americans report overall lower smoking rates compared to non-Hispanic Americans, and Black smokers demonstrate a higher number of quit attempts in the past year (Ward et al., 2015) Whether these reported smoking rates accurately translate to actual intake levels remains unclear, particularly as individuals identifying as Black and male are found to consume the highest alcohol content compared to White male, White female, and Black female groups (Kerr et al., 2009). Notably, recent research has suggested that among low nicotine-dependent smokers, Black individuals have higher incremental smoke exposure risk per cigarette when compared to White individuals, suggesting that smoking-related health outcomes faced by

Black smokers are severe (Ho et al., 2020). Indeed, research indicates that Black smokers have greater challenges in achieving smoking cessation (Nguyen-Grozavu et al., 2020). One contributing factor to this disparity is that Black persons typically have limited access to and engagement with cessation resources, including medication and counselling (Haiman et al., 2006). Moreover, Black smokers face greater rates of adverse health consequences, including cancer (Park et al., 2011) and cardiovascular disease (Oshunbade et al., 2021) than White smokers. Overall, there are higher rates of morbidity and mortality among Black Americans compared to non-Hispanic White Americans (Rostron et al., 2022), and smoking related deaths in America are highest among Black men (American Lung Association, 2019). These data speak to a public health paradox: Black smokers are less likely to smoke and have a greater amount of past year quit attempts, and yet have lower accessibility and use of cessation treatment. Such a paradox may contribute to the reported higher rates of mortality and morbidity among Black persons who smoke.

1.1.2 Smoking Among Female Persons

Between the years of 1965 and 2018, death rates associated with smoking related disease decreased more significantly among male (56%) than female smokers (32%) (American Lung Association, 2019). Nevertheless, it remains true that more male persons are ever-smokers and tend to smoke more cigarettes on average than female smokers (Cornelius et al., 2022). Female smokers may, however, have an increased vulnerability to developing nicotine dependence after beginning to smoke (Fattore et al., 2008). When trying to achieve cessation, female persons are more likely to use counseling and medication than males yet have lower rates of quitting and success with sustained remission (Centers for Disease Control, 2011; Smith et al., 2016).

Moreover, some popular cessation medications, including transdermal nicotine patches, appear to be less effective for female persons (Fattore et al., 2008). These additional challenges to quitting among female smokers may help explain the observed narrowing of the male to female ratio of smokers over the past several decades (Cornelius et al., 2022). As the proportion of female smokers continues to rise, it is troubling that female persons are more susceptible to negative health outcomes associated with smoking, including lung and oral cancers (Stapelfeld et al., 2020), cardiovascular disease (Smith et al., 2016), and early-onset COPD (Ntritsos et al., 2018). Similar to the public health paradox found among Black smokers, female smokers have lower rates of smoking but higher likelihood of negative health outcomes. Unlike many smokers with racial/ethnic marginalized statuses, however, female smokers are more likely than male smokers to have access to, and to use, counselling and medication. These data speak to the need to unpack smoking challenges by both race and sex.

1.1.3 Race, Sex, and Smoking Behavior

Some recent research has begun to explore patterns of use and cessation among varied sociodemographic groups (i.e., considering both race and sex together). Payne and colleagues (2019) found that White male smokers have the lowest mean age of smoking initiation, the greatest mean number of years regularly smoking, the highest maximum daily rate of cigarettes smoked per day, and the highest mean dependence scores. Taken together, these data suggest that White male persons would experience the most severe health outcomes and lowest chances of successful cessation, yet research has consistently suggested the opposite, whereby sex and race groupings other than White male smokers have greater negative health outcomes and lower success with cessation (Nguyen-Grozavu et al., 2020).

1.2 Craving

Craving, frequently used interchangeably with *urge*, is believed to be a key feature of smoking maintenance and relapse (Sayette, 2016). Research often conceptualizes craving as an overwhelming and intense motivational state, whereby one may become unable to resist using a substance (George & Koob, 2013; Volkow et al., 2010). Consensus is growing that craving predicts future drug use and relapse (Vafaie & Kober, 2022). With marginalized smoking populations (including Black and female smokers) experiencing greater difficulties maintaining cessation, it would be useful to investigate whether these demographic variables also impact cigarette craving.

While some research has examined the impact of person-level factors such as race and gender on craving, far more research has investigated situational factors affecting craving. A large body of research reveals that exposure to environmental (e.g., smoking) cues or changes in internal affective states can elicit or intensify an urge (Betts et al., 2021; Robinson et al., 2015). An additional driver of craving is believed to be negative affect (Sayette, 2016); experiencing negative affect has been associated with subsequent lapse, particularly as withdrawal states tend to intensify both negative affect and craving (Cambron et al., 2019). Studies also have indicated that severity of dependence may be associated with the magnitude of craving (Watson et al., 2010), even after accounting for other individual difference variables [e.g., cigarettes smoked per day (Donny et al., 2008)]. Accordingly, research contrasting race and sex differences in craving would do well to control for levels of nicotine dependence.

1.2.1 Craving in the Laboratory

Given the importance of craving to addiction (see Sayette, 2016), it is unsurprising that numerous lab studies have sought to provoke craving and then examine its correlates and consequences. A variety of manipulations have been used to generate craving in the lab, including manipulations of mood (see Sayette et al., 2000). Perhaps the most common approach to experimentally provoking craving in the lab is to use a smoking cue exposure paradigm (Sayette & Tiffany, 2013). Cue exposure paradigms expose participants to stimuli associated with their substance use, including images or videos of individuals using drugs, and imaginal exposures (Sayette, 2016). One of the most effective and widely used methods of cue exposure has been to expose smokers to in vivo cues, such as asking participants to hold a lit cigarette (Sayette & Hufford, 1994).

1.2.1.1 Cue Exposure Paradigms.

Craving has proven to be a tricky concept to measure in the laboratory (Sayette et al., 2000). Traditionally, cue exposure paradigms have relied on a cue reactivity (CR) outcome, which is calculated by subtracting either a pre-cue exposure urge rating (sometimes referred to as baseline or tonic urge) from an urge rating during smoking cue exposure (sometimes referred to as phasic craving). While in principle it is appealing to distinguish between tonic and phasic forms of craving, in fact, it is both conceptually and empirically messy (Sayette & Tiffany, 2013). For instance, having refrained from smoking, some smokers may arrive at the laboratory already in a peak craving state before the cue exposure begins, which creates ceiling effects when using CR as an outcome. Moreover, especially while in a nicotine-deprived state, even the simple use of a craving rating scale may be sufficient to cue the smoker to focus on their craving, suggesting that

administration of the measure itself precludes a purely “non-cued” baseline assessment (see Sayette & Tiffany, 2013 for elaboration). Such an occurrence is common when smokers are asked to arrive for the study having abstained from smoking. [I will retain the term “baseline” herein, as it is commonly used in the literature, but in fact, there is no true baseline (i.e., uncued) urge rating. More precisely, this assessment instead captures a “pre-cigarette-cue” urge rating, as even this initial urge assessment may involve some degree of cueing of the urge experience. Simply asking a smoker to report their urge in itself is a craving stimulus, especially when one has refrained from smoking for many hours. In other words, the difference between a baseline and a smoking cue urge is not as qualitatively distinct as one might suppose (Sayette & Tiffany, 2013). This assessment may serve as a cue exposure that is simply less robust than the subsequent cue exposure assessment that occurs during exposure to an actual cigarette.]

Perhaps to reduce this risk of ceiling effects caused by sky high baseline urges, some studies have instructed participants to smoke at the study outset, thus creating ample room on the scale for urges to rise during smoking cue exposure. Unfortunately, smoking right at study outset often reduces craving scores to close to zero (see Sayette et al., 2001), which may undermine the ability to elicit the type of overwhelming desire to smoke that is thought to characterize craving, even while holding a drug cue (George & Koob, 2013; Volkow et al., 2010).

While traditional CR analyses have proven useful to the field (see Carter & Tiffany, 1999), the concerns raised above led to an alternative, complementary approach to craving analysis, which relies on a peak provoked craving (PPC) outcome (Sayette & Tiffany, 2013). In this alternative approach, the experimenter aims to generate maximal craving by combining smoking abstinence and smoking cue exposure. The experimenter simply focuses on the PPC urge rating reported during smoking cue exposure without regard to the rating recorded prior to the cue. That is, one

no longer subtracts the pre-cigarette cue “baseline” urge score from the rating recorded during smoking cue exposure. For example, if a nicotine-deprived smoker enters the lab with a rating of a 95 on a 0 to 100 urge rating scale, and then while holding a lit cigarette they report a 100, the traditional CR rating (100 minus 95) would reveal just a modest increase of five. In contrast, the PPC score of 100 would suggest a robust craving had been experienced. Although CR is the more common approach, research indicates that a PPC outcome measure in the lab offers more clinically significant information than that of CR (e.g., providing a better predictor of subsequent relapse and treatment success, see Sayette & Tiffany, 2013).

Regardless of whether one prefers a CR or a PPC outcome when assessing urge response in the laboratory, nearly all the hundreds of smoking cue studies have relied on nomothetic (i.e., group mean differences) analyses (e.g., exposure to a cigarette leads to a significantly higher mean urge than during baseline assessment or during exposure to a control cue). Although significant increases in mean levels may imply that the prototypical participant in a study would show this increase, recently this assumption has been forcefully challenged. Grice and colleagues (2020) offered compelling examples of studies in which most participants fail to reveal the expected effects, even when robustly significant mean differences were reported. More recently, a person-centered analysis revealed that the combination of smoking abstinence and smoking cue exposure does indeed generate powerful craving, with more than $\frac{3}{4}$ of the large sample reporting at least 70% of the scale maximum (Sayette et al., 2022). These data are encouraging for the field, in that they suggest the smoking cue exposure paradigm reliably generates potent craving in the laboratory. Additionally, these findings further support the utility of conducting both person-centered and traditional means-level analyses when evaluating lab-based cigarette craving. Accordingly, the present study offers a comprehensive examination of craving across race and sex,

by examining both CR and PPC outcomes while conducting means-level and person-centered analyses.

1.2.2 Marginalized Identity Status and Craving

1.2.2.1 Racial Differences and Craving

Ecological momentary assessment (EMA) studies have broadly indicated that Black smokers report higher rates of craving and less craving relief when smoking than do White smokers (Carter et al., 2010). EMA data also indicates that Black smokers not only report higher cigarette enjoyment when smoking, compared to White smokers (Carter et al., 2010), but also report greater negative affect during smoking withdrawal (Soyster et al., 2016). Research also indicates that Black smokers may experience higher rates of craving because of increased exposure to smoking-related cues [e.g., targeted smoking advertisements in neighborhoods that are predominately Black and lower income (Davis et al., 2008; U.S. Food and Drug Administration, 2013)], lower cessation self-efficacy (Calixte-Civil & Brandon, 2021), and exposure to minority stress and discrimination (Dawson & Fletcher, 2021).

Taken together, research suggests that compared to White smokers, Black smokers: a) experience greater negative affect during abstinence; b) have greater exposure to smoking-related cues; and c) demonstrate lower smoking abstinence self-efficacy, all of which are associated with increased craving and lapse (Carter et al., 2010; Robinson et al., 2015; Davis et al., 2008). Discrimination over the course of a lifetime may increase negative affect (Dawson & Fletcher, 2021), and in turn, lower abstinence self-efficacy, thereby potentially increasing craving, especially in environments that are rich in smoking cues. These findings converge to provide

preliminary evidence that Black smokers may experience craving differently than do White smokers and highlight the value of examining this possibility experimentally.

1.2.2.2 Race and Cue Exposure Laboratory Craving Manipulations

Relatively few studies have examined race and craving using cue exposure manipulations (e.g., Erblich et al., 2022). Colamussi and colleagues (2007) found that Black smokers reacted with more intense craving than did White smokers to stressful scripts. The project did not require smoking abstinence and therefore it is difficult to know how this finding would apply during moments that included nicotine deprivation. Shiffman and colleagues (2013) found that, compared to White smokers, Black smokers showed greater increases in distress-relief craving across pre- and post-cue exposure, during both a stress and an in vivo smoking cue exposure manipulation. Again, however, the participants smoked just before the experiment, making the potency of the craving experience less clear. Nevertheless, these laboratory data at the very least further emphasize that Black and White smokers may crave differently. The present study explores whether race is associated with craving using an established in vivo cue exposure paradigm that elicits a powerful urge to smoke.

1.2.2.3 Sex Differences and Craving

In contrast to racial differences in craving, there is comparatively little naturalistic literature considering whether male and female smokers have different rates of cigarette craving. A more substantial body of work has examined whether craving is triggered or influenced by different factors for male and female smokers. Some investigators have argued that female smokers may be especially sensitive to drug cues, and in some cases, heightened sensitivity to cigarette cues may lead female smokers to be more likely to crave, and ultimately smoke, than are male smokers

(Perkins, 2001; Perkins et al., 2006). Yet other naturalistic studies offer conflicting evidence, whereby male smoking behavior appears to be more easily influenced by cues (Ferguson et al., 2015).

In addition to smoking cues, research has examined sex differences in the experience of negative affective states while quitting. Research in the natural environment finds female smokers report greater negative affect during early cessation (Leventhal et al., 2007; Messer et al., 2018). Moreover, female smokers are more likely than male smokers to anticipate reductions in negative affect when smoking (Reig-Ferrer & Cepeda-Benito, 2007). Similar findings emerge in laboratory studies inducing stress, such that when female smokers have a cigarette before a stress exposure paradigm they experience a greater anxiolytic effect than do male smokers (File et al., 2001). During the Trier Social Stress Test, current female smokers also had a lower cortisol response compared to female non-smokers, whereas there was no difference between current male smokers and non-smokers (Back et al., 2008). Qualitative research has also supported these naturalistic and laboratory findings, indicating that female smokers' reported main barriers to achieving smoking cessation were psychological factors (e.g., emotion and stress) (Dieleman et al., 2021, Tomko et al., 2018). In summary, the craving literature suggests that compared to male persons, the craving of female persons may be driven more by affective experience and possibly by smoking-related cues, and that their smoking behavior may be less motivated by dose-specific nicotine seeking behavior.

1.2.2.4 Sex and Cue Exposure Laboratory Craving Manipulations

Laboratory-based studies using a specific craving induction have reported disparate findings in terms of sex differences, likely due to inconsistent methodologies. I located 17 published studies that evaluated the relationship between sex and craving following urge

manipulations. These studies vary regarding experimental power to detect sex differences, level of smoking abstinence (if any), type of craving cue (e.g., stress paradigm, in vivo smoking cue, photo of smoking cues), and craving outcome measurement (PPC or CR).

The findings from these 17 studies fail to reveal a clear-cut conclusion, which may not be surprising given the methodological heterogeneity. Many studies observed female smokers to have higher craving in the lab than did male smokers (Carpenter et al., 2014; Colamussi et al., 2007; Doran, 2014; Erblich et al., 2022; Field & Duka, 2004; Heishman et al., 2010; Knott et al., 2008; Saladin et al., 2012; Waters et al., 2004; Wray et al., 2014). However, in close to half the studies, including some boasting the largest sample sizes with the most racial diversity, there was no evidence of sex differences in craving (Erblich & Bovbjerg, 2004; Niaura et al., 1998; Sayette et al., 2001; Shiffman et al., 2003, 2013; Tong et al., 2007; Zinser et al., 1999). Research using large samples of male and female smokers that also include adequate numbers of both Black and White smokers are needed to further probe the relationship between sex and craving.

1.2.2.5 Race, Sex, and Craving

Among these 17 laboratory-based studies, an investigation by Erblich and colleagues (2022) was distinct for examining both race and sex differences in craving. These authors used a stress-based manipulation to elicit craving and found that an acute stressor increased negative affect, which, in turn, induced cigarette craving. These effects were more pronounced for female persons and for non-White individuals. Participants did smoke at study outset and immediately before the stress manipulation, however, so overall urge levels may have been modest. Nevertheless, this recent study provides some initial evidence that Black smokers' and female smokers' desire to smoke may be more influenced by stress, whereas White males may be more affected by nicotine levels alone. Importantly, I am unaware of any cigarette craving research

investigating race-by-sex interactions using a cue exposure paradigm. Moreover, to my knowledge, beyond race and sex, previous cue exposure work has not investigated the relations between SES (e.g., household income and educational attainment), and craving. Following an intersectional perspective, the current research is the first cue exposure study to consider race by sex interactions and additional sociodemographic covariates. The design considers both PPC and CR outcomes, and it boasts a sample size much larger than any of the studies reviewed (and thus is sufficiently powered to detect both main and interaction effects). Accordingly, the overarching aim of the study is to comprehensively investigate the impact of both race (Black and White smokers), sex (male and female smokers), and SES variables, on cigarette craving.

1.3 Primary Aims

The study examined whether Black and White, male, and female smokers experience different levels of craving in an in vivo smoking cue exposure paradigm using two types of statistical analyses.

1. A traditional means-based approach, evaluating three craving outcomes:
 1. Pre-cigarette-cue (baseline) craving scores. To address the possibility that different race and sex groups report different craving levels shortly after arrival in the laboratory, I tested for main and interaction effects of race and sex on baseline (i.e., pre-cue) urge ratings.
 2. Peak provoked craving scores. I evaluated the main effects and interactions of race and sex on urge ratings recorded during smoking cue exposure.

3. Cue reactivity. I evaluated the main effects and interactions of race and sex on urge ratings recorded during smoking cue exposure after subtracting out baseline (pre-cigarette-cue) urge ratings.

Because socioeconomic status has been correlated with health inequity and race in the public health literature (Drope et al., 2018), all three of these models accounted for level of education and household income. In addition, I conducted an analysis to see if severity of dependence diminishes any discovered association between craving and either sex or race (Donny et al., 2008). Thus, the same models in Aim 1 were replicated, adding dependence as a covariate.

2. The second analytical approach was a person-centered analysis, using persons as effect sizes (Grice et al., 2020). As noted above, sometimes significant mean differences can appear, even when many participants fail to show the expected effects. This person-centered analysis further elucidated the impact of race and sex on cigarette craving.

All analyses were pre-registered to the Open Science Foundation (OSF): <https://osf.io/tybr9/>. As there is mixed research on associations with race and sex and craving in cue exposure paradigms, I did not propose a priori hypotheses for the analyses. All significant and non-significant findings are reported below.

2.0 Methods

Participants were drawn from a large dataset, merging seven previously published studies (see Table 1 for details, adapted from Sayette et al., 2022), all of which employed a traditional *in vivo* cue exposure paradigm. These datasets were considered in a recent study that did not focus on either race or sex differences (Sayette et al., 2022).

2.1 Participants

All participants included in the study were smokers between the ages of 18-69. Participants resided in the Northeastern United States at the time of data collection and were recruited through newspaper advertisements or flyers in the broader Pittsburgh, PA area. Participants were excluded if they reported a medical condition that contraindicated nicotine use or if they were illiterate. All participants reported smoking at least 10 cigarettes per day for at least 12 continuous months. A total of five subjects were excluded from the project as they were missing either a baseline or PPC urge rating. Additionally, a small portion of the subjects ($n = 55$) were excluded from the current project, as they self-identified in racial groups other than White or Black, and there was inadequate power to detect an effect within these racial groupings. The final sample for the analyses included 617 smokers.

2.2 Procedure

The procedures reported below were consistent across the seven laboratory studies in the current project. All studies included were approved by the relevant university Institutional Review Board. Participants were screened and invited to join each study based on study eligibility criteria. All data in the project were collected at either the Alcohol and Smoking Research Laboratory (ASRL) at the University of Pittsburgh (five studies) or the Behavioral Health Research Lab at Carnegie Mellon University (two studies). The Carnegie Mellon University principal investigator, Dr. Kasey Creswell, received doctoral training at the ASRL, ensuring consistent manipulation and assessment technique across the two sites. For more information regarding the studies included in the proposed project, see Table 1, which is adapted from Sayette et al. (2022). Participants were required to abstain from smoking for at least 5 hours (study range 5-12 hours; craving ratings were similar throughout this entire range, see Sayette et al., 2022). All participants completed informed consent.

During cue exposure, research staff placed a tray with a plastic cover on a desk in front of the participant. The research staff left the room and asked the participant over an intercom system to remove the cover, which revealed the participants' pack of cigarettes with a lighter and an ashtray. Participants were asked to remove a cigarette, and light it without placing it in their mouths. They were then instructed to put down the lighter and to hold the cigarette as they normally would. Participants rated their urge to smoke immediately before lifting the cover from the tray (pre-cigarette cue "baseline" craving score) and 31 seconds after lighting their cigarette (PPC rating). Participants reported their urge to smoke on a rating scale from 0 (absolutely no urge to smoke at all) to 100 (strongest urge to smoke I've ever experienced). Single-item scales may be advantageous in situations calling for repeated and rapid reporting of craving throughout an

experimental paradigm in which measurement reactivity can be problematic (e.g., experimental cue exposure studies, see Sayette et al., 2000). Further, single item urge ratings are at least as sensitive to cue exposure craving as are multi-item scales (see Betts et al., 2021; Heckman et al., 2013; Sayette, 2016; Tiffany & Wray, 2012).

2.3 Instruments

2.3.1 Independent Variables

2.3.1.1 Primary Predictors of Interest

2.3.1.1.1 Race

As part of the standard demographics form (measuring age, relationship status, sex, level of education, and household income) participants were asked to self-identify their race. Participants indicated whether they were American Indian or Alaska Native, Asian, Native Hawaiian/Pacific Islander, Black/African American, Caucasian/White, or more than one race. Only participants who indicated they were Black/African American and Caucasian/White were included in the proposed research. Race served as a dichotomous, contrast-coded variable.

2.3.1.1.2 Sex

Sex was assessed on the same standard demographics form, whereby participants self-identified as male or female. The sex variable was a dichotomous, contrast-coded variable.

2.3.1.2 Covariates

2.3.1.2.1 Educational Attainment

Level of educational attainment was self-reported highest school grade completed (including years of graduate school). the median highest grade completed was 13, as reported in Sayette et al., 2022.

2.3.1.2.2 Income

Income was assessed in the demographics form, and participants self-reported their annual household income, ranging from 1 \leq \$5,000 to 12 \geq \$80,000. The median household income ranged from \$10,000 to \$14,999 as reported in Sayette et al., 2022.

2.3.1.2.3 Severity of Dependence

The Fagerstrom Test for Nicotine Dependence (FTND) assessed severity of nicotine dependence. Composite scores were created from summing individual items. Here, 0 = *lowest level of nicotine dependence* to 10 = *highest level of nicotine dependence*.

2.3.2 Dependent Variables

To address both Aims 1 and 2, three outcome variables were used to consider craving differences among the race and sex variables. In addition to these three outcome variables, Aim 2 had two distinct outcome variables.

2.3.2.1 Aim 1 and 2

2.3.2.1.1 Baseline Craving

As noted above, baseline urge ratings refer to participants' urge ratings reported just prior to cigarette cue exposure.

2.3.2.1.2 Peak Provoked Craving

PPC scores were the participants' urge scores reported verbally during smoking cue exposure, 31 seconds after cigarette lighting.

2.3.2.1.3 Cue Reactivity

CR was the calculated difference between a participant's PPC score and baseline craving score. Scores ranged from -94 (PPC score of 5 minus baseline craving score of 99, thus equaling -94) to +100 (PPC score = 100 minus baseline craving score = 0, equals = 100).

2.3.2.2 Aim 2

To address Aim 2, I used a series of person-centered analyses to evaluate the same three outcome variables (baseline urge, PPC, and CR) used in Aim 1, and two unique outcome variables.

2.3.2.2.1 Maximal Urge

'Maximal urge' was defined as a craving score of 90 or above for either baseline or PPC. Maximal craving was operationalized as a binary variable (0 = craving score < 90 / 1 = craving score \geq 90). Because the mean CR was 11.282 (SD = 20.90), any baseline urge rating of equal 90 or above would necessarily produce a CR below the mean, suggesting evidence of potential ceiling effects. Therefore, this elevated urge score, that is, 90 or above, is referred to as a maximal craving.

Similarly, as done previously in the literature (see Sayette et al., 2022, Figure 3), a PPC score of ≥ 90 was classified as a maximal craving.

2.3.2.2.2 Level of Response

I considered levels of reactivity to cue exposure (score increase from baseline to PPC). This outcome was classified at three levels: “negative responders” (decrease urge from baseline to PPC); “zero-responders” (no change in score between baseline to PPC); and “positive responders” (any interval increases of a certain number of points, for instance, 0-5 point increase from baseline to PPC).

2.4 Data Analysis

All data analyses were conducted using R Core Team and R Studio. The primary frameworks for modeling these data were ANOVA and person-centered descriptive analyses. An HLM was additionally composed to provide further support for any findings within the ANOVA models. Through this mixed-analytic approach, I aimed to illuminate the type of analyses (e.g., means-based, or descriptive) and the type of outcome variables that may be best to consider when investigating the craving experiences of varied sociodemographic groups.

2.4.1 Means-Based Approach to Assess Craving

To address the first aim, I employed ANOVA to assess the three distinct craving outcomes of interest. The three craving outcome variables considered in these three ANOVA models were CR, PPC, and baseline, each including the two primary predictors of interest: race and sex, and the

covariates (dependence, educational attainment, and income). The primary foci in these three models were the main effects of race and sex and their potential interaction effects.

After completing the three ANOVA models, the results for PPC and baseline craving outcomes were verified in a singular HLM model. In this model, I compared baseline urge and PPC responses within the same model, as HLM accounts for interdependence of within-subjects' data. This model, predicting baseline and PPC craving, included a total of five fixed effects, including the two primary predictors of interest: race and sex, and three covariates: dependence, educational attainment, and annual household income; and two random effects: a random intercept of subject and a random slope of time.

2.4.2 Person-Centered, Data-Driven Approach to Assess Craving

To address the second aim, I used a person-centered analysis examining the distribution of the outcome variables articulated above. These descriptive analyses looked across racial groups, sex groups, and mixed race and sex groups (i.e., Black male smokers; Black female smokers; White male smokers; and White female smokers). These person-centered analyses enhanced interpretation of the traditional means-based analyses discussed in Aim 1 (see Grice et al., 2020 for elaboration of these two different approaches).

3.0 Results

The current study aimed to examine the relationships among sex, race, and cigarette craving. Reported effect sizes follow the eta-squared guidelines defined by Gignac and Szodorai (2016): very small = .0025; small = .0100; medium = .0400; large = .0900; and very large = .1600. For descriptive statistics regarding the sociodemographic groups, see Table 2.

To detect multicollinearity, chi-square tests were conducted to measure the associations among sociodemographic variables. All tests (income and education; race and income; race and education; race and sex; sex and income; sex and education) yielded $\chi < .30$, indicating the absence of excessive multicollinearity among the sociodemographic variables.

3.1 Aim 1: Means-Based Analysis

In Aim 1, I employed an ANOVA to investigate the effects of race and sex on cigarette craving in the laboratory using three primary outcome measures: CR, PPC, and baseline.

3.1.1 Cue Reactivity

First, I probed the relationship between race, sex, and covariates on CR. As noted earlier, this is the standard (and by far the most popular) approach to assessing experimentally induced craving. I found no main effects of race or sex on CR; however, a significant race-by-sex interaction emerged on CR ($F(1, 592) = 4.37, p = .037, \eta^2 = .01, 95\% \text{ CI } [0.01, 1.00]$), a finding

that remained significant while accounting for covariates of educational attainment, annual family income, and severity of dependence (see Figure 1 for interaction effect). To assess whether the race-by-sex interaction on CR was affected by the covariates, a model was fitted without education, income, and severity of dependence. The analysis indicated that the race-by-sex interaction effect remained significant on CR ($F(1, 592) = 4.32, p = .038$), indicating that this interaction was not influenced by these other variables. None of the investigated covariates had a significant association with CR; for descriptive statistics, see Table 3.

Inspection of mean CR levels revealed that White male smokers had a mean CR score of 9.88 ($SD = 17.31$) while Black male smokers reported a mean score of 11.98 ($SD = 20.37$), differences that failed to reach standard levels of significance. More pronounced were differences among female smokers: White females smokers experienced the highest CR scores ($M = 14.25, SD = 22.08$), while Black female smokers demonstrated the lowest CR scores ($M = 9.24, SD = 24.60$), a contrast that reached statistical significance ($F(1, 592) = 4.49, p = .034$), while accounting for covariates. That is, the most dramatic CR differences were observed amongst White and Black female smokers.

As noted earlier, CR is the standard (and by far the most popular) measure to assess experimentally induced craving. If one were to focus exclusively on the CR measure (as many published studies have done), the conclusion would be that White female smokers experienced greater cigarette craving than did Black female smokers. But as noted, such a conclusion would be premature and likely misleading. Specifically, analysis of PPC and baseline craving scores offers critical context for interpreting these CR interaction results.

3.1.2 Peak-Provoked Craving

To further probe the race-by-sex CR interaction, PPC scores were examined. In contrast to the CR analysis, a two-way ANOVA model revealed neither main effects of race or gender on PPC ($F(1, 592) = 3.08, p = .080$; $F = 0.11, p = .739$, respectively) nor a race-by-sex interaction on PPC ($F(1, 592) = 0.70, p = .402$), while accounting for covariates of income, educational attainment, and nicotine dependence. For descriptive statistics regarding the relationship between the covariates and PPC, see Table 3. These null findings make clear that the enhanced CR for White female smokers relative to Black female smokers in no way translate to differences in actual peak craving scores during the experimental manipulation. That is, despite CR differences, White and Black female smokers appear to reach similarly high peak craving ratings in the lab. To better understand why CR differences do not correspond to PPC differences, one needs next to examine the baseline urge ratings collected in the study.

3.1.3 Baseline Craving

The two-way ANOVA model assessing the relationship of sex and race on baseline cigarette craving revealed a significant main effect of race ($F(1, 592) = 6.47, p = .011, \eta^2 = .01$, 95% CI [0.01, 1.00]) while controlling for covariates. To investigate whether covariates were driving the effect of race on craving, I removed the covariates from the model: the findings remained, whereby Black smokers reported significantly higher overall baseline craving ($M =$

69.54, $SD = 24.97$) than did White smokers ($M = 65.30$, $SD = 22.59$, $F(1, 615) = 4.85$, $p = .028$).¹ There was no significant relationship between sex and craving, nor any significant interaction between race and sex on baseline craving. For additional descriptive statistics regarding the relationship to baseline craving and the covariates, refer to Table 3. Model comparisons were run to determine the amount of variance on craving accounted for by the two studied SES variables, for additional information regarding these models, reference Appendix A.

Inspection of the means revealed that Black female smokers reported the highest mean baseline craving scores ($M = 70.27$, $SD = 25.41$) followed by Black male smokers ($M = 68.81$, $SD = 24.59$), White male smokers ($M = 66.96$, $SD = 21.58$) and White female smokers ($M = 63.12$, $SD = 23.74$). While the interaction amongst race and sex on baseline craving was not statistically significant in the two-way ANOVA, the significant main effect of race on baseline craving strongly suggests the increased possibility of ceiling effects during the cue exposure paradigm for Black smokers. That is, because the overall baseline scores were already so high amongst Black smokers (approximately 70% of maximum of the rating scale), these smokers had less room on the rating scales to report an increase during the PPC assessment. The examination of both baseline cue and PPC ratings suggests that the CR ratings were significantly influenced by inflated baseline ratings. Consequently, Black smokers' CR scores, especially Black female smokers', may have been vulnerable to ceiling effects. This possibility could be explored further by considering a person-centered approach to the analysis.

¹ The significant relationship between race and craving was echoed in the mixed-effect model: race had a significant relationship to craving response (a compiled PPC and baseline rating measure, as described above), $t = 2.455$, $p = .014$. See Table 4 for further statistics regarding this mixed-effect model.

3.2 Aim 2: Person-Centered Analysis

The means-based results illustrate craving differences before and during cue exposure among the race-by-sex groups. To further probe these differences, the subsequent person-centered approach investigated the distributions of craving experience in the current sample.

3.2.1 Person-Centered Cue Reactivity

To investigate the potential for ceiling effects among Black smokers, a model was built considering CR response subtypes (zero responders, negative responders, positive responders) within race-by-sex groups. There were significant differences among the four groups ($\chi^2(6) = 25.42, p < .001$). White male and White female smokers exhibited the highest percentages of responders (73.40% and 77.42%, respectively), followed by Black male smokers (69.77%), and Black female smokers (52.31%). Black female smokers and White female smokers differed significantly ($\chi^2(2) = 21.10, p < .001$) in frequency of response subtype, while no difference was observed between Black male smokers and White male smokers. These findings comparing racial groups, stratified by sex, suggest that the race-by-sex interaction on CR observed in Aim 1 is primarily driven by differences in CR patterns among White and Black female smokers.

Analyzing race-by-response subtype (without considering sex) also revealed a significant difference ($\chi^2(2) = 14.76, p < .001$), with White smokers showing a higher percentage of responders (75.14%) than Black smokers (61.00%). Indeed, Black smokers were more likely to have a CR score of ≤ 0 than White smokers ($\chi^2(1) = 14.09, p < .001$, see Figure 2 for distribution of CR scores by race). These findings suggest that Black smokers are more likely to be zero responders and negative responders, though further person-centered investigation of PPC and

baseline craving scores are warranted to ascertain whether this is attributable to ceiling effects. (See Table 5 for additional statistics on response subtype within race-by-sex groups.)

Interestingly, general distributions of CR scores indicate that White male smokers demonstrated lower CR scores compared to White female smokers (Figure 3). A one-way ANOVA examining only the White participants revealed a main effect of sex on CR while accounting for covariates of educational attainment, income, and dependence, with White female smokers having significantly higher CR scores than White male smokers ($F(1, 342) = 5.11, p = .024$).

3.2.2 Person-Centered Peak-Provoked Craving

Distributions of PPC response amongst race-by-sex groups were explored. Across all four race-by-sex groups the most common outcome involved participants generating a PPC score ≥ 90 . While inspecting the data displayed in Figure 4, Black male and Black female smokers appeared to have the largest percentage of individuals reaching a PPC ≥ 90 when compared to the other two sociodemographic groups, which warranted further statistical evaluation for significance through maximal craving response.

3.2.2.1 Peak-Provoked Maximal Craving

Two chi-squared tests assessed whether maximal PPC scores explain a portion of the significant race-by-sex interaction in CR. The results indicated that Black smokers were significantly more likely to experience maximal craving during PPC compared to White smokers ($\chi^2(1) = 11.36, p = .001$, with 56.76% of Black smokers at maximal craving, compared to 43.02% of White smokers). To further disentangle this means-based CR interaction, I examined the significance of the relationship between maximal craving at a race-by-sex level. Consistent with

the previous findings, the chi-squared test yielded a significant result ($\chi^2(3) = 13.80, p = .003$), indicating that PPC maximal craving differs amongst the four sociodemographic groups (Black female smokers, Black male smokers, White female smokers, and White male smokers). Interestingly, upon further evaluation, White male smokers were the least likely to reach maximal craving (only 39.41% demonstrating maximal craving at PPC), followed by White female smokers (47.74% at maximal craving). For both Black female and Black male smokers over half met criteria for maximal craving for PPC (56.92% and 56.59% respectively). Because White female smokers had the highest mean CR scores, it is unsurprising that nearly 10% more reached maximal PPC craving scores compared to White male smokers. Notably, these racial differences did not appear for PPC in the means-based analysis above, indicating that further understanding can be gained from person-centered analyses.

3.2.3 Person-Centered Baseline Craving

Overall, Black persons reported higher baseline craving levels compared to White persons, with > 25% of Black participants having a maximal craving state during baseline (Figure 5). Moreover, ~15% of Black smokers had completely maxed out the scale (*baseline craving* = 100), significantly different compared to just 5% of White smokers ($\chi^2(1) = 16.936, p < .001$)

3.2.3.1 Baseline Maximal Craving

A Pearson's Chi-squared test further probed the relationship between race and maximal baseline craving. There was a significant relationship ($\chi^2(1) = 10.63, p = .001$), suggesting that the likelihood of maximal cravings differed across racial groups (Black smokers = 26.64% at maximal craving during baseline, White smokers = 15.92% at maximal craving during baseline). The odds

ratio of reaching a baseline score ≥ 90 for Black smokers compared to White smokers was 1.92 (95% CI [1.27, 2.91]), indicating a higher likelihood of baseline maximal craving among Black smokers during baseline.

To further explore whether baseline craving scores contributed to the means-based race-by-sex interaction found in CR, I tested for differences in maximal craving amongst race by sex groups (Black female smokers, Black male smokers, White female smokers, and White male smokers). The chi-square test showed that these groups differed significantly in terms of likelihood of maximal baseline craving ($\chi^2(3) = 11.00, p = .012$). When further probing this relationship, it was noted that both Black female and Black male smokers had nearly comparable proportions of individuals experiencing maximal craving during baseline (27.69% and 25.58% at maximal craving during baseline, respectively). While having significantly lower percentages of maximal craving compared to Black participants, White female and White male smokers exhibited similar proportions of maximal baseline craving (14.84% and 16.75%). These comparisons indicate that Black smokers in the current sample were significantly more likely to be in a state of maximal craving before the cue exposure paradigm compared to White smokers.

The cumulative results suggest that White female smokers are more highly reactive to nicotine cues during cue exposure than are White male smokers. Furthermore, the reported findings suggest that Black female and male smokers, overall, all of whom were nicotine deprived, are more likely to rate their baseline urge at a higher level and are also more likely to experience maximal craving during the cue exposure paradigm compared to White smokers.

4.0 Discussion

4.1 Summary of Aims

The present study sought to evaluate potential differences in *in vivo* cigarette craving across racial and sex identity groups. A large body of experimental literature reveals mixed findings for sex during *in vivo* cigarette craving. Moreover, the field has not adequately tested race's relationship with *in vivo* cigarette craving, and no prior work has evaluated race by sex interactions with cue exposure. By employing two complementary but distinct statistical approaches, this study sought to elucidate the craving experiences of individuals with intersecting identity factors and to better understand prior discrepancies regarding the relationship between sex and *in vivo* cigarette craving. In sum, the primary focus of the current study was to assess race-by-sex interactions with craving, while accounting for other important identity factors such as level of educational attainment and income.

4.2 Summary of Results

The present study sought to evaluate potential differences in *in vivo* cigarette craving across racial and sex identity groups. A large body of experimental literature reveals mixed findings for sex during *in vivo* cigarette craving. Moreover, the field has not adequately tested race's relationship with *in vivo* cigarette craving, and no prior work has evaluated race by sex interactions with cue exposure. By employing two complementary but distinct statistical approaches, this study

sought to elucidate the craving experiences of individuals with intersecting identity factors and to better understand prior discrepancies regarding the relationship between sex and *in vivo* cigarette craving. In sum, the primary focus of the current study was to assess race-by-sex interactions with craving, while accounting for other important identity factors such as level of educational attainment and income.

4.2.1 Means-Based Results

The means-based results suggest that White female smokers were highly sensitive to smoking cues during *in vivo* cue exposure when compared to the three other groups (White male, Black male, and Black female smokers), evidenced by the significant interaction of race-by-sex on CR. Without further analysis, the race-by-sex interaction on CR could suggest that White female smokers have the highest craving levels during cue exposure, however, this possibility was called into question when race-by-sex interactions following a similar pattern did not emerge across other studied urge outcomes (baseline and PPC).

The main effect of race on baseline urge results suggested that both Black female and male smokers endorsed overall higher craving levels before *in vivo* cue exposure compared to White smokers. Interestingly, a main effect of race was not found in the PPC outcome, a result that suggested that perhaps for Black smokers, there was a ceiling effect with the urge scale used, a possibility that warranted further investigation through a person-centered approach.

Before turning to the person-centered findings, results indicated that some of the studied covariates had significant effects on the PPC and baseline craving outcomes (Table 3), which is line with prior findings regarding dependence and SES on craving or smoking behavior (Donny et al., 2008; Dawson & Fletcher, 2021). Indeed, in the literature, differences in SES account for some

of the discrepancy in smoking disease rates among Black and White smokers, but health disparities among different racial groups persist after accounting for SES (Calixte-Civil & Brandon, 2021). Similarly, here it was found that while SES accounted for some of the variation in craving responses among Black and White smokers, the racial differences found in PPC and baseline craving response remained significant among those in the same income bracket (Appendix A). These data indicate that while SES variables have an important relationship with cigarette craving, they alone did not explain the observed racial differences on cigarette craving.

In sum, the race-by-sex interaction on CR, alongside the main effect of race on baseline craving, indicates that White females may not necessarily exhibit higher cravings in response to cues when compared specifically to Black male and female smokers. Instead, it suggests that White female smokers are more responsive to smoking cues than White male smokers, while Black smokers might encounter a ceiling effect on the urge scale before the cue exposure experiment starts, thereby affecting their potential to attain high CR scores.

4.2.2 Person-Centered Results

The person-centered approach provided additional insight into group-based differences: results revealed that Black female and Black male smokers are more likely to experience maximal craving at the outset and during the experiment, evidenced by the significant baseline and PPC results. These person-centered results suggest that Black smokers are more likely to reach maximal craving than White smokers across both PPC and baseline measures. The cumulative results in this study are supported by EMA research, whereby Black smokers report higher craving during random assessment times than White smokers (Carter et al., 2010).

4.3 Implications

4.3.1 Race-by-Sex Research

While some prior studies suggest sex differences in in vivo cigarette craving, the current data reveal a more nuanced depiction of craving. To my knowledge, only one (Colamussi et al., 2007) of 17 identified cue exposure studies considered race as a primary predictor of craving. In that study, participants were asked to smoke a cigarette immediately before the study session, which precluded the ability to compare the current results using nicotine deprived participants to their sample. Importantly, while Black smokers in their sample reported higher mean pre-cue exposure urge ratings (e.g., baseline in the current study), no statistical tests compared Black and White smokers on baseline craving scores, nor did they consider race-by-sex CR interactions. The means-based results in the current project underscore the value of including measures of race and sex when testing how different smokers crave in response to in vivo cigarette cues.

4.3.2 Sociodemographic Variable Considerations

Including a wide array of sociodemographic variables beyond race and sex (i.e., SES measures) can add to the understanding of lab-based craving. Some of the models in the current study suggest a relationship among educational attainment, income, and cigarette craving (see Limitations and Future Directions for further commentary about these relationships). These findings highlight the importance of considering multiple sociodemographic factors when evaluating the craving experience of individuals with different identity factors.

4.3.3 Data-Driven Approaches to Hypothetical Constructs

The study's findings call attention to the importance of adopting data-driven analytic approaches to understand complex hypothetical constructs, such as *in vivo* cigarette craving. In line with the literature (Sayette et al., 2022), many of the person-centered findings aligned with the means-based results. However, the current study stands as the first cue exposure study to reveal person-centered results that diverge from the means-based findings. Specifically, the PPC person-centered findings showed significant differences amongst the studied groups in terms of maximal craving, whereas there was no significant relationship amongst race and PPC craving found in the means-based results. While the lack of a main effect of race on PPC in the means-based analysis likely stems from a ceiling effect, this divergence in findings among the two analytic types for PPC emphasizes the need to employ both a complementary person-centered approach and a traditional means-based analyses to understand *in vivo* craving.

4.3.4 Cue Exposure Outcome Measures

While the current findings indicated heightened CR among White female smokers compared to the other studied groups, subsequent analyses painted a more complex picture. Despite these CR findings, across all other outcome measures (baseline, PPC, and maximal craving), Black smokers showed consistently higher levels of craving compared to White smokers. Thus, taken alone, the CR findings offer a potentially misleading account of the *in vivo* craving experience. Strikingly, the results suggest that CR, without doubt the field's preferred outcome measure, fails to capture the craving experience of Black and White smokers equally. Although

concerns with CR were observed years ago (Sayette et al., 2000), recent studies continue to feature CR as the only craving outcome, including some of the most cited work in the field (see Sayette, 2016). The current findings provide especially strong evidence that future studies should broaden the set of urge measures reported to also include baseline and PPC.

4.3.5 Craving as a Contribution to the Public Health Paradox

Recent literature emphasizes craving as a predictor of future cigarette use and relapse (Vafaie & Kober, 2022). As observed in the current project, identity factors correlate with craving severity, and as craving is linked to use and relapse, disparate craving levels among groups could contribute to the public health paradox (where individuals with marginalized identity factors encounter greater challenges with smoking and quitting despite overall lower usage). It is crucial to recognize that the differences in smoking outcomes (and potentially experiences in craving) among individuals with marginalized identity factors are largely influenced by social determinants and needs, and that factors such as ethnicity, gender, or sexual minority identity, and experiences with stress and discrimination also intersect with race and sex to impact smoking behavior and outcomes (Brady, 2020). Future work is needed to directly link group-level differences in craving to health outcomes, but at the very least, the current data highlight that craving may be an important construct to consider when considering these smoking-related challenges within specific demographic groups. Furthermore, for Black smokers, heightened craving may serve as a powerful intervention target to prevent relapse. In sum, while it is premature to assert that craving is a clear determinant of the public health disparity in smoking outcomes among marginalized groups, its

role as a potential mediator between marginalized identities and smoking health outcomes deserves further investigation.

4.4 Strengths

There are notable strengths of the current project. First, to my knowledge, this study boasts the largest sample sizes for studies using in vivo cigarette cue exposure (see Sayette et al., 2022), which provides robust power to detect interactions among sociodemographic groups and craving. Relatedly, this study recruited the largest subsamples of Black and White, male and female smokers to date, which allowed for interaction testing using two different statistical methods, means-based and person-centered. These two methods offered a complementary approach to urge assessment, providing a nuanced look at craving dynamics in the lab. Lastly, the incorporation of covariates, including SES and dependence, advances understanding of the impact of a variety of individual difference factors on craving. By using this multidimensional analytic approach, the study offers links to a broad range of prior studies and suggests directions for future studies examining craving across a variety of sociodemographic groups.

4.5 Limitations and Future Directions

4.5.1 Socioeconomic Status

While craving differences between Black and White smokers are evident, attributing them solely to racial identity would oversimplify the complex landscape of sociodemographic group differences. One factor that can drive group-level differences is SES (Calixte & Brandon, 2021). SES assessment is complex, due to its multifaceted nature: the construct encompasses factors that extend beyond education and income, including current social class, financial security, occupation, living conditions, and access to resources and opportunities for advancement. Unfortunately, the compiled datasets did not assess these contributors to SES. Future cue exposure research should include measures of these additional SES factors.

Further, the two SES factors included here had some limitations. First, the distribution of income was constrained in the sample. Specifically, the study did not capture the full range of income levels necessary to fully understand how cigarette craving associates with income. The current dataset exhibited a lower overall distribution of income compared to typical smokers in the United States (Jamal et al., 2015), with over 60% of our sample having a family income under \$20,000 USD. To elucidate income's association with craving, future research should oversample to ensure that individuals vary across income groups. The current project revealed a significant inverse relationship between educational attainment level on both PPC and baseline craving outcomes (Appendix A; Table 3). While these findings suggest that educational attainment level is important to consider when investigating individuals' experiences with in vivo cigarette craving, the absence of existing literature on this topic precludes further interpretation. Additional research is needed to comprehend educational attainments' relationship with craving.

4.5.2 Limitations in Other Sociodemographic Measurements

The study encountered certain limitations concerning the assessment of sex and race variables, and the omission of sexual orientation measurement. Firstly, it is key to distinguish between gender identity and biological sex. Gender identity pertains to one's internal comprehension of their gender and how they express it to others, whereas sex is a biological label assigned at birth (National Academies of Sciences, Engineering, and Medicine, 2022). In the current compiled database, some projects were conducted during times when such distinctions were uncommon, and thus, this distinction between sex and gender identity was at times ignored. Inclusive measurements of self-reported sex and gender identity have improved over the past 20 years, and many of the compiled studies did not collect any information regarding gender identity. Moreover, there was a lack of clarity whether participants interpreted the sex item based on their own gender identity or biological assignment at time of birth. Future research should evaluate both biological sex and gender identity. Secondly, the subject count was reduced in the current project based on self-identified racial identity. The project was underpowered to detect group racial differences among those who identified as racial groups other than Black or White, leading to the reduction in the subject count. Future research would benefit from oversampling racial and ethnic identities not studied here. Thirdly, the project did not assess self-reported sexual orientation. Minority sexual orientation status has been associated with worse smoking-related health outcomes (Gordon et al., 2021), and future work should test whether minority sexual orientation has any association with craving.

Individuals with multiple marginalized identity factors are more likely to experience discrimination over the course of their lifetime. Recent studies have emphasized the impact of racial discrimination on cessation self-efficacy among Black smokers (Calixte-Civil & Brandon,

2021), and its direct correlation with craving (Dawson & Fletcher, 2021). However, the current project lacked the necessary measures to assess whether lifetime experiences of discrimination were related to the independent variables and craving. Addressing this gap is crucial, as experiences of discrimination could serve not only as a covariate but also as a potential mediator among sociodemographic variables and in vivo cue exposure craving response.

One implication of the current findings is that Black and White smokers are differentially sensitive to ceiling effects while using an urge rating common in the literature. As noted elsewhere (Sayette & Tiffany, 2013) there is a need for additional measures of urge less subject to ceiling effects, such as magnitude estimation and computerized adaptive testing. More recently, studies have successfully employed a pressure dynamometer to capture urge (Creswell et al., 2019) and such measures, while not without their own limitations, would be useful to consider as complements to traditional urge ratings in light of the observed racial differences in maximal urge ratings.

4.5.3 Public Health Paradox: Next Steps

A clear next step to better understand the public health challenges that individuals from marginalized communities are facing in the United States is to investigate how craving may serve as a mediator between sociodemographic variables and patterns of use and relapse. Understanding the relationship between these variables may shed light on the pathways through which certain individuals continue to struggle to quit smoking. Moreover, by identifying craving as a possible mediator, interventions (e.g., just in time interventions during craving) and policies (e.g., decreasing “cues”, or advertising, in certain neighborhoods with high proportions of Black

residents) could be tailored to effectively address the disparities in tobacco use and cessation for certain groups.

4.6 Summary Statement

The present study aimed to investigate the relationships between race, sex, and in vivo cigarette craving. Findings revealed that Black female and male smokers exhibit elevated pre-in vivo cigarette cue “baseline” urge ratings and are more likely to experience maximal craving during cue exposure than White female and male smokers. Interestingly, White female smokers demonstrated heightened CR compared to White male smokers, while this pattern was not observed among Black female and male smokers, highlighting the importance of examining demographic factors such as race and sex interactively. Furthermore, while SES variables were linked to certain craving responses, they alone did not fully explain the observed racial differences. Methodologically, the findings provide the most compelling evidence yet to support a comprehensive approach to the assessment and analysis of experimentally-induced cigarette craving, with clear evidence for differential sensitivity to ceiling effects for Black and White smokers. Clinically, the results underscore the importance of considering intersecting identity factors in understanding cigarette craving and point to the need for future research to continue to study racial and sex disparities in smoking behavior and health consequences.

5.0 Figures and Tables

5.1 Figures

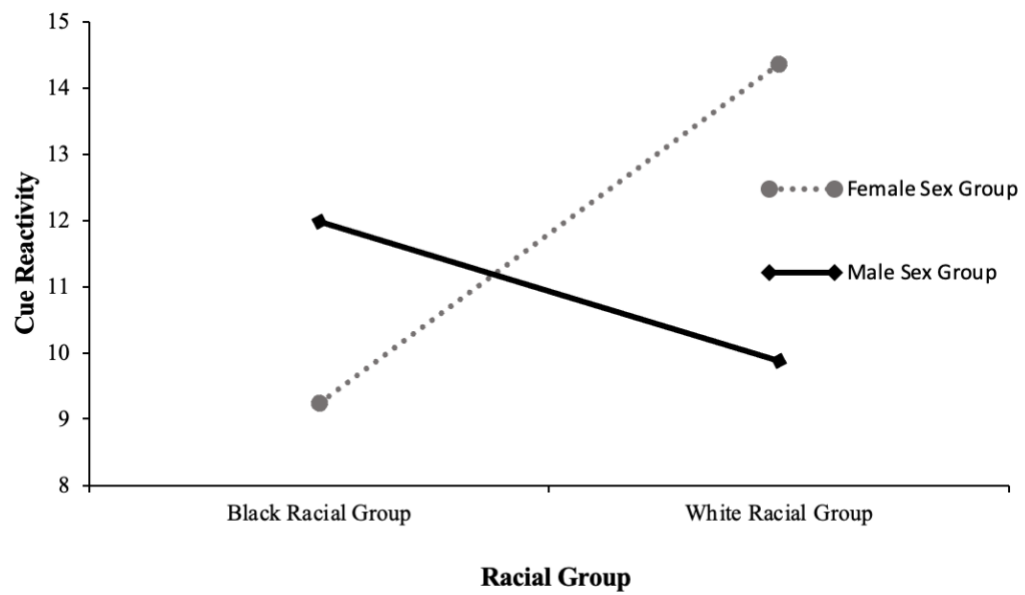


Figure 1 Mean Interaction Effect of Race by Sex on Cue Reactivity

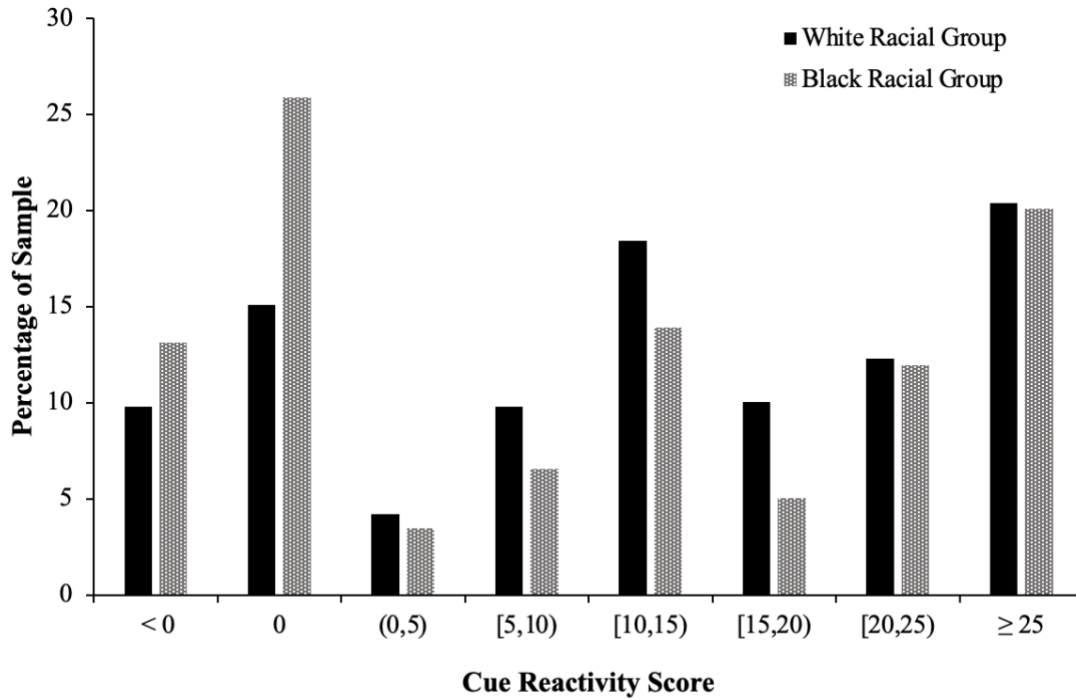


Figure 2 Percentage Distribution of Cue Reactivity Scores by Racial Groups

Note. The x-axis notation distinguishes between inclusion and exclusion within intervals. Values accompanied by brackets denote inclusion in the interval, while values accompanied by parentheses denote exclusion. For instance, "[5, 10)" indicates that 5 is included but 10 is not, whereas "(0, 5)" denotes that neither value is included.

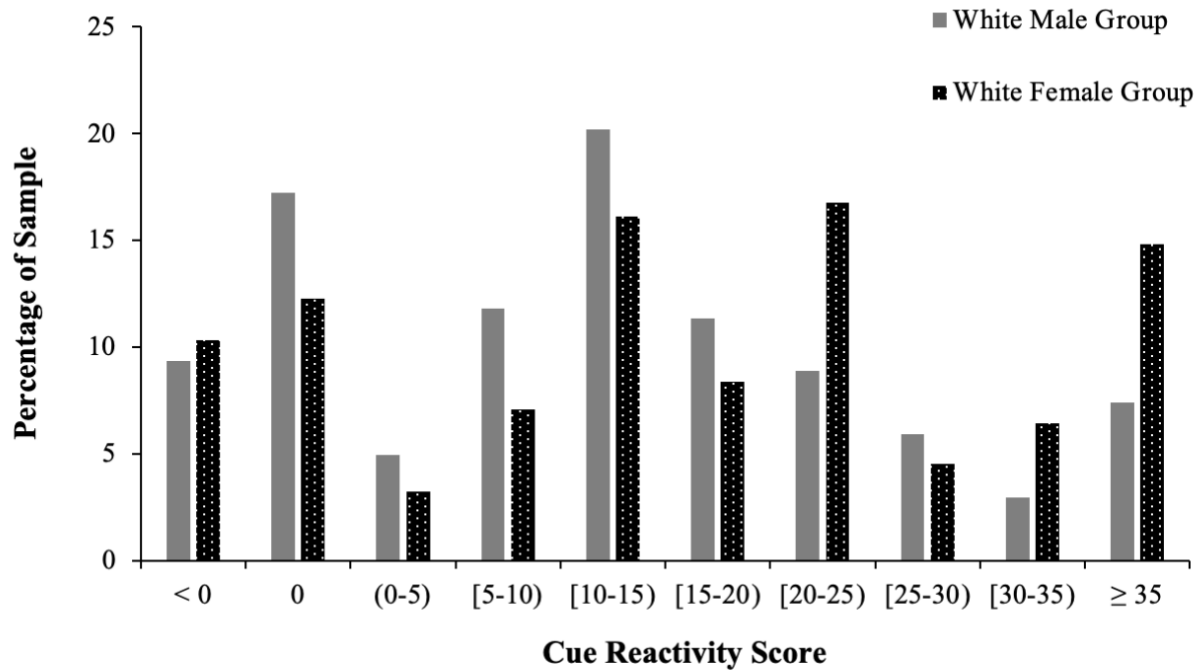


Figure 3 Percentage Distribution of Cue Reactivity by Sex Groups for White Participants

Note. The x-axis notation distinguishes between inclusion and exclusion within intervals. Values accompanied by brackets denote inclusion in the interval, while values accompanied by parentheses denote exclusion. For instance, "[5, 10)" indicates that 5 is included but 10 is not, whereas "(0, 5)" denotes that neither value is included.

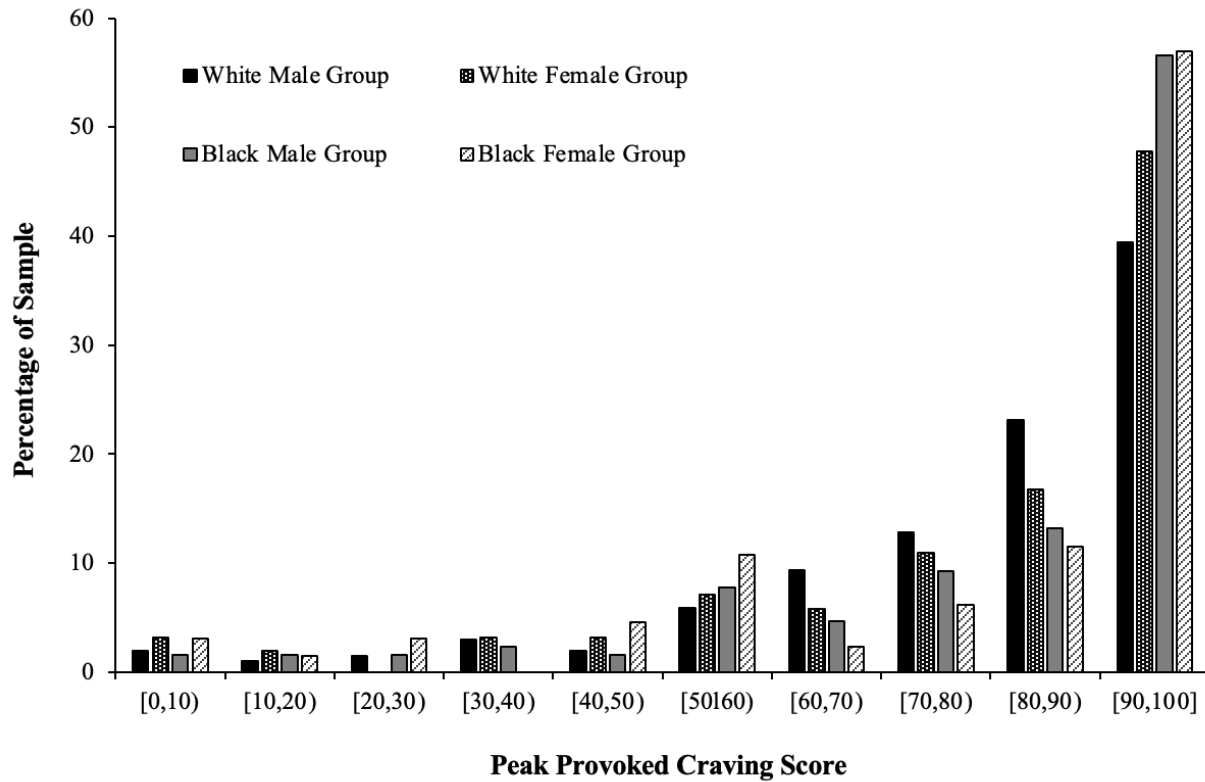


Figure 4 Percentage Distribution of Peak Provoked Craving by Race-by-Sex Group

Note. The x-axis notation distinguishes between inclusion and exclusion within intervals. Values accompanied by brackets denote inclusion in the interval, while values accompanied by parentheses denote exclusion. For instance, "[0, 10)" indicates that 0 is included but 10 is not, whereas "[90-100]" denotes that values of both 90 and 100 are included.

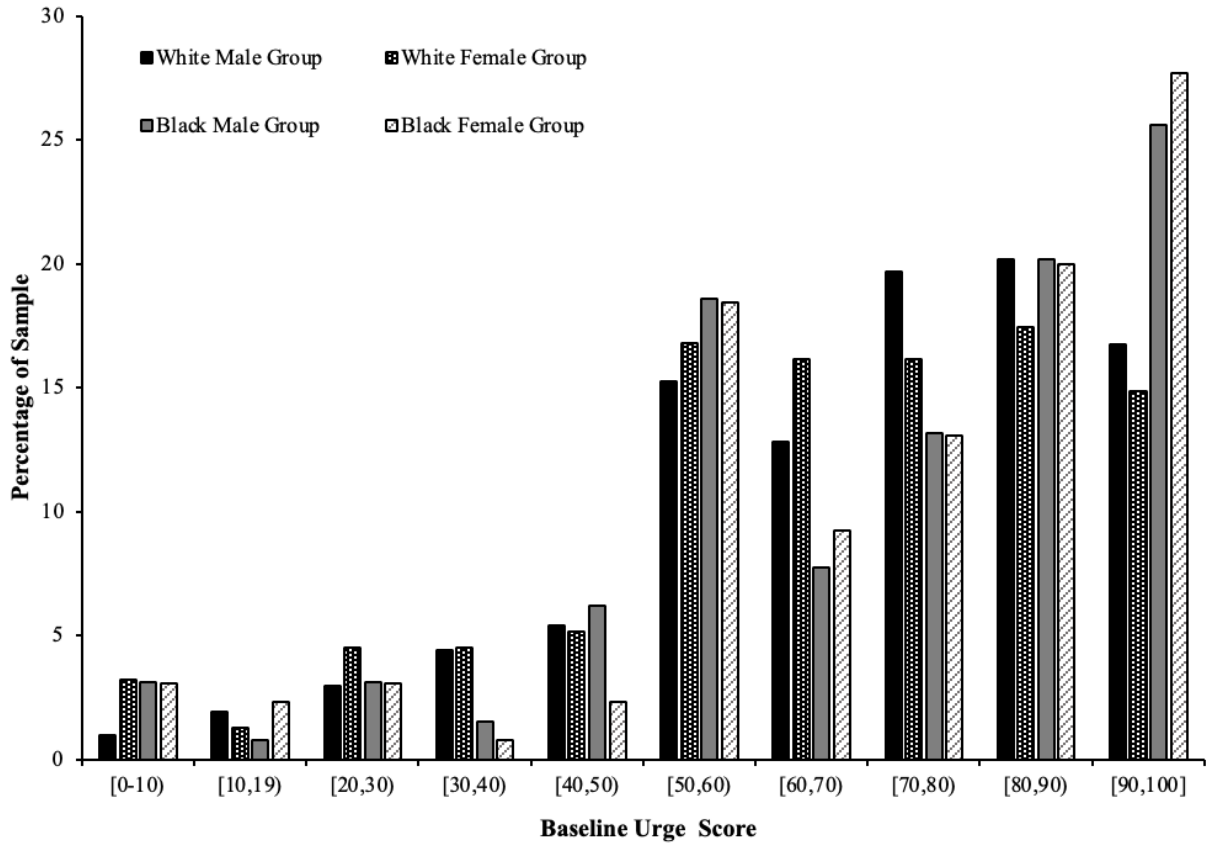


Figure 5 Percentage Distribution of Baseline Urge by Race-by-Sex Groups

Note. The x-axis notation distinguishes between inclusion and exclusion within intervals. Values accompanied by brackets denote inclusion in the interval, while values accompanied by parentheses denote exclusion. For instance, "[0, 10)" indicates that 0 is included but 10 is not, whereas "[90-100]" denotes that values of both 90 and 100 are included.

5.2 Tables

Table 1 Datasets Included in the Current Analysis

Study	N	Required	Description
	in Analysis	Deprivation	
Sayette et al. (2001)	34	7-hrs.	This dataset included smokers who participated in an experiment that examined the performance of a broad range of craving response measures. Half of the participants were randomly assigned to a 7-hr. nicotine-deprived condition; the other half could smoke freely prior to entering the laboratory. All participants were exposed to control cues (a small roll of electrical tape) and smoking cues (participants' own lit cigarette). The present analyses focused on the daily smokers who were assigned to the 7-hr nicotine-deprivation condition; craving response was examined during the cigarette cue exposure.
Sayette et al. (2005, experiment 1)	42	12-hrs.	This dataset included daily smokers who participated in a study that examined the effects of craving on temporal cognition. Following baseline assessment, participants were randomly assigned to either abstain from smoking for at least 12-hrs. (high-crave condition) or smoke normally (low-crave condition) before a 2-hr. laboratory session. The present

analyses include the participants in the high-crave condition.

Sayette et al. (2008)	59	12-hrs.	This dataset included daily smokers and examined how accurately smokers can anticipate the strength of their own future cigarette craving. Participants were randomly assigned to one of three conditions: (a) abstain from smoking for 12-hrs before two sessions, (b) smoke regularly before the first session and abstain before the second, or (c) abstain from smoking before a single session. Current analyses focused on urge ratings obtained from only those participants who were nicotine-deprived during their first or their only session. One additional participant was excluded because of missing cigarette cue urge scores. For participants who participated in two deprivation sessions, only data from the first session were used.
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Sayette & Dimoff (2016)	212	5-hrs.	This dataset included daily active smokers participating in a study examining the impact of motivation to quit and perceived opportunity to smoke imminently on craving. Participants were randomly assigned to a condition in which they were informed they either would or would not be able to smoke soon during the experiment. All participants engaged in two brief tasks and then were administered the same smoking cue exposure manipulation used in the other studies. Current analyses focused on the urge rating provided just prior to and during cue exposure. Twelve participants were excluded from the current analysis because they did not
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report complying with instructions to abstain from smoking for at least 5-hrs. before the experimental session. An additional three participants were excluded because of missing pre- and post-cigarette cue urge scores.

Sayette et al. (2019)	231	8-hrs.	<p>This dataset included daily smokers who participated in a study examining the impact of olfactory cues on cigarette craving. Smokers were required to abstain from smoking for at least 8-hrs. before the experimental session. Current analyses focused on the first experimental session during which participants reported their urge to smoke at study outset and then during smoking cue exposure. One individual was excluded from the current analysis because they did not report adhering to the 8-hr abstinence requirement. Following cue exposure, and irrelevant to the present analyses, participants received an olfactory cue to evaluate its impact on their craving.</p>
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Creswell et al. (2019)	50	6-hrs.	<p>This dataset was collected at the Creswell Lab and included daily smokers who participated in an experiment investigating a new measure of craving (i.e., squeezing a handheld dynamometer). Participants were at least 6-hr. nicotine-deprived and were exposed to a lit cigarette of their preferred brand. Smokers were randomly assigned to one of the following four conditions that varied the way in which they reported their urge to smoke during cigarette cue exposure: (a) report urge using a traditional 0-100 self-report rating</p>
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scale (verbal measure) and then indicate urge by squeezing a dynamometer, (b) indicate urge by squeezing and then report urge verbally, (c) indicate urge only by squeezing, or (d) report urge only verbally. The present study includes participants who reported their urge only on the 0-100 rating scale (i.e., the last condition). One additional participant was excluded from this analysis because they did not adhere to the abstinence requirement.

<p>Creswell & Skrzynski (2021)</p>	<p>44</p>	<p>12-hrs.</p>	<p>This dataset was collected by the Creswell lab and included daily smokers who participated in an experiment to determine whether high (vs. low) smoking motivation strengthened the associations between urge to smoke, attentional bias (AB) to smoking cues, and smoking behavior. Participants were randomly assigned to a high smoking motivation (i.e., 12-hr. nicotine-deprived + exposed to a lit cigarette of their preferred brand) or low smoking motivation (i.e., non-deprived + exposed to a control cue of a roll of tape) condition. After the cue exposure manipulation, participants engaged in an AB task in which they viewed smoking and matched control pictures while their eye movements were continuously monitored. The present study includes participants randomly assigned to the high smoking motivation condition. One participant was excluded because of incomplete cigarette cue urge scores.</p>
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Table 2 Race and Sex Group Distributions

Race	Sex	
	Male	Female
White	203 smokers self-identifying as White and male (33%)	155 smokers self-identifying as White and female (25%)
Black	129 smokers self-identifying as Black and male (21%)	130 smokers self-identifying as Black and female (21%)
Total	332 male persons	285 female persons

Table 3 ANOVA Model of Race by Sex Predicting Baseline, PPC, and CR Craving Outcomes, with inclusion of Covariates

Predictors	Baseline			PPC			CR		
	<i>F</i>	<i>p</i>	η^2	<i>F</i>	<i>p</i>	η^2	<i>F</i>	<i>p</i>	η^2
Race	6.470	.011	.011	3.074	.080	.005	0.622	.431	.001
Sex	0.280	.596	<.001	0.111	.739	<.001	0.899	.343	.002
Income	6.842	.009	.011	3.194	.074	.005	0.687	.407	.001
Educational Attainment	6.224	.012	.010	10.391	.001	.017	0.837	.360	.001
FTND	27.582	<.001	.045	18.693	<.001	.031	0.703	.402	.001
Race by Gender	1.122	.289	.001	0.7029	.402	.001	4.365	.037	.007

Table 4 Hierarchical Linear Model of Race and Sex Predicting Levels of Craving (BL + PPC compiled Measure), with inclusion of Subject-level and Time-level Random Intercepts and Covariates

Predictors	<i>F</i>	<i>p</i>	<i>ηp²</i>
Race	5.832	.016	.009
Sex	0.084	.773	<.001
FTND	28.787	<.001	.046
Income	1.866	.172	.003
Educational Attainment	6.837	.009	.011

Appendix

Model comparisons were conducted to assess whether there were significant differences in the additional SES predictors' (specifically, educational attainment and income) ability to account for variability in the craving response outcomes. These analyses were composed to further understand the relationship between the studied SES variables with the craving outcomes. The results revealed that in the models assessing CR, baseline, and PPC, there were variations in the additional socioeconomic status (SES) variables' ability to explain the variability in the respective response variables compared to models without these SES variables. Specifically, for the BL, including income and educational attainment significantly improved the model's explanatory power ($F(2, 595) = 5.91, p = .002$). Similarly, for PPC, the inclusion of the SES variables also significantly enhanced the model's explanatory capability ($F(2, 595) = 6.69, p = .001$). However, for CR, the addition of the SES variables did not yield a significant improvement in explanatory power ($F(2, 595) = 0.74, p = .478$). To further understand these relationships, I looked at the relationship of race on baseline and PPC across individuals from the same household income bracket. For this analysis, the income inclusion group was selected based on the mode, meaning the income bracket that occurred most frequently in the current sample. Across individuals ($n = 134$) with the lowest income bracket ($< \$5,000$ USD per year), there were main effects found of race on baseline and PPC craving outcomes while controlling for gender and education level ($F(1, 125) = 5.0641, p = .026$ and $F(1, 125) = 3.9815, p = .048$, respectively). Together, these data suggest that, while the observed race and sex differences in craving remained significant even after accounting for SES, it also is clear that SES explains some of the variance in craving for the PPC

and baseline models, and should be included in future research that examines potential group demographic differences.

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