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A Person-Centered Analysis of Craving in Smoking-Cue-Exposure Research

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Abstract

Smoking-cue-exposure research offers a powerful method to examine craving, test new interventions, and identify at-risk smokers. Meta-analyses consistently show smoking-cue exposure increases craving levels. By focusing on mean levels, however, investigators fail to consider person-centered analyses addressing the percentage of smokers responding to cue exposure with increased urge. We conducted preregistered analyses of the percentages of 672 nicotine-deprived daily smokers (pooled from seven studies) who reported target levels of urge before and during smoking-cue exposure. Sixty-nine percent of smokers increased their ratings during cue exposure. Note that 31% of nonresponders reported a maximal urge *before* cue exposure, which precluded their classification as a responder using traditional cue-reactivity analyses and suggests that traditional analyses underreport cue-reactivity effects. An alternative, peak-provoked-craving analysis revealed the effectiveness of cue exposure to generate potent urges (more than three quarters of the sample reported at least 70% of scale maximum). Further research integrating person-centered analyses into the craving literature promises to advance addiction theory and research.

Keywords

smoking, craving, cue reactivity, peak provoked craving, person-centered analysis, preregistered

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Craving (hereafter used interchangeably with *urge*) is a cardinal feature of addiction and lies at the heart of understanding motivation to use drugs (Piasecki et al., 2010; Sayette, 2016). Craving is a core feature of nearly all contemporary models of drug dependence and is often linked to relapse (Tiffany & Wray, 2012). In recent years, investigators have redoubled their efforts to understand and alleviate craving, and nowhere has this focus been more apparent than in the study of cigarette craving. Despite the dramatic escalation in use of e-cigarettes, combustible cigarette use remains a more dire threat to public health (Baker & McCarthy, 2021; Fairchild et al., 2019). Unfortunately, current smoking-cessation interventions fall short, in part because they fail to sufficiently address cigarette craving. Baker and McCarthy (2021), for example, argued that current pharmacotherapies inadequately address motivational factors that contribute to smoking, including a general failure to relieve withdrawal-based craving.

One of the most powerful approaches to examining cigarette craving in the laboratory is to expose smokers to cues associated with cigarette use and observe their reactions. Cue-reactivity research contrasts the urges found during smoking-cue exposure with those during an abstinence-based "baseline" or control-cue exposure (Sayette et al., 2000). Smoking-cue exposure research is rapidly proliferating and has delivered valuable insights regarding drug-motivational processes (Sayette, 2016). Meta-analytic reviews have uniformly concluded that exposure to smoking cues significantly and robustly increases participants' reported urge to smoke (Betts et al., 2021; Carter & Tiffany, 1999; Karelitz, 2020). This cue-elicited craving effect is observed regardless of whether exposure to the "cued" urge is compared with

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exposure to a neutral-cue urge rating or to a pre-smoking-cue "baseline" assessment (Sayette & Hufford, 1994; Sayette et al., 2001). Recent analyses also have supported the clinical utility of the smoking-cue exposure paradigm (see Monti & Ray, 2012). For instance, peak urge ratings during cue exposure have predicted subsequent smoking lapses and time to first lapse as well as level of nicotine dependence (see Sayette & Tiffany, 2013). Nevertheless, despite reliance on costly cue-exposure studies to test addiction theories and interventions, further advancement requires improved understanding of the craving responses that are generated in these cue-exposure studies (Baker & McCarthy, 2021; Betts et al., 2021; Sayette, 2016). Pertinent to the present study, and despite calls to investigate variability in one's craving experience (MacKillop & Monti, 2007), a person-centered approach to the analysis of urge responding has yet to be adopted.

Person-Centered Effects

Although investigators (ourselves included) have expressed confidence in the power of smoking cues to enhance self-reported craving, invariably the supporting evidence has focused on group-level change. Mean urge ratings significantly rise during smoking-cue exposure. To our knowledge, this analytic approach has never been questioned in the smoking literature. Yet experts outside the addiction research area (e.g., the psychology of personality) have cautioned against sole reliance on means, noting that they are not descriptive of the individual person (Borsboom et al., 2009). It holds, then, that a focus on mean levels is not the only way to evaluate the impact of smoking cues.

One can also consider the percentage of participants for whom the smoking-cue exposure "works" (i.e., elevates urge ratings). In an important recent article, Grice et al. (2020) encouraged researchers to consider an alternative person-centered question: "How many people in my study behaved or responded in a manner consistent with theoretical expectation?" (p. 443). Merely finding that smoking-cue exposure increases craving by an average of 10 points does not address the percentage-correct classification described by Grice and colleagues. We use the term *person-centered* to reflect a focus on whether a specific individual's craving changes from precue to cigarette-cue assessment. This effort to subtype responders—people who increase their craving—from nonresponders diverges from the way the term is used in longitudinal (e.g., ecological momentary assessment [EMA]) research, in which person centering represents a person's data as deviations from the person's own average score across multiple ratings (Howard & Hoffman, 2018).

At first glance, it would seem that a manipulation that provokes a consistent and robust mean increase in craving would exert this effect for the vast majority of participants. Indeed, implicit in its value for advancing smoking research and treatment is that the cue-exposure paradigm generates a reliable craving response. Yet Grice et al. illustrated the risk of such an assumption. They referred to a recently published study revealing a significant mean increase in the effect of suppressed affective expressions on the perception of neutral faces (the dependent variable). Specifically, participants perceived neutral faces as more smiling when those faces were linked to suppressed positive faces but viewed neutral faces to be more scowling when they were linked to suppressed negative faces. Whereas the original analysis revealed a highly significant effect—a large effect, using Cohen's (1988) guidelines—a person-centered reanalysis yields a strikingly incongruous finding: Just 24% of participants matched the expected pattern. That is, the vast majority of the participants provided data at odds with the observed mean difference. Grice et al. argued persuasively that statistical inferences drawn from groups of individuals do not always characterize the individuals themselves (see also Molenaar, 2004). The present study applies this person-centered approach to investigating the impact of an in vivo smoking-cue exposure on cigarette craving.

Peak Provoked Craving

One factor that may contribute to a lower than expected percentage-correct classification in the smoking-cue-exposure literature is measurement insensitivity because of ceiling effects. In many smoking-cue-exposure studies, participants are asked to abstain from smoking before entering the study. Typically, participants in this deprived state are asked multiple questions about their smoking patterns and history, which is likely to increase the salience of smoking and craving. Furthermore, participants are asked to rate their current level of craving at the study outset. We have detailed elsewhere in both conceptual and empirical terms the ways in which considering this urge rating to be a "baseline" or uncued craving assessment is curious at best (see Sayette & Tiffany, 2013). Rather, particularly under smoking-abstinence conditions, it would appear that this baseline assessment is itself a cue to smoke. If these pre-smoking-cue or neutral-cue craving assessments prompt a high urge rating, then there is little room on a traditional rating scale using a fixed maximum point (e.g., 100 on a 0–100 scale) to reveal an urge increase when presented with the ostensible cue (Sayette et al., 2000). At its most extreme, any participant reporting a 100 on the pre-smoking-cue baseline assessment or

during a neutral-cue assessment by definition cannot report an increase in urge when exposed to the study's explicit smoking cue, and when using a person-centered approach, such a smoker necessarily would be classified as a *nonresponder* (the term we use here to denote a participant who reports either no increase or a decrease in urge from precue to cigarette cue). A related concern is that as participants approach the scale maximum, they may become conservative in using the few remaining points. For instance, one might report a baseline urge of 90 and then, after holding the cigarette cue, report a 95 while simultaneously reporting that one's urge has now doubled or tripled (see Sayette et al., 2001).

Such concerns with ceiling effects led to consideration of an alternative to the traditional cue-reactivity paradigm, which we termed *peak provoked craving* (PPC; Sayette & Tiffany, 2013):

> The PPC approach uses nicotine-deprived smokers and focuses on urges during smoking cue-exposure without subtracting out urge ratings during control-cue or baseline assessments. This design relies on two factors found in many cue-exposure studies—nicotine deprivation and exposure to explicit smoking cues—which, when combined, can create powerful craving states. The PPC approach retains key aspects of the cue-exposure method, and in many circumstances may be a viable design for studies examining robust laboratory-induced cravings. (p. 1019)

In many instances, investigators interested in the motivational properties of craving may be less concerned with parsing the relative contributions of a cigarette cue from the impact of abstinence than with understanding the experience of what happens during a powerful craving state. For example, does one evaluate the pros and cons of smoking a cigarette differently while in a heightened craving state (Sayette & Hufford, 1997)? Does a particular intervention attenuate a peak craving state (Sayette et al., 2019)? Moreover, in many real-world instances, tobacco withdrawal and the presence of smoking cues co-occur and may be conceptually linked. For example, while one is in a nicotine-deprived state, smoking cues become more salient, and perhaps even a typically neutral cue might serve to trigger a craving (Baker et al., 2004; Field et al., 2004; Wertz & Sayette, 2001b). Accordingly, PPC offers a second approach, along with the traditional cue-reactivity method, for undertaking a person-centered analysis of smoking-cue-exposure studies. That is, in addition to tracking the percentage of smokers who increase their urges during smoking-cue exposure, one can identify the percentage of nicotine-deprived smokers who report varying levels of urge during cue exposure. Regardless of their increase from baseline or from a neutral-cue rating, a high urge rating may provide valuable information about the relative effectiveness of the craving induction.

Present Study

In the present research, we used a person-centered approach to examine urge responding (both cue reactivity and PPC) during smoking-cue exposure by requiring participants to hold, but not smoke, a lit cigarette of their preferred brand. In vivo exposure to smoking cues has a long history in the smoking field (e.g., Abrams et al., 1988; Rickard-Figueroa & Zeichner, 1985; Sayette & Hufford, 1994) and remains among the most popular approaches to smoking-cue exposure.[1] In this study, we used pre-smoking-cue baseline assessments and assessments reported during smoking-cue exposure to offer a person-centered examination of cue-elicited craving. For self-reported urge in particular, a baseline urge score is equivalent to a neutral control score.[2]

We further focused on the impact of smoking-cue exposure on nicotine-deprived daily smokers. Some studies have also examined nondeprived smokers (Betts et al., 2021). Our decision to require nicotine deprivation stems from the observation that the craving experienced by daily smokers who are deprived of nicotine is both qualitatively (e.g., different neural activation patterns) and quantitatively (i.e., more intense) different from that experienced by smokers who are not deprived of nicotine (see Wilson & Sayette, 2015). Often the urge ratings of nondeprived smokers during smoking-cue exposure fail to reach the midpoint of the urge scale and "may be clinically unremarkable" (Sayette & Tiffany, 2013). Although studying milder desires to smoke also may have important clinical implications, a focus on strong cravings makes sense from both a clinical and a scientific perspective. Consider the remarks by some of the leading experts in addiction research. Volkow and colleagues (2010) described the "overwhelming craving to take drugs" (p. 753) to be one of the most alarming features of addiction, whereas George and Koob (2013) claimed that

> craving is what makes addiction to drugs so difficult to overcome. The intense craving that follows a cue that has been previously associated with the drug, combined with a stressful state or a dysphoric state, represents an unstoppable force that leads to drug intake and relapse for most addicted individuals. (p. 4165)

Indeed, as West and Brown (2013) asserted, "for most individuals addicted to drugs, 'a weak craving' is an oxymoron" (p. 11). Studying nicotine-deprived daily smokers seems to optimally model this extreme urge state.

Method

Open science and preregistration

We took several steps to follow open science guidelines within the constraints that the data stemmed from studies that had been previously published. Accordingly, we preregistered our data analysis plan before the start of data analyses at OSF (https://osf.io/kdxft). Because these studies were conducted before the emergence of an open science perspective, the consent forms were not written to enable even deidentified data to be posted, and university institutional review boards have not permitted us to do so now.

Overview

Data from seven laboratory studies (see Table 1) were collapsed to provide a sample with ample power to comprehensively examine person-centered responses to smoking-cue exposure. The earliest study appeared in 2001, and the most recent was published in 2021. All participants included in the analysis (N = 672) were daily smokers who were required to abstain from smoking for at least 5 hr (actual abstinence requirements varied depending on the study; range = 5–12 hr) before study onset. All participants rated their urge to smoke both before and then during cigarette-cue exposure. A total of five subjects were excluded from analyses because they were missing either a precue or postcue urge rating.

Participants. The combined sample included 672 daily smokers (46% female). Among the sample, 53% were White, 39% were Black, 3% were Hispanic or Asian American, 5% were other (i.e., American Indian, Alaskan Native, Pacific Islander, more than one race), and less than 1% did not report. All participants were residing in the northeastern United States. Selection criteria were applied at screening. Participants were excluded if they reported a medical condition that contraindicated nicotine or if they were illiterate. The median household annual income was in the range of $10,000 to $14,999, and the median highest school grade completed was 13. Participants ranged in age from 18 to 69 (M = 40.0 years, SD = 12.1), and they had to report smoking at least 10 cigarettes per day (M = 16.9, SD = 6.6) for at least 12 continuous months (M = 24.4 years smoking, SD = 12.4).[3]

Procedures. All participants were recruited through newspaper advertisements or flyers. Methods important to the current analyses are described below, and the individual studies are described in Table 1. All participants were nicotine deprived, and the cue-exposure protocol was identical across all experiments.

Cigarette-cue exposure. A research assistant placed a tray containing a plastic cover on the desk in front of each participant. The research assistant then exited the room and asked the participant over an intercom system to pick up the cover, which revealed their 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 comfortably. Participants rated their urge to smoke immediately before lifting the cover from the tray (precue) and 31 s after lighting the cigarette (cigarette cue).

Reported urge to smoke. 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 (e.g., experimental cue-exposure studies) calling for repeated and rapid reporting of craving throughout an experimental paradigm in which measurement reactivity can be problematic (Sayette et al., 2000). Single-item urge scales are at least as, if not more, sensitive to cue exposure than multiitem scales (see Betts et al., 2021; Heckman et al., 2013; Sayette, 2016; Tiffany & Wray, 2012).

Data sets. With two exceptions, all the data for the present analyses were collected in the Alcohol and Smoking Research Laboratory (ASRL) at the University of Pittsburgh. K. G. Creswell, the principal investigator on the two studies conducted at Carnegie Mellon University, trained at the ASRL, which ensured a consistent approach to the manipulation and assessment of urge across the projects.

Data analyses

The overarching aims of this study were descriptive. The first aim was to calculate descriptive statistics summarizing urge ratings across the entire sample (N = 672). We examined the percentage of participants reporting varying levels of precue urge ratings, varying levels of cigarette-cue urge ratings, and varying levels of urge change from precue to cigarette cue. The second aim was to examine the distribution of precue urge ratings for smokers exhibiting varying levels of cue reactivity. Specifically, we sought to describe nonresponders' absolute

Table 1. Description of the Data Sets Used in the Present Study

Study	*N* in analysis	Required deprivation	Description
Sayette et al. (2001)	34	7 hr	This data set 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 before 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 hr	This data set 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 hr (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 hr	This data set included daily smokers and examined how accurately smokers can anticipate the strength of their own future cigarette cravings. Participants were randomly assigned to one of three conditions: (a) abstain from smoking for 12 hr 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.
Sayette & Dimoff (2016)	212	5 hr	This data set 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 before and during cue exposure. Twelve participants were excluded from the current analysis because they did not report complying with instructions to abstain from smoking for at least 5 hr 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 hr	This data set 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 hr 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.
Creswell et al. (2019)	50	6 hr	This data set 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 self-report rating scale from 0 to 100 (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 rating scale from 0 to 100 (i.e., the last condition). One additional participant did not adhere to the abstinence requirement and was excluded from this analysis.
Creswell & Skrzynski (2021)	44	12 hr	This data set 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 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., nondeprived + exposed to a control cue of a roll of tape) condition. After the cue-exposure manipulation, participants engaged in an attentional bias 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.

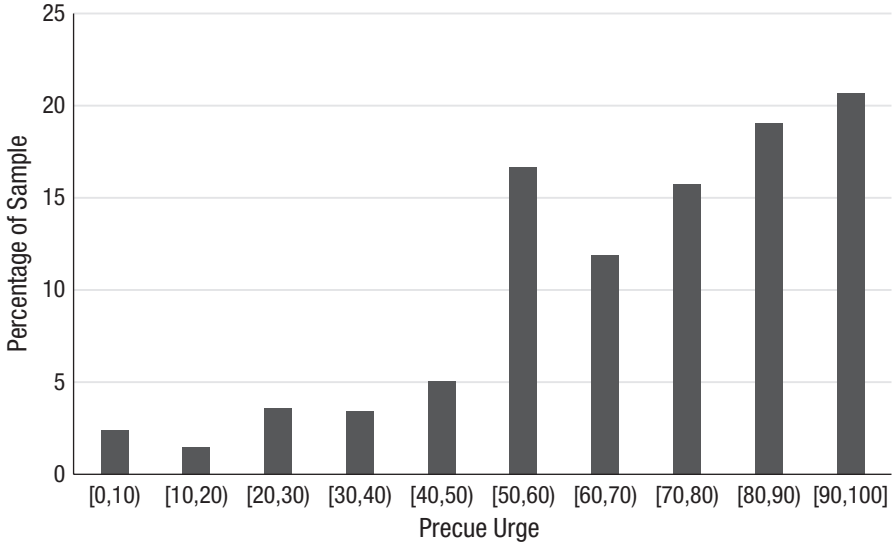

Fig. 1. Percentage distribution of precue urge ratings in the whole sample. On the *x*-axis, a value preceded or followed by a bracket is included in the interval, and a value preceded or followed by a parenthesis is excluded from the interval. For example, "[10, 20)" means that 10 is included but 20 is not; "(0, 5)" means that neither value is included in the interval. This notation thereby allows for the rare fractional response.

precue urge ratings. This second aim represents a deviation from our preregistered analysis plan, in which we said we would examine the distribution of cigarette-cue urge ratings (as opposed to precue urge ratings). Although we do briefly report cigarette-cue urge scores among nonresponders, we chose to focus instead on precue urge ratings. As noted by an anonymous reviewer, there was little incremental validity in describing cigarette-cue urge scores among participants with zero cue reactivity because precue and cigarette cue urges are identical among these individuals. Describing precue-urges categorizations therefore offers a more concise and conceptually clear examination.

Results

Urge ratings for entire sample

Precue urge. Figure 1 presents the distribution of urge ratings just before cigarette-cue exposure. Results indicate a mean rating of 66.9 (*SD* = 23.9). The vast majority of participants (84%) reported an urge at least at the midpoint (50) of the scale; 40% of the participants reported an urge of 80 or higher, and 9.7% reported the maximum urge rating of 100.

Cue reactivity. Results indicate a mean cue reactivity of 11.1 (*SD* = 20.9); urge at precue (*M* = 66.9, *SD* = 23.9) rose to 78.0 (*SD* = 24.8) during the cue. A traditional mean-level analysis reveals that this is a significant increase in urge, $t(671) = 13.795$, $p < .001$, 95% confidence interval (CI) = [9.529, 12.691], Hedges's $g_{rm} = 0.456$, 95% CI = [0.388, 0.524].[4] Figure 2 presents the distribution of cue-reactivity ratings (change from precue to cigarette cue). Sixty-nine percent of participants increased their urge ratings (i.e., reported a positive cue-reactivity rating), and 65% reported a cue-reactivity increase of 5 or more.

Peak provoked craving. Figure 3 presents the distribution of peak-provoked-craving ratings (urge during cigarette-cue exposure unadjusted for precue levels). Results indicate a mean peak provoked craving of 78.0 (*SD* = 24.8). Sixty-five percent of participants reported a peak provoked craving of 80 or higher.

Nonresponders' urge ratings

Nonresponders' precue urge. Figure 4 presents the distribution of precue ratings among participants who either reported no change (*zero responders*, *n* = 131) or reported a drop in urge (*negative responders*, *n* = 79) during cue exposure. More than half of these participants reported a precue urge of 80 or higher. More than 40% of the nonresponders reported a precue urge of 90 or higher. Note that 31% of the nonresponders reported a precue urge of 100 and were unable to increase their urge ratings during cue exposure. Whether examining mean or person-centered data, we found that these nonresponders' precue scores are greater than those found

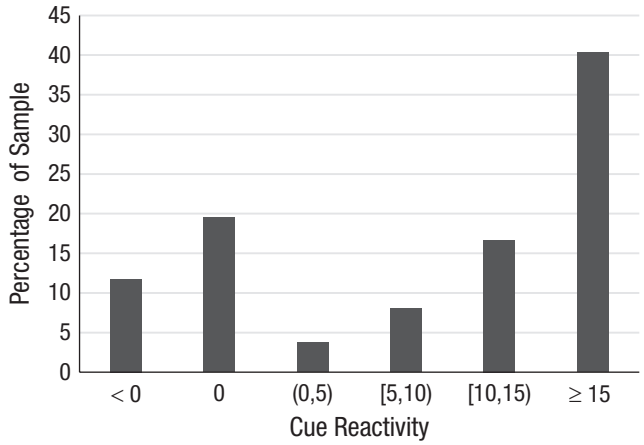

Fig. 2. Percentage distribution of cue-reactivity ratings (change in urge from precue to cigarette cue) in the whole sample. On the *x*-axis, a value preceded or followed by a bracket is included in the interval, and a value preceded or followed by a parenthesis is excluded from the interval. For example, "[10, 20)" means that 10 is included but 20 is not; "(0, 5)" means that neither value is included in the interval. This notation thereby allows for the rare fractional response.

for the entire sample (nonresponders + responders). Note that more than half of this group reported a cigarette-cue exposure urge of 70 or higher. Thirty-five percent of the nonresponders reported a cigarette cue-exposure urge of 90 or more. We also conducted, in an exploratory fashion (suggested by an anonymous reviewer), analyses to examine differences between the zero responders, the negative responders, and the 462 positive responders on precue urge ratings. Specifically, a one-way analysis of variance was computed to examine the effect of response classification (negative responder, zero responder, positive responder) on precue urge scores. There was a significant effect of response classification on precue urge, $F(2, 669) = 23.780$, $p < .001$. Post hoc comparisons using Tukey's honestly significant difference test indicated that zero responders' precue urge ($M = 79.3$, $SD = 24.4$) was significantly greater than precue urge in negative responders ($M = 66.2$, $SD = 24.5$) and positive responders ($M = 63.5$, $SD = 22.6$; both ps $< .001$). Precue urge did not differ between negative responders and positive responders ($p = .623$; see Fig. 5.)

Finally, we conducted a Pearson's χ^2 test of independence (also suggested by a reviewer and not part of the preregistered analytic plan) to determine whether required hours of smoking abstinence affected the frequency of responders. Given the natural break in distribution of deprivation hours, we split the sample into participants with a required abstinence of 12 hr (n = 145) and participants with between 5 and 8 hr of required abstinence (n = 527). Results indicated no significant relationship between required hours of abstinence and the frequency of responders, $\chi^2(1, N = 672) = 0.449$, $p = .503$.

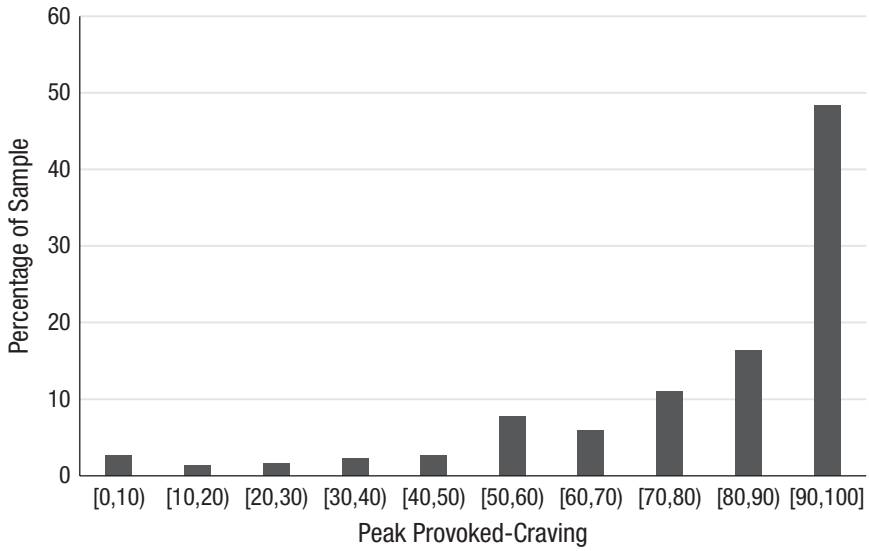

Fig. 3. Percentage distribution of ratings of peak provoked craving in the whole sample. On the *x*-axis, a value preceded or followed by a bracket is included in the interval, and a value preceded or followed by a parenthesis is excluded from the interval. For example, "[10, 20)" means that 10 is included but 20 is not; "(0, 5)" means that neither value is included in the interval. This notation thereby allows for the rare fractional response.

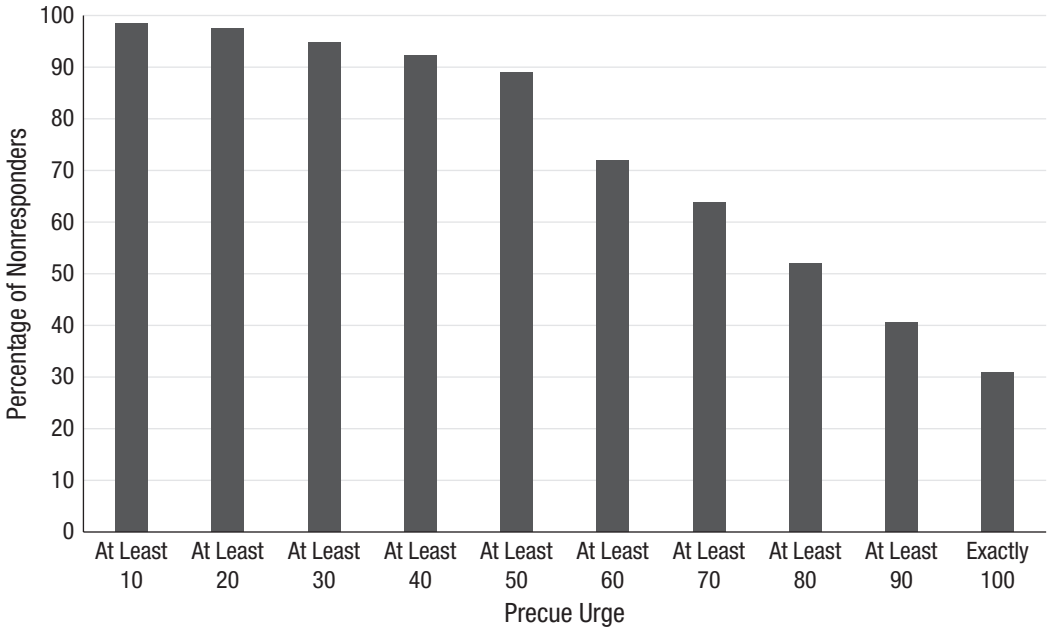

Fig. 4. Cumulative percentage distribution of precue urge ratings for nonresponders.

Discussion

In the present study, we examined the urge ratings of smokers before and during in vivo smoking-cue exposure. Although prior reviews have provided convincing evidence that mean urge scores rise significantly during smoking-cue exposure, to our knowledge, there has yet to be a person-centered analysis to examine the likelihood that an individual participant would reveal this expected increase. Previous research has found that highly significant mean increases in a response can occur even when the vast majority of participants fail to show the expected change (see Grice et al., 2020). Hundreds of studies (Betts et al., 2021; Tiffany & Wray, 2012) have relied on in vivo cue exposure to conduct often costly (e.g., functional MRI) experiments and expensive interventions, and it is important to comprehensively evaluate the effectiveness of this manipulation.

This study examined a large sample of smokers whom we anticipated would be ideally suited to experience the robust craving implied in the work of leading addiction investigators (e.g., George & Koob, 2013; Volkow et al., 2010; West & Brown, 2013). We sampled daily smokers who abstained from smoking before entering the study. Results were encouraging. While exposed to smoking cues, these smokers reported a mean urge of 78 and a significant increase in urge of more than 11 points on the rating scale. Furthermore, 69% of participants responded to the smoking cue by increasing their urge rating. These person-centered values indicate that the in vivo smoking-cue manipulation seems to work for most smokers.

Although the data compare favorably with many of the studies described by Grice et al. (2020), note that 31% of the sample did not report an increase in cue-elicited urge. One might be tempted to infer that these individuals were insensitive to the smoking cue or perhaps just not experiencing much craving, earning the label of *nonresponder*. Yet we contend that this observation instead speaks to the challenges of relying on a cue-reactivity approach to examine urge when testing nicotine-deprived daily smokers. Consider that nearly one third of these "nonresponding" participants (about 10% of the entire sample) reported the maximum urge score of 100 before in vivo cue exposure and necessarily were classified as nonresponders despite their extreme craving. Yet for at least some of these high-craving smokers, simply being prompted to report their "baseline" urge (before in vivo exposure)—while engaged in a smoking study in a smoking lab and while experiencing nicotine withdrawal—likely served as an unintended smoking cue. Accordingly, these initial precue urge ratings might also have captured some degree of smoking cue-elicited urge, which makes it difficult to assess with a self-report instrument a pure (uncued) baseline craving value. As elaborated elsewhere (Sayette & Tiffany, 2013), in situations in which one wants to test the intense urges of nicotine-deprived daily smokers, use of a cue-reactivity paradigm likely systematically underestimates cue responding. It may not be

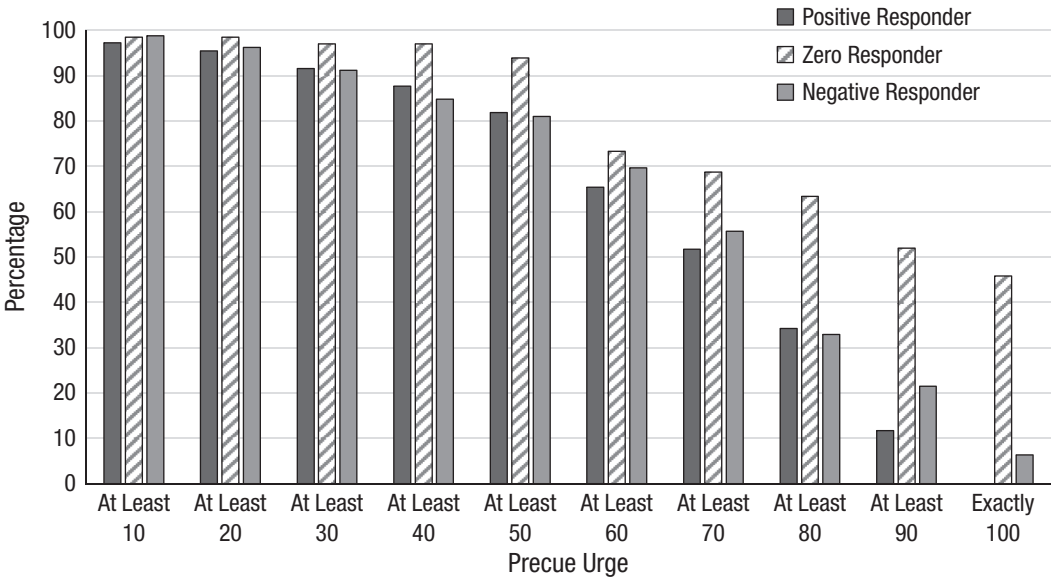

Fig. 5. Cumulative percentage distribution of precue urge ratings for positive responders, zero responders, and negative responders.

surprising, then, that comparisons of abstinent and nonabstinent smokers fail to reveal different levels of cue reactivity (see Betts et al., 2021).

Recognition of the advantages of considering a broader range of approaches when interpreting cue-exposure studies holds promise for more than just methodological advances. Various models of craving (e.g., conditioning, incentive-based, or habit-driven models) emphasize the impact of cues on the craving process (see Tiffany, 1990). Studies failing to reveal such an effect of cue exposure on craving for key subsets of drug users raises significant questions for these models. Comprehensive assessment that acknowledges the absence of a perfect way forward and instead considers the strengths and limitations of traditional cue-reactivity responses, as well as peak-provoked-craving responses, using both person-centered and traditional mean-level analyses may help offer optimal evaluation. We hope the present research will stimulate both cue-reactivity and peak-provoked-craving approaches to "elucidate clinically meaningful effects of craving . . . as well as somewhat subtler (and arguably more contrived) effects that may be of theoretical interest" (see Sayette & Tiffany, 2013, p. 1023).

There is increasing awareness of the benefits and challenges associated with integrating lab-based cue-exposure experiments and research conducted outside the laboratory using EMA methods (Baker & McCarthy, 2021; Fronk et al., 2020; Shiffman et al., 2015). Laboratory experimentation can provide precise control over both manipulations and measurement of intense, yet sometimes fleeting, urge states; at its best, it can prove instrumental in developing and refining models of drug use and can offer cost-effective approaches to testing new craving interventions (Abrams, 2000). But laboratory studies also can suffer from concerns linked to ecological validity (Fronk et al., 2020; Sayette, 2016). For lab studies to reach their potential, it is critical to recognize both these strengths and limitations. Studies plagued by ceiling effects that misclassify nontrivial subsets of participants as nonresponders or simply limit the magnitude of urge increase that is possible undermine the conclusions that can be drawn. For instance, results from studies in which abstinent smokers reported very high baseline urges suggest that abstinence may cause smoking cues to become *less* potent (see study examples reviewed in Betts et al., 2021) and likely would be questioned by anyone who knows that staring at a mouthwatering slice of pizza while hungry generates a greater craving than viewing that same greasy piece after already eating several slices.

Likewise, when perceived drug-use opportunity, a factor built into a number of motivational models of drug use and shown to affect craving (see Baker et al., 1987; Juliano & Brandon, 1998; Sayette, 2016), fails to reveal moderating effects on cue reactivity (Betts et al., 2021), it should at least give pause, especially when urge levels are high at study outset or the availability information may be communicated before the precue urge or control-cue urge ratings (see Wertz & Sayette, 2001b, Tables 1 and 2). Piasecki et al.'s (1999) observation offered more than two decades ago remains true today: "If the aim of cue-exposure research is to permit strong inference regarding stimulus control over drug

motivational processes . . . it seems clear that our research strategies require scrutiny" (p. 343). Although there have been exploratory efforts to capture craving experiences with measures that do not have maximal endpoints (e.g., reporting urge via magnitude estimation, Sayette et al., 2001; or by squeezing a handheld dynamometer, Creswell et al., 2019), consideration of peak-provoked-craving scores, whether with person-centered or a means analysis, may help to create tighter experimental models that can productively intersect with emerging EMA findings.

It has been observed that there is a need to determine in cue-exposure studies whether a neutral cue functions any differently than a baseline precue assessment (Betts et al., 2021). To address this question, we reported above that two of our prior studies, which included both a precue baseline and a control-cue assessment, yielded identical urge ratings (Sayette et al., 2001; Sayette & Hufford, 1994). Furthermore, a traditional mean-level effect size of the change in urge from precue to cigarette-cue exposure in the present study is virtually identical to the effect size observed for in vivo cues when contrasting neutral and cigarette cues in the meta-analysis conducted by Betts et al. (2021). Consequently, we believe that the person-centered findings reported here also should pertain to studies that instead contrasted urge ratings during neutral and smoking cues.

The present study boasted an unusually large sample, which was ideally suited for conducting person-centered analyses. Our sample also is notable for including 39% African Americans ($n > 250$), whose smoking rates (unlike those of White smokers) have failed to drop in recent years yet are often underrepresented in research studies. Yet so too are there limitations to the study as well as questions raised by the present findings that warrant future research. Data came from two labs using the same cue-exposure paradigm. This has the advantage of holding constant idiosyncratic aspects of the cue-exposure method, and we hope this study will stimulate other labs to undertake similar analyses. Our focus was on the high levels of craving likely to be encountered by nicotine-deprived daily smokers, and research is indicated that examines smokers expected to experience milder states of desire (e.g., intermittent smokers, nondeprived smokers). In such instances, cue-reactivity analyses are likely to be less sensitive to ceiling effects. It also would be useful to conduct person-centered analyses for other substances that have been used in cue-exposure research given that ceiling effects seem to be less problematic for some substances than others (Wertz & Sayette, 2001b).

Although it is an important topic (see MacKillop & Monti, 2007), we did not focus here on individual differences in urge responding. Associational analyses examining the link between an individual difference marker (e.g., cigarettes/day) and cue-elicited urge implicitly adopt a person-centered approach (Donny et al., 2008). Consequently, identification of subtypes of individuals showing varying levels of cigarette-craving response (see Betts et al., 2021; Karelitz, 2020; for studies using other drugs, see also Avants et al., 1995; Rohsenow et al., 1992) would not be influenced by the explicitly person-centered approach introduced here. Such an effort may require larger samples to probe associations with confidence (Howard & Hoffman, 2018). A person-centered analytic approach also is compatible with new directions in neuroimaging methods. For instance, we currently are conducting research to identify individualized "neural fingerprints" (see Anzellotti & Coutanche, 2018) linked to craving that are distinct from a traditional focus on mean differences.

The present study offered the first test of a person-centered analysis of urge responding using a single cue-exposure stimulus that involves the sight, smell, and feel of a lit cigarette. Smoking-cue-exposure studies embedded in an emotional (e.g., stressful) context also may benefit from a person-centered approach. Recent work showed how stress and craving states can reciprocally influence each other to create a vicious cycle (Fronk et al., 2020), and the ability to examine how individuals respond to exposure sequences of stressors and smoking cues might offer a promising research direction. Likewise, in studies using personalized cues (e.g., Conklin et al., 2010), a person-centered approach seems especially appropriate.

More broadly, to fully appreciate the role of craving in use and relapse, related constructs such as coping with and perceived control over the urge require further investigation. Traditional models assert that lapses occur when powerful cravings overwhelm existing coping skills. Both variables are thought to be distinct (e.g., levels of craving and coping can vary within a factorial design; see Abrams, 2000). Elsewhere, we argued that these concepts are likely tightly interconnected: "Coping sometimes may be a reflection of craving, such that modest cravings provide opportunities for coping responses to be employed, whereas strong cravings, or at least cravings accompanied by an intention to use, may preclude coping" (Sayette, 2016, p. 422). Accordingly, efforts to address issues related to one's feelings about their craving or their self-efficacy to manage their craving need to wrestle with the challenge that these constructs reciprocally influence each other (for elaboration, see Sayette, 2016).

Note that a person-centered approach that examines simply whether a participant reports increased craving during cue exposure risks losing important data regarding

the magnitude of change. Whereas the present study was largely descriptive and we preregistered our intention to display the percentage of responders across a variety of values (> 0, 5, 10, or 15 points on the scale), other studies may wish to apply alternative preset (and preregistered) "imprecision values" to determine whether a person is classified correctly. Grice et al. (2020) acknowledged this:

> Of course, just as is the case in setting the minimally important difference in an effect-size computation, the onus is on the researcher to determine, explain, and defend any imprecision value used to correctly classify observations for the [percentage correct classifications] index. (p. 10)

In the present study, we initially took the position that smokers who did not manifest any increase in urge during smoking-cue exposure or who exhibited a drop in urge during cue exposure were in either case not responding to the cue in the predicted manner. As outlined by Grice et al. (2020), both types of participants would be considered to be misclassified. We also conducted an analysis to contrast those nonresponders who manifested no change in urge during cue exposure with those who actually showed a drop in urge ratings. The significant difference in precue urge among these two subgroups supports the possibility that an urge decrease (perhaps one finds the cigarette to be aversive or unappealing in the moment) may signal something quite different from when there is no change in urge. Comparing nonresponders who have high compared with low peak-provoked-craving scores on other motivational indices or subsequent smoking or relapse behaviors would be informative.

Conclusion

Results using a person-centered approach provide converging evidence to reinforce the conclusions from traditional mean-level analyses that self-reported urge reliably captures cue reactivity. Such findings support the view that cue reactivity is a fundamental aspect of addiction for daily smokers and that smoking cues can exert a clear effect on motivational responses. The findings also provide, however, a vivid demonstration of the limitations of cue-reactivity analyses when testing powerful craving states in nicotine-deprived smokers. Nearly one third of all nonresponders reported extraordinary (maximal) urges *before* holding the cigarette. In studies that aim to test such potentially overwhelming craving states noted to be central to addiction (George & Koob, 2013; Volkow et al., 2010), it should be concerning that the traditional cue-reactivity approach used in many experiments will necessarily be unable to properly capture these effects. Consistent with the recommendations of Grice et al. (2020), the present results demonstrate that computing percentages of urge responders who matched or failed to match expectation can offer complementary findings to traditional mean-level analyses and as a consequence reveal patterns that inform development of motivational models of smoking and drug use and refine clinical interventions. It therefore would be useful for researchers to expand their findings by also noting the percentage of participants who revealed urge ratings consistent with study manipulations and, especially if the percentage is fairly low, to consider the implications for their work.

Transparency

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Author Contributions

M. A. Sayette, K. G. Creswell, and J. D. Dimoff developed the initial study concept. All of the authors contributed to refinement of this initial concept. Data management was handled by M. E. Goodwin and K. G. Creswell. All of the authors contributed to the data analytic plan, and M. E. Goodwin performed data analysis. M. A. Sayette drafted the manuscript, and all the remaining authors provided critical revisions. All of the authors approved the final manuscript for submission.

Declaration of Conflicting Interests

The author(s) declared that there were no conflicts of interest with respect to the authorship or the publication of this article.

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Open Practices

The design and analysis plans for the experiments were preregistered at OSF and can be accessed at https://osf.io/kdxft. This article has received the badge for Preregistration. More information about the Open Practices badges can be found at https://www.psychologicalscience.org/publications/badges.

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Notes

1. Other cue modalities include exposure to a stressor or other mood induction, pictorial images related to smoking, scripted imagery, videos, and virtual reality (Sayette et al., 2000). Although there have been efforts to evaluate the relative potency of these cues (Betts et al., 2021; Karelitz, 2020; Niaura et al., 1998), research is hampered by the considerable heterogeneity within cue modality. For instance, holding an unlit cigarette as opposed to a lit cigarette while in the presence of another smoker or alone may affect the power of the in vivo induction. Likewise, the quality of virtual-reality approaches has improved considerably in recent years (Sayette & Goodwin, 2020), whereas photographic cues vary substantially (e.g., whether the images are personalized; Conklin et al., 2010).

2. We note that some reviews of cue reactivity have focused exclusively on studies that contrast urge responses during a neutral (control) cue from those during a smoking cue (Betts et al., 2021; Carter & Tiffany, 1999). We believe this comparison makes particular sense for some measures of urge responding. For instance, measures of attentional focus or of neurobiological or psychophysiological response may need to parse out the impact of merely holding an object in one's hand from the "craving" experience. Yet when it comes to self-reported urge, we are less persuaded that reporting one's urge while holding a neutral cue (e.g., roll of tape) generates an urge that differs at all from that reported during a precue assessment (without holding an object). Indeed, as we noted above, the prompt to report one's urge during an urge assessment likely is a far greater cue for craving than whether one is holding a neutral object. We have observed virtually identical urge ratings during precue baseline urge and a corresponding neutral-cue urge assessment (Sayette & Hufford, 1994; Sayette et al., 2001). In the latter study, for example, nicotine-deprived daily smokers reported an urge rating of 49 (on a 0–100 scale) during both a precue baseline and a control-cue assessment.

3. For two of the seven databases used in the present analysis (Rows 2 and 3 in Table 1, comprising 15% of the entire sample), the precise length of time smoking at daily rates was unavailable. Note that these (and all) participants in the present analyses did meet the daily smoking requirements noted above.

4. Hedges's g_{rm}, which corrects for the correlation between preurge and posturge scores in a within-subjects design, was calculated using the *effsize* package (Version 0.8.1; Torchiano, 2020) for the R software environment (Version 3.6.1; R Core Team, 2019).

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